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OFFICE OF AIR AND RADIATION
NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY
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April 2024

MEMORANDUM

SUBJECT: Redline Version of EPA's Final Regulation for Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles: Phase 3

FROM: Jessica Brakora, Assessment and Standards Division

TO: Docket EPA-HQ-OAR-2022-0985

EPA is adopting new greenhouse gas emission standards for heavy-duty highway vehicles with amendments to the regulations for heavy-duty highway vehicles and other sectors. The attached files highlight the changes in the final rule, with redline relative to the existing text in the Code of Federal Regulations. Changes from the proposed rule are reflected in red font and changes made after the proposal in blue font.

The first three attachments include full regulatory text for 40 CFR parts 1036 (excluding appendices), 1037, and 1065 with redline to highlight the proposed and final changes. In several cases where we chose not to finalize new regulatory provisions that we had proposed, the proposed text is simply omitted from the redline file to avoid confusion. The final attachment reproduces the amendatory instructions from the final regulation for three individual provisions updated in other parts, with redline to highlight the changes.

Note that the proposed rule included revisions to regulations addressing preemption of state regulation of new locomotives and new engines used in locomotives. Those revisions were finalized in a separate action on November 8, 2023¹ and changes to 40 CFR 1074 are not reflected in this memo.

The regulations in the attached files are intended to be the same as what will be published in the Federal Register. However, there will likely be some minor differences as a result of preparing the document for publication. The document published in the Federal Register is the official copy.

¹ Final Rulemaking for Locomotives and Locomotive Engines; Preemption of State and Local Regulations. 88 FR 77004, November 8, 2023.

Attachments

- Attachment 1: 40 CFR part 1036 (excluding appendices)
- Attachment 2: 40 CFR part 1037
- Attachment 3: 40 CFR part 1065
- Attachment 4: 40 CFR 86.1819-14, 1039.705, and 1054.501

PART 1036— CONTROL OF EMISSIONS FROM NEW AND IN-USE HEAVY-DUTY HIGHWAY ENGINES

Authority: 42 U.S.C. 7401 - 7671q.

Subpart A—Overview and Applicability

§ 1036.1 Applicability.

(a) Except as specified in § 1036.5, the provisions of this part apply for engines that will be installed in heavy-duty vehicles (including glider vehicles). Heavy-duty engines produced before December 20, 2026 are subject to greenhouse gas emission standards and related provisions under this part as specified in § 1036.108; these engines are subject to exhaust emission standards for NO_x, HC, PM, and CO, and related provisions under 40 CFR part 86, subpart A and subpart N, instead of this part, except as follows:

(1) The provisions of §§ 1036.115, 1036.501(d), and 1036.601 apply.

(2) 40 CFR parts 85 and 86 may specify that certain provisions in this part apply.

(3) This part describes how several individual provisions are optional or mandatory before model year 2027. For example, § 1036.150(a) describes how you may generate emission credits by meeting the standards of this part before model year 2027.

(b) The provisions of this part also apply for fuel conversions of all engines described in paragraph (a) of this section as described in 40 CFR 85.502.

(c) Gas turbine heavy-duty engines and other heavy-duty engines not meeting the definition of *compression-ignition* or *spark-ignition* are deemed to be compression-ignition engines for purposes of this part.

(d) For the purpose of applying the provisions of this part, engines include all emission-related components and any components or systems that should be identified in your application for certification, such as hybrid components for engines that are certified as hybrid engines or hybrid powertrains.

§ 1036.2 Compliance responsibility.

The regulations in this part contain provisions that affect both engine manufacturers and others. However, the requirements of this part are generally addressed to the engine manufacturer(s). The term "you" generally means the engine manufacturer(s), especially for issues related to certification. Additional requirements and prohibitions apply to other persons as specified in subpart G of this part and 40 CFR part 1068.

§ 1036.5 Excluded engines.

(a) The provisions of this part do not apply to engines used in medium-duty passenger vehicles or other heavy-duty vehicles that are subject to regulation under 40 CFR part 86, subpart S, except as specified in 40 CFR part 86, subpart S, and § 1036.150(j). For example, this exclusion applies for engines used in vehicles certified to the standards of 40 CFR 86.1818 and 86.1819.

(b) An engine installed in a heavy-duty vehicle that is not used to propel the vehicle is not a heavy-duty engine. The provisions of this part therefore do not apply to these engines. Note that engines used to indirectly propel the vehicle (such as electrical generator engines that provide power to batteries for propulsion) are subject to this part. See 40 CFR part 1039, 1048, or 1054

for other requirements that apply for these auxiliary engines. See 40 CFR part 1037 for requirements that may apply for vehicles using these engines, such as the evaporative and refueling emission requirements of 40 CFR 1037.103.

(c) The provisions of this part do not apply to aircraft or aircraft engines. Standards apply separately to certain aircraft engines, as described in 40 CFR part 87.

(d) The provisions of this part do not apply to engines that are not internal combustion engines. For example, the provisions of this part generally do not apply to fuel cells. Note that gas turbine engines are internal combustion engines.

(e) The provisions of this part do not apply for model year 2013 and earlier heavy-duty engines unless they were:

(1) Voluntarily certified to this part.

(2) Installed in a glider vehicle subject to 40 CFR part 1037.

§ 1036.10 Organization of this part.

This part is divided into the following subparts:

(a) Subpart A of this part defines the applicability of this part and gives an overview of regulatory requirements.

(b) Subpart B of this part describes the emission standards and other requirements that must be met to certify engines under this part. Note that § 1036.150 describes certain interim requirements and compliance provisions that apply only for a limited time.

(c) Subpart C of this part describes how to apply for a certificate of conformity.

(d) Subpart D of this part addresses testing of production engines.

(e) Subpart E of this part describes provisions for testing in-use engines.

(f) Subpart F of this part describes how to test your engines (including references to other parts of the Code of Federal Regulations).

(g) Subpart G of this part describes requirements, prohibitions, and other provisions that apply to engine manufacturers, vehicle manufacturers, owners, operators, rebuilders, and all others.

(h) Subpart H of this part describes how you may generate and use emission credits to certify your engines.

(i) Subpart I of this part contains definitions and other reference information.

§ 1036.15 Other applicable regulations.

(a) Parts 85 and 86 of this chapter describe additional provisions that apply to engines that are subject to this part. See § 1036.601.

(b) Part 1037 of this chapter describes requirements for controlling evaporative and refueling emissions and greenhouse gas emissions from heavy-duty vehicles, whether or not they use engines certified under this part.

(c) Part 1065 of this chapter describes procedures and equipment specifications for testing engines to measure exhaust emissions. Subpart F of this part describes how to apply the provisions of part 1065 of this chapter to determine whether engines meet the exhaust emission standards in this part.

(d) The requirements and prohibitions of part 1068 of this chapter apply as specified in § 1036.601 to everyone, including anyone who manufactures, imports, installs, owns, operates, or rebuilds any of the engines subject to this part, or vehicles containing these engines. See § 1036.601 to determine how to apply the part 1068 regulations for heavy-duty engines. The issues addressed by these provisions include these seven areas:

(1) Prohibited acts and penalties for engine manufacturers, vehicle manufacturers, and others.

- (2) Rebuilding and other aftermarket changes.
 - (3) Exclusions and exemptions for certain engines.
 - (4) Importing engines.
 - (5) Selective enforcement audits of your production.
 - (6) Recall.
 - (7) Procedures for hearings.
- (e) Other parts of this chapter apply if referenced in this part.

§ 1036.30 Submission of information.

Unless we specify otherwise, send all reports and requests for approval to the Designated Compliance Officer (see § 1036.801). See § 1036.825 for additional reporting and recordkeeping provisions.

Subpart B—Emission Standards and Related Requirements

§ 1036.101 Overview of exhaust emission standards.

~~This part contains standards and other regulations applicable to the emission of the air pollutant defined as the aggregate group of six greenhouse gases: carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.~~

- (a) You must show that engines meet the following exhaust emission standards:
- (1) Criteria pollutant standards for NO_x, HC, PM, and CO apply as described in § 1036.104. ~~These pollutants are sometimes described collectively as “criteria pollutants” because they are either criteria pollutants under the Clean Air Act or precursors to the criteria pollutants ozone and PM.~~
 - (2) ~~This part contains standards and other regulations applicable to the emission of the air pollutant defined as the aggregate group of six greenhouse gases: carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.~~ Greenhouse gas (GHG) standards for CO₂, CH₄, and N₂O apply as described in § 1036.108.
- (b) You may optionally demonstrate compliance with the emission standards of this part by testing ~~hybrid engines and~~ hybrid powertrains, rather than testing the engine alone. Except as specified, provisions of this part that reference engines apply equally to ~~hybrid engines and~~ hybrid powertrains.

§ 1036.104 Criteria pollutant emission standards—NO_x, HC, PM, and CO.

This section describes the applicable NO_x, HC, CO, and PM standards for model years 2027 and later. These standards apply equally for all primary intended service classes unless otherwise noted.

(a) *Emission standards.* Exhaust emissions may not exceed the standards in this section, as follows:

- (1) The following emission standards apply for Light HDE, Medium HDE, and Heavy HDE over the FTP, SET, and LLC duty cycles using the test procedures described in subpart F of this part:

TABLE 1 TO PARAGRAPH (a)(1) OF § 1036.104— COMPRESSION-IGNITION STANDARDS FOR DUTY CYCLE TESTING

Duty Cycle	NO _x mg/hp·hr	HC mg/hp·hr	PM mg/hp·hr	CO g/hp·hr
SET and FTP	35	60	5	6.0
LLC	50	140	5	6.0

(2) The following emission standards apply for Spark-ignition HDE over the FTP and SET duty cycles using the test procedures described in subpart F of this part:

TABLE 2 TO PARAGRAPH (a)(2) OF § 1036.104— SPARK-IGNITION STANDARDS FOR DUTY CYCLE TESTING

Duty Cycle	NO _x mg/hp·hr	HC mg/hp·hr	PM mg/hp·hr	CO g/hp·hr
SET	35	60	5	14.4
FTP	35	60	5	6.0

(3) The following off-cycle emission standards apply for Light HDE, Medium HDE, and Heavy HDE using the procedures specified in § 1036.530, as follows:

TABLE 3 TO PARAGRAPH (a)(3) OF § 1036.104— COMPRESSION-IGNITION STANDARDS FOR OFF-CYCLE TESTING

Off-Cycle Bin	NO _x	Temperature adjustment ^a	HC mg/hp·hr	PM mg/hp·hr	CO g/hp·hr
Bin 1	10.0 g/hr	$(25.0 - \bar{T}_{amb}) \cdot 0.25$	—	—	—
Bin 2	58 mg/hp·hr	$(25.0 - \bar{T}_{amb}) \cdot 2.2$	120	7.5	9

^a \bar{T}_{amb} is the mean ambient temperature over a shift-day, or equivalent. Adjust the off-cycle NO_x standard for \bar{T}_{amb} below 25.0 °C by adding the calculated temperature adjustment to the specified NO_x standard. Round the temperature adjustment to the same precision as the NO_x standard for the appropriate bin. If you declare a NO_x FEL for the engine family, do not apply the FEL scaling calculation from paragraph (c)(3) of this section to the calculated temperature adjustment.

(b) *Clean Idle.* You may optionally certify compression-ignition engines to the Clean Idle NO_x emission standard using the Clean Idle test specified in § 1036.525. The optional Clean Idle NO_x emission standard is 30.0 g/h for model years 2024 through 2026, and 10.0 g/hr for model year 2027 and later. The standard applies separately to each mode of the Clean Idle test. If you certify an engine family to the Clean Idle standards, it is subject to all these voluntary standards as if they were mandatory.

(c) *Averaging, banking, and trading.* You may generate or use emission credits under the averaging, banking, and trading (ABT) program described in subpart H of this part for demonstrating compliance with NO_x emission standards in paragraph (a) of this section. You must meet the PM, HC, and CO emission standards in § 1036.104(a) without generating or using emission credits.

(1) To generate or use emission credits, you must specify a family emission limit for each engine family. Declare the family emission limit corresponding to full useful life for engine operation over the FTP duty cycle, FEL_{FTP} , expressed to the same number of decimal places as the emission standard. Use FEL_{FTP} to calculate emission credits in subpart H of this part.

(2) The following NO_x FEL caps are the maximum value you may specify for FEL_{FTP} :

(i) 65 mg/hp·hr for model years 2027 through 2030.

(ii) 50 mg/hp·hr for model year 2031 and later.

~~(iii) 70 mg/hp·hr for model year 2031 and later Heavy HDE.~~

(3) Calculate the NO_x family emission limit, $FEL_{[cycle]NO_x}$, that applies for each duty-cycle or off-cycle standard using the following equation:

$$FEL_{[cycle]NO_x} = Std_{[cycle]NO_x} \cdot \frac{FEL_{FTPNO_x}}{Std_{FTPNO_x}}$$

Eq. 1036.104-1

Where:

$Std_{[cycle]NO_x}$ = the NO_x emission standard that applies for the applicable cycle or for off-cycle testing under paragraph (a) of this section for engines not participating in the ABT program.

FEL_{FTPNO_x} = the engine family's declared FEL for NO_x over the FTP duty cycle from paragraph (c)(1) of this section.

Std_{FTPNO_x} = the NO_x emission standard that applies for the FTP duty cycle under paragraph (a) of this section for engines not participating in the ABT program.

Example for model year 2029 Medium HDE for the SET:

$Std_{SETNO_x} = 35 \text{ mg/hp}\cdot\text{hr}$

$FEL_{FTP} = 121 \text{ mg/hp}\cdot\text{hr}$

$Std_{FTPNO_x} = 35 \text{ mg/hp}\cdot\text{hr}$

$FEL_{SETNO_x} = 35 \cdot \frac{121}{35} = 121 \text{ mg/hp}\cdot\text{hr}$

$FEL_{SETNO_x} = 121 \text{ mg/hp}\cdot\text{hr}$

(4) The family emission limits you select under this paragraph (c) serve as the emission standards for compliance testing instead of the standards specified in this section.

(d) *Fuel types.* The exhaust emission standards in this section apply for engines using the fuel type on which the engines in the engine family are designed to operate. You must meet the numerical emission standards for HC in this section based on the following types of hydrocarbon emissions for engines powered by the following fuels:

(1) Alcohol-fueled engines: NMHCE emissions.

(2) Gaseous-fueled engines: NMNEHC emissions.

(3) Other engines: NMHC emissions.

(e) *Useful life.* The exhaust emission standards of this section apply for the useful life, expressed in vehicle miles, or hours of engine operation, or years in service, whichever comes first, as follows:

TABLE 4 TO PARAGRAPH (e) OF § 1036.104—USEFUL LIFE BY PRIMARY INTENDED SERVICE CLASS

Primary Intended Service Class	Model year 2026 and earlier			Model year 2027 and later		
	Miles	Years	Hours	Miles	Years	Hours
Spark-ignition HDE	110,000	10	-	200,000	15	10,000
Light HDE	110,000	10	-	270,000	15	13,000
Medium HDE	185,000	10	-	350,000	12	17,000
Heavy HDE	435,000	10	22,000	650,000	11	32,000

(f) *Applicability for testing.* The emission standards in this subpart apply to all testing, including certification, selective enforcement audits, and in-use testing. For selective enforcement audits, we may require you to perform the appropriate duty-cycle testing as specified in §§ 1036.510, 1036.512, and 1036.514. We may direct you to do additional testing to show that your engines meet the off-cycle standards.

§ 1036.108 Greenhouse gas emission standards—CO₂, CH₄, and N₂O.

This section contains standards and other regulations applicable to the emission of the air pollutant defined as the aggregate group of six greenhouse gases: carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. This section describes the applicable CO₂, N₂O, and CH₄ standards for engines.

(a) *Emission standards.* Emission standards apply for engines and optionally powertrains measured using the test procedures specified in subpart F of this part as follows:

(1) CO₂ emission standards in this paragraph (a)(1) apply based on testing as specified in subpart F of this part. The applicable test cycle for measuring CO₂ emissions differs depending on the engine family’s primary intended service class and the extent to which the engines will be (or were designed to be) used in tractors. For Medium HDE and Heavy HDE certified as tractor engines, measure CO₂ emissions using the SET steady-state duty cycle specified in § 1036.510. This testing with the SET duty cycle is intended for engines designed to be used primarily in tractors and other line-haul applications. Note that the use of some SET-certified tractor engines in vocational applications does not affect your certification obligation under this paragraph (a)(1); see other provisions of this part and 40 CFR part 1037 for limits on using engines certified to only one cycle. For Medium HDE and Heavy HDE certified as both tractor and vocational engines, measure CO₂ emissions using the SET duty cycle specified in § 1036.510 and the FTP transient duty cycle specified in § 1036.512. Testing with both SET and FTP duty cycles is intended for engines that are designed for use in both tractor and vocational applications. For all other engines (including Spark-ignition HDE), measure CO₂ emissions using the FTP transient duty cycle specified in § 1036.512.

(i) *Spark-ignition standards.* The CO₂ standard for all spark-ignition engines is 627 g/hp·hr for model years 2016 through 2020. This standard continues to apply in later model years for all spark-ignition engines that are not Heavy HDE. Spark-ignition engines that qualify as Heavy HDE under § 1036.140(b)(2) for model years 2021 and later are subject to the compression-ignition engine standards for Heavy HDE-Vocational or Heavy HDE-Tractor, as applicable. You may certify spark-ignition engines to the compression-ignition standards for the appropriate model year under this paragraph (a). If you do this, those engines are treated as compression-ignition engines for all the provisions of this part.

(ii) Compression-ignition standards. The following CO₂ standards apply for compression-ignition engines and model year 2021 and later spark-ignition engines that qualify as Heavy HDE:

TABLE 1 TO PARAGRAPH (a)(1)(ii) OF § 1036.108—COMPRESSION-IGNITION CO₂ STANDARDS [g/hp·hr]

<u>Phase</u>	<u>Model Years</u>	<u>Light HDE</u>	<u>Medium HDE-Vocational</u>	<u>Heavy HDE-Vocational</u>	<u>Medium HDE-Tractor</u>	<u>Heavy HDE-Tractor</u>
<u>1</u>	<u>2014-2016</u>	<u>600</u>	<u>600</u>	<u>567</u>	<u>502</u>	<u>475</u>
	<u>2017-2020</u>	<u>576</u>	<u>576</u>	<u>555</u>	<u>487</u>	<u>460</u>
<u>2</u>	<u>2021-2023</u>	<u>563</u>	<u>545</u>	<u>513</u>	<u>473</u>	<u>447</u>
	<u>2024-2026</u>	<u>555</u>	<u>538</u>	<u>506</u>	<u>461</u>	<u>436</u>
	<u>2027 and later</u>	<u>552</u>	<u>535</u>	<u>503</u>	<u>457</u>	<u>432</u>

(i) The Phase 1 CO₂ standard is 627 g/hp-hr for all spark-ignition engines for model years 2016 through 2020. This standard continues to apply in later model years for all spark-ignition engines that are not Heavy HDE.

(ii) The following Phase 1 CO₂ standards apply for compression-ignition engines (in g/hp-hr):

TABLE 1 TO PARAGRAPH (a)(1)(ii) OF § 1036.108—COMPRESSION-IGNITION ENGINE STANDARDS FOR MODEL YEARS 2014—2020

<u>Model years</u>	<u>Light HDE</u>	<u>Medium HDE-Vocational</u>	<u>Heavy HDE-Vocational</u>	<u>Medium HDE-Tractor</u>	<u>Heavy HDE-Tractor</u>
<u>2014-2016</u>	<u>600</u>	<u>600</u>	<u>567</u>	<u>502</u>	<u>475</u>
<u>2017-2020</u>	<u>576</u>	<u>576</u>	<u>555</u>	<u>487</u>	<u>460</u>

(iii) The following Phase 2 and Phase 3 CO₂ standards apply for compression-ignition engines and all Heavy HDE (in g/hp-hr):

TABLE 2 TO PARAGRAPH (a)(1)(iii) OF § 1036.108—COMPRESSION-IGNITION ENGINE STANDARDS FOR MODEL YEARS 2021 AND LATER

<u>Model Years</u>	<u>Light HDE</u>	<u>Medium HDE-Vocational</u>	<u>Heavy HDE-Vocational</u>	<u>Medium HDE-Tractor</u>	<u>Heavy HDE-Tractor</u>
<u>2021-2023</u>	<u>563</u>	<u>545</u>	<u>513</u>	<u>473</u>	<u>447</u>
<u>2024-2026</u>	<u>555</u>	<u>538</u>	<u>506</u>	<u>461</u>	<u>436</u>
<u>2027 and later</u>	<u>552</u>	<u>535</u>	<u>503</u>	<u>457</u>	<u>432</u>

(iv) You may certify spark-ignition engines to the compression-ignition standards for the appropriate model year under this paragraph (a). If you do this, those engines are treated as compression-ignition engines for all the provisions of this part.

(2) The CH₄ emission standard is 0.10 g/hp·hr when measured over the applicable FTP transient duty cycle specified in § 1036.512. This standard begins in model year 2014 for compression-ignition engines and in model year 2016 for spark-ignition engines. Note that this standard applies for all fuel types just like the other standards of this section.

(3) The N₂O emission standard is 0.10 g/hp-hr when measured over the applicable FTP transient duty cycle specified in § 1036.512. This standard begins in model year 2014 for compression-ignition engines and in model year 2016 for spark-ignition engines.

(b) *Family Certification Levels.* You must specify a CO₂ Family Certification Level (FCL) for each engine family expressed to the same number of decimal places as the emission standard. The FCL may not be less than the certified emission level for the engine family. The CO₂ family emission limit (FEL) for the engine family is equal to the FCL multiplied by 1.03.

(c) *Averaging, banking, and trading.* You may generate or use emission credits under the averaging, banking, and trading (ABT) program described in subpart H of this part for demonstrating compliance with CO₂ emission standards. Credits (positive and negative) are calculated from the difference between the FCL and the applicable emission standard. As described in § 1036.705, you may use CO₂ credits to certify your engine families to FELs for N₂O and/or CH₄, instead of the N₂O/CH₄ standards of this section that otherwise apply. Except as specified in §§ 1036.150 and 1036.705, you may not generate or use credits for N₂O or CH₄ emissions.

(d) *Useful life.* The exhaust emission standards of this section apply for the useful life, expressed as vehicle miles, or hours of engine operation, or years in service, whichever comes first, as follows:

TABLE 3 TO PARAGRAPH (d) OF § 1036.108—USEFUL LIFE BY PRIMARY INTENDED SERVICE CLASS FOR MODEL YEAR 2021 AND LATER

Primary intended service class	Miles	Years
Spark-ignition HDE ^a	150,000	15
Light HDE ^a	150,000	15
Medium HDE	185,000	10
Heavy HDE ^b	435,000	10

^aUseful life for Spark-ignition HDE and Light HDE before model year 2021 is 110,000 miles or 10 years, whichever occurs first.

^bUseful life for Heavy HDE is also expressed as 22,000 operating hours. For an individual engine, the useful life is no shorter than 10 years or 100,000 miles, whichever occurs first, regardless of operating hours.

(e) *Applicability for testing.* The emission standards in this subpart apply as specified in this paragraph (e) to all duty-cycle testing (according to the applicable test cycles) of testable configurations, including certification, selective enforcement audits, and in-use testing. The CO₂ FCLs serve as the CO₂ emission standards for the engine family with respect to certification and confirmatory testing instead of the standards specified in paragraph (a)(1) of this section. The FELs serve as the emission standards for the engine family with respect to all other duty-cycle testing. See §§ 1036.235 and 1036.241 to determine which engine configurations within the engine family are subject to testing. Note that engine fuel maps and powertrain test results also serve as standards as described in §§ 1036.535, 1036.540, 1036.545, and 1036.630 ~~and 40 CFR 1037.550~~.

§ 1036.110 Diagnostic controls.

Onboard diagnostic (OBD) systems must generally detect malfunctions in the emission control system, store trouble codes corresponding to detected malfunctions, and alert operators appropriately. Starting in model year 2027, new engines must have OBD systems as described in

this section. You may optionally comply with any or all of the requirements of this section instead of 40 CFR 86.010-18 in earlier model years.

(a) Chassis-based OBD requirements apply instead of the requirements of this section for certain engines as follows:

(1) Heavy-duty engines intended to be installed in heavy duty vehicles at or below 14,000 pounds GVWR must meet the requirements in 40 CFR 86.1806. Note that 40 CFR 86.1806 allows for using later versions of specified OBD requirements from the California Air Resources Board, which includes meeting the 2019 heavy-duty OBD requirements adopted for California and updated emission thresholds as described in this section.

(2) Heavy-duty spark-ignition engines intended to be installed in heavy-duty vehicles above 14,000 pounds GVWR may meet the requirements in 40 CFR 86.1806 if the same engines are also installed in vehicles certified under 40 CFR part 86, subpart S, where both sets of vehicles share similar emission controls.

(b) Engines must comply with the 2019 heavy-duty OBD requirements adopted for California as described in this paragraph (b). California's 2019 heavy-duty OBD requirements are part of 13 CCR 1968.2, 1968.5, 1971.1, and 1971.5 (incorporated by reference, [see](#) ~~in~~ § 1036.810). We may approve your request to certify an OBD system meeting alternative specifications if you submit information as needed to demonstrate that it meets the intent of this section. For example, we may approve your request for a system that meets a later version of California's OBD requirements if you demonstrate that it meets the intent of this section; the demonstration must include identification of any approved deficiencies and your plans to resolve such deficiencies. To demonstrate that your engine meets the intent of this section, the OBD system meeting alternative specifications must address all the provisions described in this paragraph (b) and in paragraph (c) of this section. The following clarifications and exceptions apply for engines certified under this part:

(1) We may approve a small manufacturer's request to delay complying with the requirements of this section for up to three model years if that manufacturer has not certified those engines or other comparable engines in California for those model years.

(2) For engines not certified in California, references to vehicles meeting certain California Air Resources Board emission standards are understood to refer to the corresponding EPA emission standards for a given family, where applicable. Use good engineering judgment to correlate the specified standards with the EPA standards that apply under this part. You must describe in your application for certification how you will perform testing to demonstrate compliance with OBD requirements to represent all your engine families over five or fewer model years.

(3) Engines must comply with OBD requirements throughout the useful life as specified in § 1036.104(e).

(4) The purpose and applicability statements in 13 CCR 1971.1(a) and (b) do not apply.

(5) Emission thresholds apply as follows:

(i) Spark-ignition engines are subject to a NO_x threshold of 0.35 g/hp·hr for catalyst monitoring and 0.30 g/hp·hr in all other cases. Spark-ignition engines are subject to a PM threshold of 0.015 g/hp·hr. Thresholds apply for operation on the FTP and SET duty cycles.

(ii) Compression-ignition engines are subject to a NO_x threshold of 0.40 g/hp·hr and a PM threshold of 0.03 g/hp·hr for operation on the FTP and SET duty cycles.

(iii) All engines are subject to HC and CO thresholds as specified in 13 CCR 1968.2 and 1971.1, except that the "applicable standards" for determining these thresholds are 0.14 g/hp·hr for HC, 14.4 g/hp·hr for CO from spark-ignition engines, and 15.5 g/hp·hr for CO from compression-ignition engines.

(iv) Compression-ignition engines may be exempt from certain monitoring in 13 CCR 1968.2 and 1971.1 based on specified test-out criteria. To calculate these test-out criteria, the “applicable standards” are 0.20 g/hp·hr for NO_x, 0.14 g/hp·hr for HC, 0.01 g/hp·hr for PM, 14.4 g/hp·hr for CO from spark-ignition engines, and 15.5 g/hp·hr for CO from compression-ignition engines.

(6) The provisions related to verification of in-use compliance in 13 CCR 1971.1(l)(4) do not apply. The provisions related to manufacturer self-testing in 13 CCR 1971.5(c) also do not apply.

(7) The deficiency provisions described in paragraph (d) of this section apply instead of 13 CCR 1971.1(k).

(8) Include the additional data-stream signals in 13 CCR 1971.1(h)(4.2.3)(E), (F), and (G) as freeze-frame conditions as required in 13 CCR 1971.1(h)(4.3).

(9) Design compression-ignition engines to make the following additional data-stream signals available on demand with a generic scan tool according to 13 CCR 1971.1(h)(4.2), if the engine is so equipped with the relevant components and OBD monitoring is required for those components (or modeling is required for some parameter related to those components):

(i) *Engine and vehicle parameters.* Status of parking brake, neutral switch, brake switch, and clutch switch, wastegate control solenoid output, wastegate position (commanded and actual), speed and output shaft torque consistent with § 1036.115(d).

(ii) *Diesel oxidation catalyst parameters.* Include inlet and outlet pressure and temperature for the diesel oxidation catalyst.

(iii) *Particulate filter parameters.* Include filter soot load and ash load for all installed particulate filters.

(iv) *EGR parameters.* Include differential pressure for exhaust gas recirculation.

(v) *SCR parameters.* Include DEF quality-related signals, DEF coolant control valve position (commanded and actual), DEF tank temperature, DEF system pressure, DEF pump commanded percentage, DEF doser control status, DEF line heater control outputs, aftertreatment dosing quantity commanded and actual.

(vi) *Derating parameters.* Include any additional parameters used to apply inducements under § 1036.111 or any other SCR-related or DPF-related engine derates under § 1036.125.

(10) Design spark-ignition engines to make the following additional parameters available for reading with a generic scan tool, if applicable:

(i) *Air-fuel enrichment parameters.* Percent of time in enrichment, both for each trip (key-on to key-off) and as a cumulative lifetime value. Track values separately for enrichment based on throttle, engine protection, and catalyst protection. Include all time after engine warm-up when the engine is not operating at the air-fuel ratio designed for peak three-way catalyst efficiency. Peak efficiency typically involves closed-loop feedback control.

(ii) [Reserved]

(11) If you have an approved Executive order from the California Air Resources Board for a given engine family, we may rely on that Executive order to evaluate whether you meet federal OBD requirements for that same engine family or an equivalent engine family. Engine families are equivalent if they are identical in all aspects material to emission characteristics; for example, we would consider different inducement strategies and different warranties not to be material to emission characteristics relevant to these OBD testing requirements. EPA would count two equivalent engine families as one for the purposes of determining OBD demonstration testing requirements. Send us the following information:

- (i) You must submit additional information as needed to demonstrate that you meet the requirements of this section that are not covered by the California Executive order.
 - (ii) Send us results from any testing you performed for certifying engine families (including equivalent engine families) with the California Air Resources Board, including the results of any testing performed under 13 CCR 1971.1(l) for verification of in-use compliance and 13 CCR 1971.5(c) for manufacturer self-testing within the deadlines set out in 13 CCR 1971.1 and 1971.5.
 - (iii) We may require that you send us additional information if we need it to evaluate whether you meet the requirements of this paragraph (b)(11). This may involve sending us copies of documents you send to the California Air Resources Board.
- (12) You may ask us to approve conditions for which the diagnostic system may disregard trouble codes, as described in 13 CCR 1971.1(g)(5.3)-(5.6).
- (13) References to the California ARB Executive Officer are deemed to be the EPA Administrator.
- (c) Design the diagnostic system to display the following information in the cab:
- (1) For inducements specified in § 1036.111 and any other AECD that derates engine output related to SCR or DPF systems, indicate the fault code for the detected problem, a description of the fault code, and the current speed restriction. For inducement faults under § 1036.111, identify whether the fault condition is for DEF quantity level, DEF quality, or tampering; for other faults, identify whether the fault condition is related to SCR or DPF systems. If there are additional derate stages, also indicate the next speed restriction and the time remaining until starting the next restriction. If the derate involves something other than restricting vehicle speed, such as a torque derate, adjust the information to correctly identify any current and pending restrictions.
 - (2) Identify on demand the total number of diesel particulate filter regeneration events that have taken place since installing the current particulate filter.
 - (3) Identify on demand the historical and current rate of DEF consumption, such as gallons of DEF consumed per mile or gallons of DEF consumed per gallon of diesel fuel consumed.
- Design the system to allow the operator to reset the current rate of DEF consumption.
- (d) You may ask us to accept as compliant an engine that does not fully meet specific requirements under this section. The following provisions apply regarding OBD system deficiencies:
- (1) We will not approve a deficiency for gasoline-fueled or diesel-fueled engines if it involves the complete lack of a major diagnostic monitor, such as monitors related to exhaust aftertreatment devices, oxygen sensors, air-fuel ratio sensors, NO_x sensors, engine misfire, evaporative leaks, and diesel EGR (if applicable). We may approve such deficiencies for engines using other fuels if you demonstrate that the alternative fuel causes these monitors to be unreliable.
 - (2) We will approve a deficiency only if you show us that full compliance is infeasible or unreasonable considering any relevant factors, such as the technical feasibility of a given monitor, or the lead time and production cycles of vehicle designs and programmed computing upgrades.
 - (3) Our approval for a given deficiency applies only for a single model year, though you may continue to ask us to extend a deficiency approval in renewable one-year increments. We may approve an extension if you demonstrate an acceptable level of progress toward compliance and you show that the necessary hardware or software modifications would pose an unreasonable burden. We will approve a deficiency for more than three years only if you further demonstrate that you need the additional lead time to make substantial changes to engine hardware.

(4) We will not approve deficiencies retroactively.

§ 1036.111 Inducements related to SCR.

Engines using SCR to control emissions depend on a constant supply of diesel exhaust fluid (DEF). This section describes how manufacturers must design their engines to derate power output to induce operators to take appropriate actions to ensure the SCR system is working properly. The requirements of this section apply equally for engines installed in heavy-duty vehicles at or below 14,000 lbs GVWR. The requirements of this section apply starting in model year 2027, though you may comply with the requirements of this section in earlier model years.

(a) *General provisions.* The following terms and general provisions apply under this section:

(1) As described in § 1036.110, this section relies on terms and requirements specified for OBD systems by California ARB in 13 CCR 1968.2 and 1971.1 (incorporated by reference, [see in](#) § 1036.810).

(2) The provisions of this section apply differently based on an individual vehicle's speed history. A vehicle's speed category is based on the OBD system's recorded value for average speed for the preceding 30 hours of non-idle engine operation. The vehicle speed category applies at the point that the engine first detects ~~an inducement triggering a fault~~ condition identified under paragraph (b) of this section and continues to apply until the ~~fault~~ inducement triggering condition is fully resolved as specified in paragraph (e) of this section. Non-idle engine operation includes all operating conditions except those that qualify as idle based on OBD system controls as specified in 13 CCR 1971.1(h)(5.4.10). Apply speed derates based on the following categories:

TABLE 1 TO PARAGRAPH (a)(2) OF § 1036.111—VEHICLE CATEGORIES

Vehicle category ^a	Average speed (mi/hr)
Low-speed	speed < 15
Medium-speed	15 < speed < 25
High-speed	speed ≥ 25

^a A vehicle is presumed to be a high-speed vehicle if it has not yet logged 30 hours of non-idle operation.

(3) Where engines derate power output as specified in this section, the derate must decrease vehicle speed by 1 mi/hr for every five minutes of engine operation until reaching the specified derate speed. This requirement applies at the onset of an inducement, at any transition to a different step of inducement, and for any derate that recurs under paragraph (e)(3) of this section.

(b) ~~Fault-Inducement triggering~~ conditions. Create derate strategies that monitor for and trigger an inducement based on the following conditions:

(1) DEF supply falling to 2.5 percent of DEF tank capacity or a level corresponding to three hours of engine operation, based on available information on DEF consumption rates.

(2) DEF quality failing to meet your concentration specifications.

(3) Any signal indicating that a catalyst is missing.

(4) Open circuit faults related to the following: DEF tank level sensor, DEF pump, DEF quality sensor, SCR wiring harness, NO_x sensors, DEF dosing valve, DEF tank heater, DEF tank temperature sensor, and aftertreatment control module.

(c) [Reserved]

(d) *Derate schedule.* Engines must follow the derate schedule described in this paragraph (d) if the engine detects ~~a fault~~ an inducement triggering condition identified in paragraph (b) of this

section. The derate takes the form of a maximum drive speed for the vehicle. This maximum drive speed decreases over time based on hours of non-idle engine operation without regard to engine starting.

(1) Apply speed-limiting derates according to the following schedule:

TABLE 2 TO PARAGRAPH (d)(1) OF § 1036.111—DERATE SCHEDULE FOR DETECTED ~~FAULTS~~INDUCEMENT TRIGGERING CONDITIONS^a

High-speed vehicles		Medium Low-speed vehicles		Low-speed vehicles	
Hours of non-idle engine operation	Maximum speed (mi/hr)	Hours of non-idle engine operation	Maximum speed (mi/hr)	Hours of non-idle engine operation	Maximum speed (mi/hr)
0	65	0	55	0	45
6	60	6	50	5	40
12	55	12	45	10	35
20	50	45	40	30	25
86	45	70	35	—	—
119	40	90	25	—	—
144	35	—	—	—	—
164	25	—	—	—	—

^aHours start counting when the engine detects an inducement triggering a fault condition specified in paragraph (b) of this section. For DEF supply, you may program the engine to reset the timer to three hours when the engine detects an empty DEF tank.

(2) You may design and produce engines that will be installed in motorcoaches with an alternative derate schedule that starts with a 65 mi/hr derate when a fault-an inducement triggering condition is first detected, steps down to 50 mi/hr after 80 hours, and concludes with a final derate speed of 25 mi/hr after 180 hours of non-idle operation.

(e) *Deactivating derates.* Program the engine to deactivate derates as follows:

(1) Evaluate whether the detected fault-inducement triggering condition continues to apply. Deactivate derates if the engine confirms that the detected fault-inducement triggering condition is resolved.

(2) Allow a generic scan tool to deactivate inducement triggering related fault codes while the vehicle is not in motion.

(3) Treat any detected fault-inducement triggering condition that recurs within 40 hours of engine operation as the same detected fault-inducement triggering condition, which would restart the derate at the same point in the derate schedule that the system last deactivated the derate.

§ 1036.115 Other requirements.

Engines that are required to meet the emission standards of this part must meet the following requirements, except as noted elsewhere in this part:

(a) *Crankcase emissions.* Engines may not discharge crankcase emissions into the ambient atmosphere throughout the useful life, other than those that are routed to the exhaust upstream of exhaust aftertreatment during all operation, except as follow:

(1) Engines equipped with turbochargers, pumps, blowers, or superchargers for air induction may discharge crankcase emissions to the ambient atmosphere if the emissions are added to the exhaust emissions (either physically or mathematically) during all emission testing.

(2) If you take advantage of this exception, you must manufacture the engines so that all crankcase emissions can be routed into the applicable sampling systems specified in 40 CFR

part 1065. You must also account for deterioration in crankcase emissions when determining exhaust deterioration factors as described in § 1036.240(c)(5).

(b) *Fuel mapping*. You must perform fuel mapping for your engine as described in § 1036.505(b).

(c) *Evaporative and refueling emissions*. You must design and produce your engines to comply with evaporative and refueling emission standards as follows:

(1) For complete heavy-duty vehicles you produce, you must certify the vehicles to emission standards as specified in 40 CFR 1037.103.

(2) For incomplete heavy-duty vehicles, and for engines used in vehicles you do not produce, you do not need to certify your engines to evaporative and refueling emission standards or otherwise meet those standards. However, vehicle manufacturers certifying their vehicles with your engines may depend on you to produce your engines according to their specifications. Also, your engines must meet applicable exhaust emission standards in the installed configuration.

(d) *Torque broadcasting*. Electronically controlled engines must broadcast their speed and output shaft torque (in newton-meters). Engines may alternatively broadcast a surrogate value for determining torque. Engines must broadcast engine parameters such that they can be read with a remote device or broadcast them directly to their controller area networks.

(e) *EPA access to broadcast information*. If we request it, you must provide us any hardware, tools, and information we would need to readily read, interpret, and record all information broadcast by an engine's on-board computers and electronic control modules. If you broadcast a surrogate parameter for torque values, you must provide us what we need to convert these into torque units. We will not ask for hardware or tools if they are readily available commercially.

(f) *Adjustable parameters*. Engines that have adjustable parameters must meet all the requirements of this part for any adjustment in the practically adjustable range.

(1) We may require that you set adjustable parameters to any specification within the practically adjustable range during any testing, including certification testing, selective enforcement auditing, or in-use testing.

(2) General provisions apply for adjustable parameters as specified in 40 CFR 1068.50.

(3) DEF supply and DEF quality are adjustable parameters. The physically adjustable range includes any amount of DEF for which the engine's diagnostic system does not trigger inducement provisions under § 1036.111.

(g) *Prohibited controls*. (1) *General provisions*. You may not design your engines with emission control devices, systems, or elements of design that cause or contribute to an unreasonable risk to public health, welfare, or safety while operating. For example, this would apply if the engine emits a noxious or toxic substance it would otherwise not emit that contributes to such an unreasonable risk.

(2) *Vanadium sublimation in SCR catalysts*. For engines equipped with vanadium-based SCR catalysts, you must design the engine and its emission controls to prevent vanadium sublimation and protect the catalyst from high temperatures. We will evaluate your engine design based on the following information that you must include in your application for certification:

(i) Identify the threshold temperature for vanadium sublimation for your specified SCR catalyst formulation as described in 40 CFR 1065.1113 through 1065.1121.

(ii) Describe how you designed your engine to prevent catalyst inlet temperatures from exceeding the temperature you identify in paragraph (g)(2)(i) of this section, including consideration of engine wear through the useful life. Also describe your design for catalyst protection in case catalyst temperatures exceed the specified temperature. In your description, include how you considered elevated catalyst temperature resulting from

sustained high-load engine operation, catalyst exotherms, particulate filter regeneration, and component failure resulting in unburned fuel in the exhaust stream.

(h) *Defeat devices*. You may not equip your engines with a defeat device. A defeat device is an auxiliary emission control device (AECD) that reduces the effectiveness of emission controls under conditions that may reasonably be expected in normal operation and use. However, an AECD is not a defeat device if you identify it in your application for certification and any of the following is true:

- (1) The conditions of concern were substantially included in the applicable procedure for duty-cycle testing as described in subpart F of this part.
- (2) You show your design is necessary to prevent engine (or vehicle) damage or accidents. Preventing engine damage includes preventing damage to aftertreatment or other emission-related components.
- (3) The reduced effectiveness applies only to starting the engine.
- (4) The AECD applies only for engines that will be installed in *emergency vehicles*, and the need is justified in terms of preventing the engine from losing speed, torque, or power due abnormal conditions of the emission control system, or in terms of preventing such abnormal conditions from occurring, during operation related to emergency response. Examples of such abnormal conditions may include excessive exhaust backpressure from an overloaded particulate trap, and running out of diesel exhaust fluid for engines that rely on urea-based selective catalytic reduction. [The emission standards do not apply when any AECDs approved under this paragraph \(h\)\(4\) are active.](#)

(i) *DEF tanks*. Diesel exhaust fluid tanks must be sized to require refilling no more frequently than the vehicle operator will need to refill the fuel tank, even for worst-case assumptions related to fuel efficiency and refueling volumes.

(j) *Special provisions for spark-ignition engines*. The following provisions apply for spark-ignition engines that control air-fuel ratios at or near stoichiometry starting with model year 2027:

- (1) Catalyst bed temperature during extended idle may not fall below 350 °C, or a lower temperature that we approve. Describe how you designed your engine to meet this requirement in your application for certification. You may ask us to approve alternative strategies to prevent emissions from increasing during idle.
- (2) In addition to the information requirements of § 1036.205(b), describe why you rely on any AECDs instead of other engine designs for thermal protection of catalyst or other emission-related components. Also describe the accuracy of any modeled or measured temperatures used to activate the AECD. We may ask you to submit a second-by-second comparison of any modeled and measured component temperatures as part of your application for certification.

§ 1036.120 Emission-related warranty requirements.

(a) *General requirements*. You must warrant to the ultimate purchaser and each subsequent purchaser that the new engine, including all parts of its emission control system, meets two conditions:

- (1) It is designed, built, and equipped so it conforms at the time of sale to the ultimate purchaser with the requirements of this part.
- (2) It is free from defects in materials and workmanship that may keep it from meeting these requirements.

(b) *Warranty period*. Your emission-related warranty must be valid for at least as long as the minimum warranty periods listed in this paragraph (b) in vehicle miles, or hours of engine

operation, or years in service, whichever comes first. You may offer an emission-related warranty more generous than we require. The emission-related warranty for the engine may not be shorter than any published warranty you offer without charge for the engine. Similarly, the emission-related warranty for any component may not be shorter than any published warranty you offer without charge for that component. If an extended warranty requires owners to pay for a portion of repairs, those terms apply in the same manner to the emission-related warranty. The warranty period begins when the vehicle is placed into service. The following minimum warranty periods apply:

TABLE 1 TO PARAGRAPH (b) OF § 1036.120—WARRANTY BY PRIMARY INTENDED SERVICE CLASS

Primary intended service class	Model year 2026 and earlier			Model year 2027 and later		
	Mileage	Years	Hours	Mileage	Years	Hours
Spark-Ignition HDE	50,000	5	-	160,000	10	8,000
Light HDE	50,000	5	-	210,000	10	10,000
Medium HDE	100,000	5	-	280,000	10	14,000
Heavy HDE	100,000	5	-	450,000	10	22,000

(c) *Components covered.* The emission-related warranty covers all components listed in 40 CFR part 1068, appendix A, and components from any other system you develop to control emissions. Note that this includes hybrid system components when a manufacturer's certified configuration includes hybrid system components that you specify in a certified configuration. The emission-related warranty covers any components, regardless of the company that produced them, that are the original components or the same design as components from the certified configuration.

(d) *Limited applicability.* You may deny warranty claims under this section if the operator caused the problem through improper maintenance or use, subject to the provisions in § 1036.125 and 40 CFR 1068.115.

(e) *Owners manual.* Describe in the owners manual the emission-related warranty provisions from this section that apply to the engine.

§ 1036.125 Maintenance instructions and allowable maintenance.

Maintenance includes any inspection, adjustment, cleaning, repair, or replacement of components and is classified as either emission-related or not emission-related and each of these can be classified as either scheduled or unscheduled. Further, some emission-related maintenance is also classified as critical emission-related maintenance. Give the ultimate purchaser of each new engine written instructions for maintaining and using the engine. As described in paragraph (h) of this section, these instructions must identify how owners properly maintain and use engines to clarify responsibilities for regulatory requirements such as emission-related warranty and defect reporting.

(a) *Critical emission-related maintenance.* Critical emission-related maintenance includes any adjustment, cleaning, repair, or replacement of components listed in paragraph (a)(2) of this section. Critical emission-related maintenance may also include other maintenance that you determine is critical, including maintenance on other emission-related components as described in 40 CFR part 1068, appendix A, if we approve it in advance. You may perform scheduled critical emission-related maintenance during service accumulation on your emission-data engines at the intervals you specify.

(1) *Maintenance demonstration.* You must demonstrate that the maintenance is reasonably likely to be done at your recommended intervals on in-use engines. We will accept DEF

replenishment as reasonably likely to occur if your engine meets the specifications in § 1036.111. We will accept other scheduled maintenance as reasonably likely to occur if you satisfy any of the following conditions:

- (i) You present data showing that, if a lack of maintenance increases emissions, it also unacceptably degrades the engine’s performance.
- (ii) You design and produce your engines with a system we approve that displays a visible signal to alert drivers that maintenance is due, either as a result of component failure or the appropriate degree of engine or vehicle operation. The signal must clearly display “maintenance needed”, “check engine”, or a similar message that we approve. The signal must be continuous while the engine is operating and not be easily eliminated without performing the specified maintenance. Your maintenance instructions must specify resetting the signal after completing the specified maintenance. We must approve the method for resetting the signal. You may not design the system to be less effective at the end of the useful life. If others install your engine in their vehicle, you may rely on installation instructions to ensure proper mounting and operation of the display. Disabling or improperly resetting the system for displaying these maintenance-related signals without performing the indicated maintenance violates the tampering prohibition in 42 U.S.C. 7522(a)(3).
- (iii) You present survey data showing that at least 80 percent of engines in the field get the maintenance you specify at the recommended intervals.
- (iv) You provide the maintenance free of charge and clearly say so in your maintenance instructions.
- (v) You otherwise show us that the maintenance is reasonably likely to be done at the recommended intervals.

(2) *Minimum scheduled maintenance intervals.* You may not schedule critical emission-related maintenance more frequently than the minimum intervals specified or allowed in this paragraph (a), except as specified in paragraph (g) of this section. The minimum intervals specified for each component applies to actuators, sensors, tubing, valves, and wiring associated with that component, except as specified.

TABLE 1 TO PARAGRAPH (a)(2) OF § 1036.125—MINIMUM SCHEDULED MAINTENANCE INTERVALS FOR REPLACEMENT IN MILES (OR HOURS)

Components	Spark-Ignition HDE	Light HDE	Medium HDE	Heavy HDE
Spark plugs	25,000 (750)	-	-	-
DEF filters	-	100,000 (3,000)	100,000 (3,000)	100,000 (3,000)
Crankcase ventilation valves and filters	60,000 (1,800)	60,000 (1,800)	60,000 (1,800)	60,000 (1,800)
Ignition wires and coils	50,000 (1,500)	-	-	-
Oxygen sensors	80,000 (2,400)	-	-	-
Air injection system components	110,000 (3,300)	-	-	-
Sensors, actuators, and related control modules that are not integrated into other systems ...	100,000 (3,000)	100,000 (3,000)	150,000 (4,500)	150,000 (4,500)
Particulate filtration systems (other than filter substrates)	100,000 (3,000)	100,000 (3,000)	250,000 (7,500)	250,000 (7,500)
Catalyst systems (other than catalyst substrates), fuel	110,000 (3,300)	110,000 (3,300)	185,000 (5,550)	435,000 (13,050)

injectors, electronic control modules, hybrid system components, turbochargers, and EGR system components (including filters and coolers) ..				
Catalyst substrates and particulate filter substrates	200,000 (10,000)	270,000 (13,000)	350,000 (17,000)	650,000 (32,000)

TABLE 2 TO PARAGRAPH (a)(2) OF § 1036.125—MINIMUM SCHEDULED MAINTENANCE INTERVALS FOR ADJUSTMENT OR CLEANING

Component	Accumulated miles (hours) for components			
	Spark-ignition HDE	Light HDE	Medium HDE	Heavy HDE
Spark plugs	25,000 (750)	-	-	-
EGR-related filters and coolers, fuel injectors, and crankcase ventilation valves and filters	50,000 (1,500)	50,000 (1,500)	50,000 (1,500)	50,000 (1,500)
DEF filters	-	50,000 (1,500)	50,000 (1,500)	50,000 (1,500)
Ignition wires and coils	50,000 (1,500)	-	-	-
Oxygen sensors	80,000 (2,400)	-	-	-
Air injection system components ..	100,000 (3,000)	-	-	-
Catalyst system components, EGR system components (other than filters or coolers), particulate filtration system components, and turbochargers	100,000 (3,000)	100,000 (3,000)	100,000 (3,000), then 150,000 (4,500)	100,000 (3,000), then 150,000 (4,500)

(3) *New technology.* You may ask us to approve scheduled critical emission-related maintenance of components not identified in paragraph (a)(2) of this section that is a direct result of the implementation of new technology not used in model year 2020 or earlier engines, subject to the following provisions:

(i) Your request must include your recommended maintenance interval, including data to support the need for the maintenance, and a demonstration that the maintenance is likely to occur at the recommended interval using one of the conditions specified in paragraph (a)(1) of this section.

(ii) For any such new technology, we will publish a *Federal Register* notice based on information you submit and any other available information to announce that we have established new allowable minimum maintenance intervals. Any manufacturer objecting to our decision may ask for a hearing (see § 1036.820).

(4) *System components.* The following provisions clarify which components are included in certain systems:

(i) Catalyst system refers to the aftertreatment assembly used for gaseous emission control and generally includes catalyst substrates, substrate housings, exhaust gas temperature sensors, gas concentration sensors, and related control modules. SCR-based catalyst systems also include DEF level sensors, DEF quality sensors, and DEF temperature sensors.

(ii) Particulate filtration system refers to the aftertreatment assembly used for exhaust PM filtration and generally includes filter substrates, substrate housings, pressure sensors, pressure lines and tubes, exhaust gas temperature sensors, fuel injectors for active regeneration, and related control modules.

(b) *Recommended additional maintenance.* You may recommend any amount of critical emission-related maintenance that is additional to what we approve in paragraph (a) of this section, as long as you state clearly that the recommended additional maintenance steps are not necessary to keep the emission-related warranty valid. If operators do the maintenance specified in paragraph (a) of this section, but not the recommended additional maintenance, this does not allow you to disqualify those engines from in-use testing or deny a warranty claim. Do not take these maintenance steps during service accumulation on your emission-data engines.

(c) *Special maintenance.* You may specify more frequent maintenance to address problems related to special situations, such as atypical engine operation. For example, you may specify more frequent maintenance if operators fuel the engine with an alternative fuel such as biodiesel. You must clearly state that this special maintenance is associated with the special situation you are addressing. We may disapprove your maintenance instructions if we determine that you have specified special maintenance steps to address engine operation that is not atypical, or that the maintenance is unlikely to occur in use. If we determine that certain maintenance items do not qualify as special maintenance under this paragraph (c), you may identify them as recommended additional maintenance under paragraph (b) of this section.

(d) *Noncritical emission-related maintenance.* You may specify any amount of emission-related inspection or other maintenance that is not approved critical emission-related maintenance under paragraph (a) of this section, subject to the provisions of this paragraph (d). Noncritical emission-related maintenance generally includes maintenance on the components we specify in 40 CFR part 1068, appendix A, that is not covered in paragraph (a) of this section. You must state in the owners manual that these steps are not necessary to keep the emission-related warranty valid. If operators fail to do this maintenance, this does not allow you to disqualify those engines from in-use testing or deny a warranty claim. Do not take these inspection or other maintenance steps during service accumulation on your emission-data engines.

(e) *Maintenance that is not emission-related.* You may schedule any amount of maintenance unrelated to emission controls that is needed for proper functioning of the engine. This might include adding engine oil; changing air, fuel, or oil filters; servicing engine-cooling systems; adjusting idle speed, governor, engine bolt torque, valve lash, injector lash, timing, or tension of air pump drive belts; and lubricating the heat control valve in the exhaust manifold. For maintenance that is not emission-related, you may perform the maintenance during service accumulation on your emission-data engines at the least frequent intervals that you recommend to the ultimate purchaser (but not the intervals recommended for special situations).

(f) [Reserved]

(g) *Payment for scheduled maintenance.* Owners are responsible for properly maintaining their engines, which generally includes paying for scheduled maintenance. However, you may commit to paying for scheduled maintenance as described in paragraph (a)(1)(iv) of this section to demonstrate that the maintenance will occur. You may also schedule maintenance not otherwise allowed by paragraph (a)(2) of this section if you pay for it. You must pay for scheduled maintenance on any component during the useful life if it meets all the following conditions:

- (1) Each affected component was not in general use on similar engines before 1980.
- (2) The primary function of each affected component is to reduce emissions.
- (3) The cost of the maintenance is more than 2 percent of the price of the engine.
- (4) Failure to perform the maintenance would not cause clear problems that would significantly degrade the engine's performance.

(h) *Owners manual*. Include the following maintenance-related information in the owners manual, consistent with the requirements of this section:

(1) Clearly describe the scheduled maintenance steps, consistent with the provisions of this section, using nontechnical language as much as possible. Include a list of components for which you will cover scheduled replacement costs.

(2) Identify all maintenance you consider necessary for the engine to be considered properly maintained for purposes of making valid warranty claims. Describe what documentation you consider appropriate for making these demonstrations. Note that you may identify failure to repair critical emission-related components as improper maintenance if the repairs are related to an observed defect. Your maintenance instructions under this section may not require components or service identified by brand, trade, or corporate name. Also, do not directly or indirectly require that the engine be serviced by your franchised dealers or any other service establishments with which you have a commercial relationship. However, you may disregard these limitations on your maintenance requirements if you do one of the following things:

(i) Provide a component or service without charge under the purchase agreement.

(ii) Get us to waive this prohibition in the public's interest by convincing us the engine will work properly only with the identified component or service.

(3) Describe how the owner can access the OBD system to troubleshoot problems and find emission-related diagnostic information and codes stored in onboard monitoring systems as described in § 1036.110(b) and (c). These instructions must at a minimum include identification of the OBD communication protocol used, location and type of OBD connector, brief description of what OBD is (including type of information stored, what a MIL is, and explanation that some MILs may self-extinguish), and a note that generic scan tools can provide engine maintenance information.

(4) Describe the elements of the emission control system and provide an overview of how they function.

(5) Include one or more diagrams of the engine and its emission-related components with the following information:

(i) The flow path for intake air and exhaust gas.

(ii) The flow path of evaporative and refueling emissions for spark-ignition engines, and DEF for compression-ignition engines, as applicable.

(iii) The flow path of engine coolant if it is part of the emission control system described in the application for certification.

(iv) The identity, location, and arrangement of relevant sensors, DEF heater and other DEF delivery components, and other critical emission-related components. Terminology to identify components must be consistent with codes you use for the OBD system.

(6) Include one or more exploded-view drawings that allow the owner to identify the following components: EGR valve, EGR actuator, EGR cooler, all emission sensors (such as NO_x sensors and soot sensors), temperature and pressure sensors (such as sensors related to EGR, DPF, DOC, and SCR and DEF), quality sensors, DPF filter, DOC, SCR catalyst, fuel (DPF-related) and DEF dosing units and components (e.g., pumps, metering units, filters, nozzles, valves, injectors), aftertreatment-related control modules, any other DEF delivery-related components (such as delivery lines and freeze-protection components), and separately replaceable aftertreatment-related wiring harnesses. Terminology to identify components must be consistent with codes you use for the OBD system. Include part numbers for sensors and filters related to SCR and DPF systems for the current model year or any earlier model year.

(7) Include the following statement: "Technical service bulletins, emission-related recalls, and other information for your engine may be available at www.nhtsa.gov/recalls."

(8) Include a troubleshooting guide to address the following warning signals related to SCR inducement:

- (i) The inducement derate schedule (including indication that inducements will begin prior to the DEF tank being completely empty).
- (ii) The meaning of any trouble lights that indicate specific problems (e.g., DEF level).
- (iii) A description of the three types of SCR-related derates (DEF ~~quality level~~, DEF quality and tampering) and that further information on the inducement cause (e.g., trouble codes) is available using the OBD system.

(9) Describe how to access OBD fault codes related to DPF-related derates.

(10) Identify a web site for the service information required in 40 CFR 86.010-38(j).

§ 1036.130 Installation instructions for vehicle manufacturers.

(a) If you sell an engine for someone else to install in a vehicle, give the engine installer instructions for installing it consistent with the requirements of this part. Include all information necessary to ensure that an engine will be installed in its certified configuration.

(b) Make sure these instructions have the following information:

(1) Include the heading: “Emission-related installation instructions”.

(2) State: “Failing to follow these instructions when installing a certified engine in a heavy-duty motor vehicle violates federal law, subject to fines or other penalties as described in the Clean Air Act.”

(3) Provide all instructions needed to properly install the exhaust system and any other components. Include any appropriate instructions for configuring the exhaust system in the vehicle to allow for collecting emission samples for in-use testing where that is practical.

(4) Describe any necessary steps for installing any diagnostic system required under § 1036.110.

(5) Describe how your certification is limited for any type of application. For example, if you certify Heavy HDE to the CO₂ standards using only transient FTP testing, you must make clear that the engine may not be installed in tractors.

(6) Describe any other instructions to make sure the installed engine will operate according to design specifications in your application for certification. This may include, for example, instructions for installing aftertreatment devices when installing the engines.

(7) Give the following instructions if you do not ship diesel exhaust fluid tanks with your engines:

(i) Specify that vehicle manufacturers must install diesel exhaust fluid tanks meeting the specifications of § 1036.115(i).

(ii) Describe how vehicle manufacturers must install diesel exhaust fluid tanks with sensors as needed to meet the requirements of §§ 1036.110 and 1036.111.

(8) State: “If you install the engine in a way that makes the engine’s emission control information label hard to read during normal engine maintenance, you must place a duplicate label on the vehicle, as described in 40 CFR 1068.105.”

(9) Describe how vehicle manufacturers need to apply stickers to qualifying vehicles as described in § 1036.136 if you certify engines to the Clean Idle NO_x standard of § 1036.104(b).

(c) Give the vehicle manufacturer fuel map results as described in § 1036.505(b).

(d) You do not need installation instructions for engines that you install in your own vehicles.

(e) Provide instructions in writing or in an equivalent format. For example, you may post instructions on a publicly available website for downloading or printing. If you do not provide

the instructions in writing, explain in your application for certification how you will ensure that each installer is informed of the installation requirements.

§ 1036.135 Labeling.

- (a) Assign each engine a unique identification number and permanently affix, engrave, or stamp it on the engine in a legible way.
- (b) At the time of manufacture, affix a permanent and legible label identifying each engine. The label must meet the requirements of 40 CFR 1068.45.
- (c) The label must –
 - (1) Include the heading “EMISSION CONTROL INFORMATION”.
 - (2) Include your full corporate name and trademark. You may identify another company and use its trademark instead of yours if you comply with the branding provisions of 40 CFR 1068.45.
 - (3) Include EPA’s standardized designation for the engine family.
 - (4) Identify the primary intended service class.
 - (5) State the engine’s displacement (in liters); however, you may omit this from the label if all the engines in the engine family have the same per-cylinder displacement and total displacement.
 - (6) State the date of manufacture [DAY (optional), MONTH, and YEAR]; however, you may omit this from the label if you stamp, engrave, or otherwise permanently identify it elsewhere on the engine, in which case you must also describe in your application for certification where you will identify the date on the engine.
 - (7) State the NO_x FEL to which the engines are certified if applicable. Identify the Clean Idle standard if you certify the engine to the NO_x standard of § 1036.104(b).
 - (8) State: “THIS ENGINE COMPLIES WITH U.S. EPA REGULATIONS FOR [MODEL YEAR] HEAVY-DUTY HIGHWAY ENGINES.”
 - (9) Identify any limitations on your certification. For example, if you certify Heavy HDE to the CO₂ standards using only steady-state testing, include the statement “TRACTORS ONLY”. Similarly, for engines with one or more approved AECDs for emergency vehicle applications under § 1036.115(h)(4), the statement: “THIS ENGINE IS FOR INSTALLATION IN EMERGENCY VEHICLES ONLY”.
- (d) You may add information to the emission control information label as follows:
 - (1) You may identify other emission standards that the engine meets or does not meet. You may add the information about the other emission standards to the statement we specify, or you may include it in a separate statement.
 - (2) You may add other information to ensure that the engine will be properly maintained and used.
 - (3) You may add appropriate features to prevent counterfeit labels. For example, you may include the engine’s unique identification number on the label.
- (e) You may ask us to approve modified labeling requirements in this part if you show that it is necessary or appropriate. We will approve your request if your alternate label is consistent with the requirements of this part. We may also specify modified labeling requirements to be consistent with the intent of 40 CFR part 1037.
- (f) If you obscure the engine label while installing the engine in the vehicle such that the label cannot be read during normal maintenance, you must place a duplicate label on the vehicle. If others install your engine in their vehicles in a way that obscures the engine label, we require them to add a duplicate label on the vehicle (see 40 CFR 1068.105); in that case, give them the number of duplicate labels they request and keep the following records for at least five years:

- (1) Written documentation of the request from the vehicle manufacturer.
- (2) The number of duplicate labels you send for each engine family and the date you sent them.

§ 1036.136 Clean Idle sticker.

- (a) Design and produce stickers showing that your engines meet the federal Clean Idle standard if you certify engines to the Clean Idle NO_x standard of § 1036.104(b). The sticker must—
 - (1) Meet the requirements of 40 CFR 1068.45 for permanent labels. The preferred location for sticker placement is on the driver's side of the hood.
 - (2) Include one or both of your corporate name and trademark.
 - (3) Identify that the engine is qualified to meet the federal Clean Idle NO_x standard.
 - (4) Include a serial number or other method to confirm that stickers have been properly applied to vehicles.
- (b) The following provisions apply for placing Clean Idle stickers on vehicles with installed engines that have been certified to the NO_x standard of § 1036.104(b):
 - (1) If you install engines in vehicles you produce, you must apply a sticker to each vehicle certified to the Clean Idle standard.
 - (2) If you ship engines for others to install in vehicles, include in your purchasing documentation the manufacturer's request for a specific number of labels corresponding to the number of engines ordered. Supply the vehicle manufacturer with exactly one sticker for each shipped engine certified to the Clean Idle standard. Prepare your emission-related installation instructions to ensure that vehicle manufacturers meet all application requirements. Keep the following records for at least five years:
 - (i) Written documentation of the vehicle manufacturer's request for stickers.
 - (ii) Tracking information for stickers you send and the date you sent them.
- (c) The provisions in 40 CFR 1068.101 apply for the Clean Idle sticker in the same way that those provisions apply for emission control information labels.

§ 1036.140 Primary intended service class and engine cycle.

You must identify a single primary intended service class for each engine family that best describes vehicles for which you design and market the engine, as follows:

- (a) Divide compression-ignition engines into primary intended service classes based on the following engine and vehicle characteristics:
 - (1) Light HDE includes engines that are not designed for rebuild and do not have cylinder liners. Vehicle body types in this group might include any heavy-duty vehicle built from a light-duty truck chassis, van trucks, multi-stop vans, and some straight trucks with a single rear axle. Typical applications would include personal transportation, light-load commercial delivery, passenger service, agriculture, and construction. The GVWR of these vehicles is normally at or below 19,500 pounds.
 - (2) Medium HDE includes engines that may be designed for rebuild and may have cylinder liners. Vehicle body types in this group would typically include school buses, straight trucks with single rear axles, city tractors, and a variety of special purpose vehicles such as small dump trucks, and refuse trucks. Typical applications would include commercial short haul and intra-city delivery and pickup. Engines in this group are normally used in vehicles whose GVWR ranges from 19,501 to 33,000 pounds.
 - (3) Heavy HDE includes engines that are designed for multiple rebuilds and have cylinder liners. Vehicles in this group are normally tractors, trucks, straight trucks with dual rear

axles, and buses used in inter-city, long-haul applications. These vehicles normally exceed 33,000 pounds GVWR.

- (b) Divide spark-ignition engines into primary intended service classes as follows:
 - (1) Spark-ignition engines that are best characterized by paragraph (a)(1) or (2) of this section are in a separate Spark-ignition HDE primary intended service class.
 - (2) Spark-ignition engines that are best characterized by paragraph (a)(3) of this section are included in the Heavy HDE primary intended service class along with compression-ignition engines. Gasoline-fueled engines are presumed not to be characterized by paragraph (a)(3) of this section; for example, vehicle manufacturers may install some number of gasoline-fueled engines in Class 8 trucks without causing the engine manufacturer to consider those to be Heavy HDE.
- (c) References to “spark-ignition standards” in this part relate only to the spark-ignition engines identified in paragraph (b)(1) of this section. References to “compression-ignition standards” in this part relate to compression-ignition engines, to spark-ignition engines optionally certified to standards that apply to compression-ignition engines, and to all engines identified under paragraph (b)(2) of this section as Heavy HDE.

§ 1036.150 Interim provisions.

The provisions in this section apply instead of other provisions in this part. This section describes when these interim provisions expire, if applicable.

(a) *Transitional ABT credits for NO_x emissions.* You may generate NO_x credits from model year 2026 and earlier engines and use those as transitional credits for model year 2027 and later engines using any of the following methods:

(1) *Discounted credits.* Generate discounted credits by certifying any model year 2022 through 2026 engine family to meet all the requirements that apply under 40 CFR part 86, subpart A. Calculate discounted credits for certifying engines in model years 2027 through 2029 as described in § 1036.705 relative to a NO_x emission standard of 200 mg/hp-hr and multiply the result by 0.6. You may not use discounted credits for certifying model year 2030 and later engines.

(2) *Partial credits.* Generate partial credits by certifying any model year 2024 through 2026 compression-ignition engine family as described in this paragraph (a)(2). You may not use partial credits for certifying model year 2033 and later engines. Certify engines for partial credits to meet all the requirements that apply under 40 CFR part 86, subpart A, with the following adjustments:

(i) Calculate credits as described in § 1036.705 relative to a NO_x emission standard of 200 mg/hp-hr using the appropriate useful life mileage from 40 CFR 86.004-2. Your declared NO_x family emission limit applies for the FTP and SET duty cycles.

(ii) Engines must meet a NO_x standard when tested over the Low Load Cycle as described in § 1036.514. Engines must also meet an off-cycle NO_x standard as specified in § 1036.104(a)(3). Calculate the NO_x family emission limits for the Low Load Cycle and for off-cycle testing as described in § 1036.104(c)(3) with Std_{FTPNOx} set to 35 mg/hp-hr and $Std_{[cycle]NOx}$ set to the values specified in § 1036.104(a)(21) or (3), respectively. No standard applies for HC, PM, and CO emissions for the Low Load Cycle or for off-cycle testing, but you must record measured values for those pollutants and include those measured values where you report NO_x emission results.

(iii) For engines selected for in-use testing, we may specify that you perform testing as described in 40 CFR part 86, subpart T, or as described in subpart E of this part.

(iv) Add the statement “Partial credit” to the emission control information label.

(3) *Full credits.* Generate full credits by certifying any model year 2024 through 2026 engine family to meet all the requirements that apply under this part. Calculate credits as described in § 1036.705 relative to a NO_x emission standard of 200 mg/hp·hr. You may not use full credits for certifying model year 2033 and later engines.

(4) *2026 service class pull-ahead credits.* Generate credits from diesel-fueled engines under this paragraph (a)(4) by certifying all your model year 2026 diesel-fueled Heavy HDE to meet all the requirements that apply under this part, with a NO_x family emission limit for FTP testing at or below 50 mg/hp·hr. Calculate credits as described in § 1036.705 relative to a NO_x emission standard of 200 mg/hp·hr. You may use credits generated under this paragraph (a)(4) through model year 2034, but not for later model years. Credits generated by Heavy HDE may be used for certifying Medium HDE after applying a 10 percent discount (multiply credits by 0.9). Engine families using credits generated under this paragraph (a)(4) are subject to a NO_x FEL cap of 50 mg/hp·hr for FTP testing.

(b) *Model year 2014 N₂O standards.* In model year 2014 and earlier, manufacturers may show compliance with the N₂O standards using an engineering analysis. This allowance also applies for later families certified using carryover CO₂ data from model 2014 consistent with § 1036.235(d).

(c) *Engine cycle classification.* Through model year 2020, engines meeting the definition of spark-ignition, but regulated as compression-ignition engines under § 1036.140, must be certified to the requirements applicable to compression-ignition engines under this part. Such engines are deemed to be compression-ignition engines for purposes of this part. Similarly, through model year 2020, engines meeting the definition of compression-ignition, but regulated as Otto-cycle under 40 CFR part 86 must be certified to the requirements applicable to spark-ignition engines under this part. Such engines are deemed to be spark-ignition engines for purposes of this part. See § 1036.140 for provisions that apply for model year 2021 and later.

(d) *Small manufacturers.* The greenhouse gas standards of this part apply on a delayed schedule for manufacturers meeting the small business criteria specified in 13 CFR 121.201. Apply the small business criteria for NAICS code 336310 for engine manufacturers with respect to gasoline-fueled engines and 333618 for engine manufacturers with respect to other engines; the employee limits apply to the total number employees together for affiliated companies.

Qualifying small manufacturers are not subject to the greenhouse gas emission standards in § 1036.108 for engines with a date of manufacture on or after November 14, 2011 but before January 1, 2022. In addition, qualifying small manufacturers producing engines that run on any fuel other than gasoline, E85, or diesel fuel may delay complying with every later greenhouse gas standard under this part by one model year; however, small manufacturers may generate emission credits only by certifying all their engine families within a given averaging set to standards that apply for the current model year. ~~Small manufacturers may certify their engines and generate emission credits under this part before standards start to apply, but only if they certify their entire U.S. directed production volume within that averaging set for that model year.~~

Note that engines not yet subject to standards must nevertheless supply fuel maps to vehicle manufacturers as described in paragraph (n) of this section. Note also that engines produced by small manufacturers are subject to criteria pollutant standards.

(e) *Alternate phase-in standards for greenhouse gas emissions.* Where a manufacturer certifies all of its model year 2013 compression-ignition engines within a given primary intended service class to the applicable alternate standards of this paragraph (e), its compression-ignition engines within that primary intended service class are subject to the standards of this paragraph (e) for model years 2013 through 2016. This means that once a manufacturer chooses to certify a primary intended service class to the standards of this paragraph (e), it is not allowed to opt out of these standards.

TABLE 1 TO PARAGRAPH (e) OF § 1036.150—ALTERNATE PHASE-IN STANDARDS (g/hp·hr)

Vehicle type	Model years	Light HDE	Medium HDE	Heavy HDE
Tractors	2013-2015	NA	512 g/hp·hr	485 g/hp·hr.
	2016 and later ^a	NA	487 g/hp·hr	460 g/hp·hr.
Vocational	2013-2015	618 g/hp·hr	618 g/hp·hr	577 g/hp·hr.
	2016 through 2020 ^a	576 g/hp·hr	576 g/hp·hr	555 g/hp·hr.

^aNote: these alternate standards for 2016 and later are the same as the otherwise applicable standards for 2017 through 2020.

(f) Testing exemption for qualifying hydrogen engines. Tailpipe CO₂ emissions from engines fueled with neat hydrogen are deemed to be 3 g/hp·hr and tailpipe CH₄, HC, and CO emissions are deemed to comply with the applicable standard. Fuel mapping, and no testing for CO₂, CH₄, HC, or CO is required optional under this part for these engines. ~~Reserved~~

(g) *Default deterioration factors for greenhouse gas standards.* You may use default deterioration factors (DFs) without performing your own durability emission tests or engineering analysis as follows:

(1) You may use a default additive DF of 0.0 g/hp·hr for CO₂ emissions from engines that do not use advanced or off-cycle technologies. If we determine it to be consistent with good engineering judgment, we may allow you to use a default additive DF of 0.0 g/hp·hr for CO₂ emissions from your engines with advanced or off-cycle technologies.

(2) You may use a default additive DF of 0.010 g/hp·hr for N₂O emissions from any engine through model year 2021, and 0.020 g/hp·hr for later model years.

(3) You may use a default additive DF of 0.020 g/hp·hr for CH₄ emissions from any engine.

(h) *Advanced-technology credits.* If you generate CO₂ credits from model year 2020 and earlier engines certified for advanced technology, you may multiply these credits by 1.5.

(i) *CO₂ credits for low N₂O emissions.* If you certify your model year 2014, 2015, or 2016 engines to an N₂O FEL less than 0.04 g/hp·hr (provided you measure N₂O emissions from your emission-data engines), you may generate additional CO₂ credits under this paragraph (i). Calculate the additional CO₂ credits from the following equation instead of the equation in § 1036.705:

$$CO_2 \text{ credits (Mg)} = (0.04 - FEL_{N_2O}) \cdot CF \cdot Volume \cdot UL \cdot 10^{-6} \cdot 298$$

Eq. 1036.150-1

(j) *Alternate standards under 40 CFR part 86.* This paragraph (j) describes alternate emission standards that apply for model year 2023 and earlier for loose engines certified under 40 CFR 86.1819-14(k)(8). The standards of § 1036.108 do not apply for these engines. The standards in this paragraph (j) apply for emissions measured with the engine installed in a complete vehicle consistent with the provisions of 40 CFR 86.1819-14(k)(8)(vi). The only requirements of this part that apply to these engines are those in this paragraph (j), §§ 1036.115 through 1036.135, 1036.535, and 1036.540.

(k) *Limited production volume allowance under ABT.* You may produce a limited number of Heavy HDE that continue to meet the standards that applied under 40 CFR 86.007-11 in model years 2027 through 2029. The maximum number of engines you may produce under this limited production allowance is 5 percent of the annual average of your actual ~~U.S.-directed~~ production volume of Heavy HDE in model years 2023-2025 for calculating emission credits under § 1036.705. Engine certification under this paragraph (k) is subject to the following conditions and requirements:

- (1) Engines must meet all the standards and other requirements that apply under 40 CFR part 86 for model year 2026. Engine must be certified in separate engine families that qualify for carryover certification as described in § 1036.235(d).
- (2) The NOx FEL must be at or below 200 mg/hp-hr. Calculate negative credits as described in § 1036.705 by comparing the NOx FEL to the FTP emission standard specified in § 1036.104(a)(1), with a value for useful life of 650,000 miles. Meet the credit reporting and recordkeeping requirements in §§ 1036.730 and 1036.735.
- (3) Label the engine as described in 40 CFR 86.095-35, but include the following alternate compliance statement: “THIS ENGINE CONFORMS TO U.S. EPA REGULATIONS FOR MODEL YEAR 2026 ENGINES UNDER 40 CFR 1036.150(k).”

(l) *Credit adjustment for spark-ignition engines and light heavy-duty compression-ignition engines.* For greenhouse gas emission credits generated from model year 2020 and earlier spark-ignition and light heavy-duty engines, multiply any banked CO₂ credits that you carry forward to demonstrate compliance with model year 2021 and later standards by 1.36.

(m) *Infrequent regeneration.* For model year 2020 and earlier, you may invalidate any test interval with respect to CO₂ measurements if an infrequent regeneration event occurs during the test interval. Note that § 1036.580 specifies how to apply infrequent regeneration adjustment factors for later model years.

(n) *Supplying fuel maps.* Engine manufacturers not yet subject to standards under § 1036.108 in model year 2021 must supply vehicle manufacturers with fuel maps (or powertrain test results) as described in § 1036.130 for those engines.

(o) *Engines used in glider vehicles.* For purposes of recertifying a used engine for installation in a glider vehicle, we may allow you to include in an existing certified engine family those engines you modify (or otherwise demonstrate) to be identical to engines already covered by the certificate. We would base such an approval on our review of any appropriate documentation. These engines must have emission control information labels that accurately describe their status.

(p) *Transition to Phase 2 CO₂ standards.* If you certify all your model year 2020 engines within an averaging set to the model year 2021 FTP and SET standards and requirements, you may apply the provisions of this paragraph (p) for enhanced generation and use of emission credits. These provisions apply separately for Medium HDE and Heavy HDE.

(1) Greenhouse gas emission credits you generate with model year 2018 through 2024 engines may be used through model year 2030, instead of being limited to a five-year credit life as specified in § 1036.740(d).

(2) You may certify your model year 2024 through 2026 engines to the following alternative standards:

TABLE 2 TO PARAGRAPH (p)(2) OF § 1036.150—ALTERNATIVE STANDARDS FOR MODEL YEARS 2024 THROUGH 2026

Model years	Medium heavy-duty-vocational	Heavy heavy-duty-vocational	Medium heavy-duty-tractor	Heavy heavy-duty-tractor
2024-2026	542	510	467	442

(q) *Confirmatory [and in-use](#) testing of fuel maps defined in § 1036.505(b).* For model years 2021 and later, where the results from Eq. 1036.235-1 for a confirmatory [or in-use](#) test are at or below 2.0 %, we will not replace the manufacturer’s fuel maps.

(r) *Fuel maps for the transition to updated GEM.* (1) You may use fuel maps from model year 2023 and earlier engines for certifying model year 2024 and later engines using carryover provisions in § 1036.235(d).

(2) Compliance testing will be based on the GEM version you used to generate fuel maps for certification. For example, if you perform a selective enforcement audit with respect to fuel maps, use the same GEM version that you used to generate fuel maps for certification. Similarly, we will use the same GEM version that you used to generate fuel maps for certification if we perform confirmatory testing with one of your engine families.

(s) *Greenhouse gas compliance testing.* Select duty cycles and measure emissions to demonstrate compliance with greenhouse gas emission standards before model year 2027 as follows:

(1) For model years 2016 through 2020, measure emissions using the FTP duty cycle specified in § 1036.512 and the SET duty cycle specified in 40 CFR 86.1362, as applicable.

(2) The following provisions apply for model years 2021 through 2026:

(i) Determine criteria pollutant emissions during any testing used to demonstrate compliance with greenhouse gas emission standards; however, the duty-cycle standards of § 1036.104 apply for measured criteria pollutant emissions only as described in subpart F of this part.

(ii) You may demonstrate compliance with SET-based greenhouse gas emission standards in § 1036.108(a)(1) using the SET duty cycle specified in 40 CFR 86.1362 if you collect emissions with continuous sampling. Integrate the test results by mode to establish separate emission rates for each mode (including the transition following each mode, as applicable). Apply the CO₂ weighting factors specified in 40 CFR 86.1362 to calculate a composite emission result.

(t) *Model year 2027 compliance date.* The following provisions describe when this part 1036 starts to apply for model year 2027 engines:

(1) *Split model year.* Model year 2027 engines you produce before December 20, 2026 are subject to the criteria standards and related provisions in 40 CFR part 86, subpart A, as described in § 1036.1(a). Model year 2027 engines you produce on or after December 20, 2026 are subject to all the provisions of this part.

(2) *Optional early compliance.* You may optionally certify model year 2027 engines you produce before December 20, 2026 to all the provisions of this part.

(3) *Certification.* If you certify any model year 2027 engines to 40 CFR part 86, subpart A, under paragraph (t)(1) of this section, certify the engine family by dividing the model year into two partial model years. The first portion of the model year starts when it would normally start and ends when you no longer produce engines meeting standards under 40 CFR part 86, subpart A, on or before December 20, 2026. The second portion of the model year starts when you begin producing engines meeting standards under this part 1036, and ends on the day your model year would normally end. The following additional provisions apply for model year 2027 if you split the model year as described in this paragraph (t):

(i) You may generate emission credits only with engines that are certified under this part 1036.

(ii) In your production report under § 1036.250(a), identify production volumes separately for the two parts of the model year.

(iii) OBD testing demonstrations apply singularly for the full model year.

(u) *Crankcase emissions.* The provisions of 40 CFR 86.007-11(c) for crankcase emissions continue to apply through model year 2026.

(v) *OBD communication protocol.* We may approve the alternative communication protocol specified in SAE J1979-2 (incorporated by reference, [see](#) ~~in~~ § 1036.810) if the protocol is approved by the California Air Resources Board. The alternative protocol would apply instead of SAE J1939 and SAE J1979 as specified in 40 CFR 86.010-18(k)(1). Engines designed to comply with SAE J1979-2 must meet the freeze-frame requirements in § 1036.110(b)(8) and in 13 CCR

1971.1(h)(4.3.2) (incorporated by reference, [see](#) § 1036.810). This paragraph (v) also applies for model year 2026 and earlier engines.

(w) *Greenhouse gas warranty*. For model year 2027 and later engines, you may ask us to approve the model year 2026 warranty periods specified in § 1036.120 for components or systems needed to comply with greenhouse gas emission standards if those components or systems do not play a role in complying with criteria pollutant standards.

(x) *Powertrain testing for criteria pollutants*. You may apply the powertrain testing provisions of § 1036.101(b) for demonstrating compliance with criteria pollutant emission standards in 40 CFR part 86 before model year 2027.

(y) *NO_x compliance allowance for in-use testing*. A NO_x compliance allowance of 15 mg/hp·hr applies for any in-use testing of Medium HDE and Heavy HDE as described in subpart E of this part. Add the compliance allowance to the NO_x standard that applies for each duty cycle and for off-cycle testing, with both field testing and laboratory testing. The NO_x compliance allowance does not apply for the bin 1 off-cycle standard. As an example, for manufacturer-run field-testing of a Heavy HDE, add the 15 mg/hp·hr compliance allowance and the 5 mg/hp·hr accuracy margin from § 1036.420 to the 58 mg/hp·hr bin 2 off-cycle standard to calculate a 78 mg/hp·hr NO_x standard.

(z) *Alternate family pass criteria for in-use testing*. The following family pass criteria apply for manufacturer-run in-use testing instead of the pass criteria described in § 1036.425 for model years 2027 and 2028:

(1) Start by measuring emissions from five engines using the procedures described in subpart E of this part and § 1036.530. If four or five engines comply fully with the off-cycle bin standards, the engine family passes and you may stop testing.

(2) If exactly two of the engines tested under paragraph (z)(1) of this section do not comply fully with the off-cycle bin standards, test five more engines. If these additional engines all comply fully with the off-cycle bin standards, the engine family passes and you may stop testing.

(3) If three or more engines tested under paragraphs (z)(1) and (2) of this section do not comply fully with the off-cycle bin standards, test a total of at least 10 but not more than 15 engines. Calculate the arithmetic mean of the bin emissions from all the engine tests as specified in § 1036.530(g) for each pollutant. If the mean values are at or below the off-cycle bin standards, the engine family passes. If the mean value for any pollutant is above an off-cycle bin standard, the engine family fails.

[\(aa\) Correcting credit calculations. If you notify us by October 1, 2024 that errors mistakenly decreased your balance of GHG emission credits for 2020 or any earlier model years, you may correct the errors and recalculate the balance of emission credits after applying a 10 percent discount to the credit correction.](#)

Subpart C—Certifying Engine Families

§ 1036.201 General requirements for obtaining a certificate of conformity.

(a) You must send us a separate application for a certificate of conformity for each engine family. A certificate of conformity is valid from the indicated effective date until December 31 of the model year for which it is issued.

(b) The application must contain all the information required by this part and must not include false or incomplete statements or information (see § 1036.255).

(c) We may ask you to include less information than we specify in this subpart, as long as you maintain all the information required by § 1036.250.

- (d) You must use good engineering judgment for all decisions related to your application (see 40 CFR 1068.5).
- (e) An authorized representative of your company must approve and sign the application.
- (f) See § 1036.255 for provisions describing how we will process your application.
- (g) We may require you to deliver your test engines to a facility we designate for our testing (see § 1036.235(c)). Alternatively, you may choose to deliver another engine that is identical in all material respects to the test engine, or another engine that we determine can appropriately serve as an emission-data engine for the engine family.
- (h) For engines that become new after being placed into service, such as rebuilt engines installed in new vehicles, we may specify alternate certification provisions consistent with the intent of this part. See 40 CFR 1068.120(h) and the definition of “new motor vehicle engine” in § 1036.801.

§ 1036.205 Requirements for an application for certification.

This section specifies the information that must be in your application, unless we ask you to include less information under § 1036.201(c). We may require you to provide additional information to evaluate your application.

(a) Identify the engine family’s primary intended service class and describe how that conforms to the specifications in §1036.140. Also, describe the engine family’s specifications and other basic parameters of the engine’s design and emission controls with respect to compliance with the requirements of this part. List the fuel type on which your engines are designed to operate (for example, gasoline, diesel fuel, or natural gas). For engines that can operate on multiple fuels, identify whether they are dual-fuel or flexible-fuel engines; also identify the range of mixtures for operation on blended fuels, if applicable. List each engine configuration in the engine family. List the rated power for each engine configuration.

(b) Explain how the emission control system operates. Describe in detail all system components for controlling greenhouse gas and criteria pollutant emissions, including all auxiliary emission control devices (AECDs) and all fuel-system components you will install on any production or test engine. Identify the part number of each component you describe. For this paragraph (b), treat as separate AECDs any devices that modulate or activate differently from each other.

Include all the following:

- (1) Give a general overview of the engine, the emission control strategies, and all AECDs.
- (2) Describe each AECD’s general purpose and function.
- (3) Identify the parameters that each AECD senses (including measuring, estimating, calculating, or empirically deriving the values). Include engine-based parameters and state whether you simulate them during testing with the applicable procedures.
- (4) Describe the purpose for sensing each parameter.
- (5) Identify the location of each sensor the AECD uses.
- (6) Identify the threshold values for the sensed parameters that activate the AECD.
- (7) Describe the parameters that the AECD modulates (controls) in response to any sensed parameters, including the range of modulation for each parameter, the relationship between the sensed parameters and the controlled parameters and how the modulation achieves the AECD’s stated purpose. Use graphs and tables, as necessary.
- (8) Describe each AECD’s specific calibration details. This may be in the form of data tables, graphical representations, or some other description.
- (9) Describe the hierarchy among the AECDs when multiple AECDs sense or modulate the same parameter. Describe whether the strategies interact in a comparative or additive manner and identify which AECD takes precedence in responding, if applicable.

- (10) Explain the extent to which the AECD is included in the applicable test procedures specified in subpart F of this part.
- (11) Do the following additional things for AECDs designed to protect engines or vehicles:
- (i) Identify any engine and vehicle design limits that make protection necessary and describe any damage that would occur without the AECD.
 - (ii) Describe how each sensed parameter relates to the protected components' design limits or those operating conditions that cause the need for protection.
 - (iii) Describe the relationship between the design limits/parameters being protected and the parameters sensed or calculated as surrogates for those design limits/parameters, if applicable.
 - (iv) Describe how the modulation by the AECD prevents engines and vehicles from exceeding design limits.
 - (v) Explain why it is necessary to estimate any parameters instead of measuring them directly and describe how the AECD calculates the estimated value, if applicable.
 - (vi) Describe how you calibrate the AECD modulation to activate only during conditions related to the stated need to protect components and only as needed to sufficiently protect those components in a way that minimizes the emission impact.
- (c) Explain in detail how the engine diagnostic system works, describing especially the engine conditions (with the corresponding diagnostic trouble codes) that cause the malfunction indicator to go on. You may ask us to approve conditions under which the diagnostic system disregards trouble codes as described in § 1036.110.
- (d) Describe the engines you selected for testing and the reasons for selecting them.
- (e) Describe any test equipment and procedures that you used, including any special or alternate test procedures you used (see § 1036.501).
- (f) Describe how you operated the emission-data engine before testing, including the duty cycle and the number of engine operating hours used to stabilize emission levels. Explain why you selected the method of service accumulation. Describe any scheduled maintenance you did.
- (g) List the specifications of the test fuel to show that it falls within the required ranges we specify in 40 CFR part 1065.
- (h) Identify the engine family's useful life.
- (i) Include the warranty statement and maintenance instructions you will give to the ultimate purchaser of each new engine (see §§ 1036.120 and 1036.125).
- (j) Include the emission-related installation instructions you will provide if someone else installs your engines in their vehicles (see § 1036.130).
- (k) Describe your emission control information label (see § 1036.135). We may require you to include a copy of the label.
- (l) Identify the duty-cycle emission standards from §§ 1036.104(a) and (b) and 1036.108(a) that apply for the engine family. Also identify FELs and FCLs as follows:
- (1) Identify the NO_x FEL over the FTP for the engine family.
 - (2) Identify the CO₂ FCLs for the engine family; also identify any FELs that apply for CH₄ and N₂O. The actual U.S.-directed production volume of configurations that have CO₂ emission rates at or below the FCL and CH₄ and N₂O emission rates at or below the applicable standards or FELs must be at least one percent of your actual (not projected) U.S.-directed production volume for the engine family. Identify configurations within the family that have emission rates at or below the FCL and meet the one percent requirement. For example, if your U.S.-directed production volume for the engine family is 10,583 and the U.S.-directed production volume for the tested rating is 75 engines, then you can comply with this provision by setting your FCL so that one more rating with a U.S.-directed

production volume of at least 31 engines meets the FCL. Where applicable, also identify other testable configurations required under § 1036.230(f)(2)(ii).

(m) Identify the engine family's deterioration factors and describe how you developed them (see §§ 1036.240 and 1036.241). Present any test data you used for this. For engines designed to discharge crankcase emissions to the ambient atmosphere, use the deterioration factors for crankcase emission to determine deteriorated crankcase emission levels of NO_x, HC, PM, and CO as specified in § 1036.240(e).

(n) State that you operated your emission-data engines as described in the application (including the test procedures, test parameters, and test fuels) to show you meet the requirements of this part.

(o) Present emission data from all valid tests on an emission-data engine to show that you meet emission standards. Note that § 1036.235 allows you to submit an application in certain cases without new emission data. Present emission data as follows:

(1) For hydrocarbons (such as NMHC or NMHCE), NO_x, PM, and CO, as applicable, show your engines meet the applicable exhaust emission standards we specify in § 1036.104. Show emission figures for duty-cycle exhaust emission standards before and after applying adjustment factors for regeneration and deterioration factors for each engine.

(2) For CO₂, CH₄, and N₂O, show that your engines meet the applicable emission standards we specify in § 1036.108. Show emission figures before and after applying deterioration factors for each engine. In addition to the composite results, show individual measurements for cold-start testing and hot-start testing over the transient test cycle. For each of these tests, also include the corresponding exhaust emission data for criteria emissions.

(3) If we specify more than one grade of any fuel type (for example, a summer grade and winter grade of gasoline), you need to submit test data only for one grade, unless the regulations of this part specify otherwise for your engine.

(p) State that all the engines in the engine family comply with the off-cycle emission standards we specify in § 1036.104 for all normal operation and use when tested as specified in § 1036.530. Describe any relevant testing, engineering analysis, or other information in sufficient detail to support your statement. We may direct you to include emission measurements representing typical engine in-use operation at a range of ambient conditions. For example, we may specify certain transient and steady-state engine operation that is typical for the types of vehicles that use your engines. See § 1036.210.

(q) We may ask you to send information to confirm that the emission data you submitted were from valid tests meeting the requirements of this part and 40 CFR part 1065. You must indicate whether there are test results from invalid tests or from any other tests of the emission-data engine, whether or not they were conducted according to the test procedures of subpart F of this part. We may require you to report these additional test results.

(r) Describe all adjustable operating parameters (see § 1036.115(f)), including production tolerances. For any operating parameters that do not qualify as adjustable parameters, include a description supporting your conclusion (see 40 CFR 1068.50(c)). Include the following in your description of each adjustable parameter:

(1) For practically adjustable operating parameters, include the nominal or recommended setting, the intended practically adjustable range, and the limits or stops used to establish adjustable ranges. State that the limits, stops, or other means of inhibiting adjustment are effective in preventing adjustment of parameters on in-use engines to settings outside your intended practically adjustable ranges and provide information to support this statement.

(2) For programmable operating parameters, state that you have restricted access to electronic controls to prevent parameter adjustment on in-use engines that would allow

operation outside the practically adjustable range. Describe how your engines are designed to prevent unauthorized adjustments.

- (s) Provide the information to read, record, and interpret all the information broadcast by an engine's onboard computers and ECMs as described in § 1036.115(d). State that, upon request, you will give us any hardware, software, or tools we would need to do this.
- (t) State whether your certification is limited for certain engines. For example, you might certify engines only for use in tractors, in emergency vehicles, or in vehicles with hybrid powertrains. If this is the case, describe how you will prevent use of these engines in vehicles for which they are not certified.
- (u) Unconditionally certify that all the engines in the engine family comply with the requirements of this part, other referenced parts of the CFR, and the Clean Air Act. Note that § 1036.235 specifies which engines to test to show that engines in the entire family comply with the requirements of this part.
- (v) Include good-faith estimates of ~~nationwide-U.S.-directed~~ production volumes. Include a justification for the estimated production volumes if they are substantially different than actual production volumes in earlier years for similar models.
- (w) Include the information required by other subparts of this part. For example, include the information required by § 1036.725 if you participate in the ABT program.
- (x) Include other applicable information, such as information specified in this part or 40 CFR part 1068 related to requests for exemptions.
- (y) Name an agent for service located in the United States. Service on this agent constitutes service on you or any of your officers or employees for any action by EPA or otherwise by the United States related to the requirements of this part.
- (z) For imported engines, identify the following:
 - (1) Describe your normal practice for importing engines. For example, this may include identifying the names and addresses of anyone you have authorized to import your engines. Engines imported by nonauthorized agents are not covered by your certificate.
 - (2) The location of a test facility in the United States where you can test your engines if we select them for testing under a selective enforcement audit, as specified in 40 CFR part 1068, subpart E.
- (aa) Include information needed to certify vehicles to greenhouse gas standards under 40 CFR part 1037 as described in § 1036.505.

§ 1036.210 Preliminary approval before certification.

If you send us information before you finish the application, we may review it and make any appropriate determinations, especially for questions related to engine family definitions, auxiliary emission control devices, adjustable parameters, deterioration factors, testing for service accumulation, and maintenance. Decisions made under this section are considered to be preliminary approval, subject to final review and approval. We will generally not reverse a decision where we have given you preliminary approval, unless we find new information supporting a different decision. If you request preliminary approval related to the upcoming model year or the model year after that, we will make best-efforts to make the appropriate determinations as soon as practicable. We will generally not provide preliminary approval related to a future model year more than two years ahead of time.

§ 1036.225 Amending applications for certification.

Before we issue you a certificate of conformity, you may amend your application to include new or modified engine configurations, subject to the provisions of this section. After we have issued your certificate of conformity, you may send us an amended application any time before the end of the model year requesting that we include new or modified engine configurations within the scope of the certificate, subject to the provisions of this section. You must also amend your application if any changes occur with respect to any information that is included or should be included in your application.

(a) You must amend your application before you take any of the following actions:

(1) Add an engine configuration to an engine family. In this case, the engine configuration added must be consistent with other engine configurations in the engine family with respect to the design aspects listed in § 1036.230.

(2) Change an engine configuration already included in an engine family in a way that may affect emissions, or change any of the components you described in your application for certification. This includes production and design changes that may affect emissions any time during the engine's lifetime.

(3) Modify an FEL or FCL for an engine family as described in paragraph (f) of this section.

(b) To amend your application for certification, send the relevant information to the Designated Compliance Officer.

(1) Describe in detail the addition or change in the engine model or configuration you intend to make.

(2) Include engineering evaluations or data showing that the amended engine family complies with all applicable requirements. You may do this by showing that the original emission-data engine is still appropriate for showing that the amended family complies with all applicable requirements.

(3) If the original emission-data engine for the engine family is not appropriate to show compliance for the new or modified engine configuration, include new test data showing that the new or modified engine configuration meets the requirements of this part.

(4) Include any other information needed to make your application correct and complete.

(c) We may ask for more test data or engineering evaluations. You must give us these within 30 days after we request them.

(d) For engine families already covered by a certificate of conformity, we will determine whether the existing certificate of conformity covers your newly added or modified engine. You may ask for a hearing if we deny your request (see § 1036.820).

(e) The amended application applies starting with the date you submit the amended application, as follows:

(1) For engine families already covered by a certificate of conformity, you may start producing a new or modified engine configuration any time after you send us your amended application and before we make a decision under paragraph (d) of this section. However, if we determine that the affected engines do not meet applicable requirements in this part, we will notify you to cease production of the engines and may require you to recall the engines at no expense to the owner. Choosing to produce engines under this paragraph (e) is deemed to be consent to recall all engines that we determine do not meet applicable emission standards or other requirements in this part and to remedy the nonconformity at no expense to the owner. If you do not provide information required under paragraph (c) of this section within 30 days after we request it, you must stop producing the new or modified engines.

(2) [Reserved]

(f) You may ask us to approve a change to your FEL in certain cases after the start of production, but before the end of the model year. If you change an FEL for CO₂, your FCL for CO₂ is automatically set to your new FEL divided by 1.03. The changed FEL may not apply to engines you have already introduced into U.S. commerce, except as described in this paragraph (f). You may ask us to approve a change to your FEL in the following cases:

(1) You may ask to raise your FEL for your engine family at any time. In your request, you must show that you will still be able to meet the emission standards as specified in subparts B and H of this part. Use the appropriate FELs/FCLs with corresponding production volumes to calculate emission credits for the model year, as described in subpart H of this part.

(2) You may ask to lower the FEL for your engine family only if you have test data from production engines showing that emissions are below the proposed lower FEL (or below the proposed FCL for CO₂). The lower FEL/FCL applies only to engines you produce after we approve the new FEL/FCL. Use the appropriate FEL/FCL with corresponding production volumes to calculate emission credits for the model year, as described in subpart H of this part.

(g) You may produce engines or modify in-use engines as described in your amended application for certification and consider those engines to be in a certified configuration. Modifying a new or in-use engine to be in a certified configuration does not violate the tampering prohibition of 40 CFR 1068.101(b)(1), as long as this does not involve changing to a certified configuration with a higher family emission limit.

§ 1036.230 Selecting engine families.

(a) For purposes of certification to the standards of this part, divide your product line into families of engines that are expected to have similar characteristics for criteria emissions throughout the useful life as described in this section. Your engine family is limited to a single model year.

(b) Group engines in the same engine family if they are the same in all the following design aspects:

(1) The combustion cycle and fuel. See paragraph (g) of this section for special provisions that apply for dual-fuel and flexible-fuel engines.

(2) The cooling system (water-cooled vs. air-cooled).

(3) Method of air aspiration, including the location of intake and exhaust valves or ports and the method of intake-air cooling, if applicable.

(4) The arrangement and composition of catalytic converters and other aftertreatment devices.

(5) Cylinder arrangement (such as in-line vs. vee configurations) and bore center-to-center dimensions.

(6) Method of control for engine operation other than governing (i.e., mechanical or electronic).

(7) The numerical level of the applicable criteria emission standards. For example, an engine family may not include engines certified to different family emission limits for criteria emission standards, though you may change family emission limits without recertifying as specified in § 1036.225(f).

(c) You may subdivide a group of engines that is identical under paragraph (b) of this section into different engine families if you show the expected criteria emission characteristics are different during the useful life.

(d) In unusual circumstances, you may group engines that are not identical with respect to the design aspects listed in paragraph (b) of this section in the same engine family if you show that their criteria emission characteristics during the useful life will be similar.

(e) Engine configurations certified as ~~hybrid engines or~~ hybrid powertrains may not be included in an engine family with engines that have nonhybrid powertrains. Note that this does not prevent you from including engines in a nonhybrid family if they are used in hybrid vehicles, as long as you certify them based on engine testing.

(f) You must certify your engines to the greenhouse gas standards of § 1036.108 using the same engine families you use for criteria pollutants. The following additional provisions apply with respect to demonstrating compliance with the standards in § 1036.108:

(1) You may subdivide an engine family into subfamilies that have a different FCL for CO₂ emissions. These subfamilies do not apply for demonstrating compliance with criteria standards in § 1036.104.

(2) If you certify engines in the family for use as both vocational and tractor engines, you must split your family into two separate subfamilies.

(i) Calculate emission credits relative to the vocational engine standard for the number of engines sold into vocational applications and relative to the tractor engine standard for the number of engines sold into non-vocational tractor applications. You may assign the numbers and configurations of engines within the respective subfamilies at any time before submitting the report required by § 1036.730. If the family participates in averaging, banking, or trading, you must identify the type of vehicle in which each engine is installed; we may alternatively allow you to use statistical methods to determine this for a fraction of your engines. Keep records to document this determination.

(ii) If you restrict use of the test configuration for your split family only to tractors, or only to vocational vehicles, you must identify a second testable configuration for the other type of vehicle (or an unrestricted configuration). Identify this configuration in your application for certification. The FCL for the engine family applies for this configuration as well as the primary test configuration.

(3) If you certify both engine fuel maps and powertrain fuel maps for an engine family, you may split the engine family into two separate subfamilies. Indicate this in your application for certification, and identify whether one or both of these sets of fuel maps applies for each group of engines. If you do not split your family, all engines within the family must conform to the engine fuel maps, including any engines for which the powertrain maps also apply.

(4) If you certify in separate engine families engines that could have been certified in vocational and tractor engine subfamilies in the same engine family, count the two families as one family for purposes of determining your obligations with respect to the OBD requirements and in-use testing requirements. Indicate in the applications for certification that the two engine families are covered by this paragraph (f)(4).

(5) Except as described in this paragraph (f), engine configurations within an engine family must use equivalent greenhouse gas emission controls. Unless we approve it, you may not produce nontested configurations without the same emission control hardware included on the tested configuration. We will only approve it if you demonstrate that the exclusion of the hardware does not increase greenhouse gas emissions.

(g) You may certify dual-fuel or flexible-fuel engines in a single engine family. You may include dedicated-fuel versions of this same engine model in the same engine family, as long as they are identical to the engine configuration with respect to that fuel type for the dual-fuel or flexible-fuel version of the engine. For example, if you produce an engine that can alternately run on gasoline and natural gas, you can include the gasoline-only and natural gas-only versions of the

engine in the same engine family as the dual-fuel engine if engine operation on each fuel type is identical with or without installation of components for operating on the other fuel.

§ 1036.235 Testing requirements for certification.

This section describes the emission testing you must perform to show compliance with the emission standards in §§ 1036.104 and 1036.108.

- (a) Select and configure one or two emission-data engines from each engine family as follows:
- (1) You may use one engine for criteria pollutant testing and a different engine for greenhouse gas emission testing, or you may use the same engine for all testing.
 - (2) For criteria pollutant emission testing, select the engine configuration with the highest volume of fuel injected per cylinder per combustion cycle at the point of maximum torque - unless good engineering judgment indicates that a different engine configuration is more likely to exceed (or have emissions nearer to) an applicable emission standard or FEL. If two or more engines have the same fueling rate at maximum torque, select the one with the highest fueling rate at rated speed. In making this selection, consider all factors expected to affect emission-control performance and compliance with the standards, including emission levels of all exhaust constituents, especially NO_x and PM. To the extent we allow it for establishing deterioration factors, select for testing those engine components or subsystems whose deterioration best represents the deterioration of in-use engines.
 - (3) For greenhouse gas emission testing, the standards of this part apply only with respect to emissions measured from the tested configuration and other configurations identified in § 1036.205(l)(2). Note that configurations identified in § 1036.205(l)(2) are considered to be “tested configurations” whether or not you test them for certification. However, you must apply the same (or equivalent) emission controls to all other engine configurations in the engine family. In other contexts, the tested configuration is sometimes referred to as the “parent configuration”, although the terms are not synonymous.
- (b) Test your emission-data engines using the procedures and equipment specified in subpart F of this part. In the case of dual-fuel and flexible-fuel engines, measure emissions when operating with each type of fuel for which you intend to certify the engine.
- (1) For criteria pollutant emission testing, measure NO_x, PM, CO, and NMHC emissions using each duty cycle specified in § 1036.104.
 - (2) For greenhouse gas emission testing, measure CO₂, CH₄, and N₂O emissions; the following provisions apply regarding test cycles for demonstrating compliance with tractor and vocational standards:
 - (i) If you are certifying the engine for use in tractors, you must measure CO₂ emissions using the SET duty cycle specified in § 1036.510, taking into account the interim provisions in § 1036.150(s), and measure CH₄ and N₂O emissions using the FTP transient cycle.
 - (ii) If you are certifying the engine for use in vocational applications, you must measure CO₂, CH₄, and N₂O emissions using the appropriate FTP transient duty cycle, including cold-start and hot-start testing as specified in § 1036.512.
 - (iii) You may certify your engine family for both tractor and vocational use by submitting CO₂ emission data and specifying FCLs from both SET and FTP transient duty cycles.
 - (iv) Some of your engines certified for use in tractors may also be used in vocational vehicles, and some of your engines certified for use in vocational may be used in tractors. However, you may not knowingly circumvent the intent of this part (to reduce in-use emissions of CO₂) by certifying engines designed for tractors or vocational vehicles (and rarely used in the other application) to the wrong cycle. For example, we would generally

not allow you to certify all your engines to the SET duty cycle without certifying any to the FTP transient cycle.

(c) We may perform confirmatory testing by measuring emissions from any of your emission-data engines. If your certification includes powertrain testing as specified in § 1036.630, this paragraph (c) also applies for the powertrain test results.

(1) We may decide to do the testing at your plant or any other facility. If we do this, you must deliver the engine to a test facility we designate. The engine you provide must include appropriate manifolds, aftertreatment devices, ECMs, and other emission-related components not normally attached directly to the engine block. If we do the testing at your plant, you must schedule it as soon as possible and make available the instruments, personnel, and equipment we need.

(2) If we measure emissions on your engine, the results of that testing become the official emission results for the engine as specified in this paragraph (c). Unless we later invalidate these data, we may decide not to consider your data in determining if your engine family meets applicable requirements in this part.

(3) Before we test one of your engines, we may set its adjustable parameters to any point within the practically adjustable ranges (see § 1036.115(f)).

(4) Before we test one of your engines, we may calibrate it within normal production tolerances for anything we do not consider an adjustable parameter. For example, we may calibrate it within normal production tolerances for an engine parameter that is subject to production variability because it is adjustable during production, but is not considered an adjustable parameter because it is permanently sealed. For parameters that relate to a level of performance that is itself subject to a specified range (such as maximum power output), we will generally perform any calibration under this paragraph (c)(4) in a way that keeps performance within the specified range.

(5) For greenhouse gas emission testing, we may use our emission test results for steady-state, idle, cycle-average and powertrain fuel maps defined in § 1036.505(b) as the official emission results. We will not replace individual points from your fuel map.

(i) We will determine fuel masses, $m_{\text{fuel}[\text{cycle}]}$, and mean idle fuel mass flow rates, $\bar{m}_{\text{fuel}[\text{idle}]}$, if applicable, using both direct and indirect measurement. We will determine the result for each test point based on carbon balance error verification as described in § 1036.535(g)(3)(i) and (ii).

(ii) We will perform this comparison using the weighted results from GEM, using vehicles that are appropriate for the engine under test. For example, we may select vehicles that the engine went into for the previous model year.

(iii) If you supply cycle-average engine fuel maps for the highway cruise cycles instead of generating a steady-state fuel map for these cycles, we may perform a confirmatory test of your engine fuel maps for the highway cruise cycles by either of the following methods:

(A) Directly measuring the highway cruise cycle-average fuel maps.

(B) Measuring a steady-state fuel map as described in this paragraph (c)(5) and using it in GEM to create our own cycle-average engine fuel maps for the highway cruise cycles.

(iv) We will replace fuel maps as a result of confirmatory testing as follows:

(A) Weight individual duty cycle results using the vehicle categories determined in paragraph (c)(5)(i) of this section and respective weighting factors in 40 CFR 1037.510(c) to determine a composite CO₂ emission value for each vehicle configuration; then repeat the process for all the unique vehicle configurations used to generate the manufacturer's fuel maps.

(B) The average percent difference between fuel maps is calculated using the following equation:

$$difference = \left(\frac{\sum_{i=1}^N \frac{e_{CO2compEPAi} - e_{CO2compManui}}{e_{CO2compManui}}}{N} \right) \cdot 100 \%$$

Eq. 1036.235-1

Where:

i = an indexing variable that represents one individual weighted duty cycle result for a vehicle configuration.

N = total number of vehicle configurations.

*e*_{CO2compEPA*i*} = unrounded composite mass of CO₂ emissions in g/ton-mile for vehicle configuration *i* for the EPA test.

*e*_{CO2compManu*i*} = unrounded composite mass of CO₂ emissions in g/ton-mile for vehicle configuration *i* for the manufacturer-declared map.

(C) Where the unrounded average percent difference between our composite weighted fuel map and the manufacturer's is at or below 0 %, we will not replace the manufacturer's maps, and we will consider an individual engine to have passed the fuel map.

(6) We may perform confirmatory testing with an engine dynamometer to simulate normal engine operation to determine whether your emission-data engine meets off-cycle emission standards. The accuracy margins described in § 1036.420(a) do not apply for such laboratory testing.

(d) You may ask to use carryover emission data from a previous model year instead of doing new tests, but only if all the following are true:

(1) The engine family from the previous model year differs from the current engine family only with respect to model year, items identified in § 1036.225(a), or other characteristics unrelated to emissions. We may waive this criterion for differences we determine not to be relevant.

(2) The emission-data engine from the previous model year remains the appropriate emission-data engine under paragraph (a) of this section.

(3) The data show that the emission-data engine would meet all the requirements that apply to the engine family covered by the application for certification.

(e) We may require you to test a second engine of the same configuration in addition to the engines tested under paragraph (a) of this section.

(f) If you use an alternate test procedure under 40 CFR 1065.10 and later testing shows that such testing does not produce results that are equivalent to the procedures specified in subpart F of this part, we may reject data you generated using the alternate procedure.

(g) We may evaluate or test your engines to determine whether they have a defeat device before or after we issue a certificate of conformity. We may test or require testing on any vehicle or engine at a designated location, using driving cycles and conditions that may reasonably be expected in normal operation and use to investigate a potential defeat device. If we designate an engine's AECD as a possible defeat device, you must demonstrate to us that that the AECD does not reduce emission control effectiveness when the engine operates under conditions that may reasonably be expected in normal operation and use, unless one of the specific exceptions described in § 1036.115(h) applies.

§ 1036.240 Demonstrating compliance with criteria pollutant emission standards.

(a) For purposes of certification, your engine family is considered in compliance with the duty-cycle emission standards in § 1036.104(a)(1) and (2) if all emission-data engines representing that family have test results showing official emission results and deteriorated emission levels at or below these standards (including all corrections and adjustments). This also applies for all test points for emission-data engines within the family used to establish deterioration factors. Note that your FELs are considered to be the applicable emission standards with which you must comply if you participate in the ABT program in subpart H of this part. Use good engineering judgment to demonstrate compliance with off-cycle standards throughout the useful life.

(b) Your engine family is deemed not to comply if any emission-data engine representing that family has test results showing an official emission result or a deteriorated emission level for any pollutant that is above an applicable emission standard (including all corrections and adjustments). Similarly, your engine family is deemed not to comply if any emission-data engine representing that family has test results showing any emission level above the applicable off-cycle emission standard for any pollutant. This also applies for all test points for emission-data engines within the family used to establish deterioration factors.

(c) To compare emission levels from the emission-data engine with the applicable duty-cycle emission standards, apply deterioration factors to the measured emission levels for each pollutant. Section 1036.245 specifies how to test engines and engine components to develop deterioration factors that represent the deterioration expected in emissions over your engines' useful life. Section 1036.246 describes how to confirm or modify deterioration factors based on in-use verification testing. Your deterioration factors must take into account any available data from other in-use testing with similar engines. Small manufacturers may use assigned deterioration factors that we establish. Apply deterioration factors as follows:

(1) *Additive deterioration factor for exhaust emissions.* Except as specified in paragraph (c)(2) of this section, use an additive deterioration factor for exhaust emissions. An additive deterioration factor is the difference between exhaust emissions at the end of the useful life and exhaust emissions at the low-hour test point. In these cases, adjust the official emission results for each tested engine at the selected test point by adding the factor to the measured emissions. If the factor is less than zero, use zero. Additive deterioration factors must be specified to one more decimal place than the applicable standard.

(2) *Multiplicative deterioration factor for exhaust emissions.* Use a multiplicative deterioration factor if good engineering judgment calls for the deterioration factor for a pollutant to be the ratio of exhaust emissions at the end of the useful life to exhaust emissions at the low-hour test point. For example, if you use aftertreatment technology that controls emissions of a pollutant proportionally to engine-out emissions, it is often appropriate to use a multiplicative deterioration factor. Adjust the official emission results for each tested engine at the selected test point by multiplying the measured emissions by the deterioration factor. If the factor is less than one, use one. A multiplicative deterioration factor may not be appropriate in cases where testing variability is significantly greater than engine-to-engine variability. Multiplicative deterioration factors must be specified to one more significant figure than the applicable standard.

(3) *Sawtooth and other nonlinear deterioration patterns.* The deterioration factors described in paragraphs (c)(1) and (2) of this section assume that the highest useful life emissions occur either at the end of useful life or at the low-hour test point. The provisions of this paragraph (c)(3) apply where good engineering judgment indicates that the highest useful life emissions will occur between these two points. For example, emissions may increase with service accumulation until a certain maintenance step is performed, then return to the low-hour

emission levels and begin increasing again. Such a pattern may occur with battery-based ~~electric hybrid engines or hybrid powertrains~~. Base deterioration factors for engines with such emission patterns on the difference between (or ratio of) the point at which the highest emissions occur and the low-hour test point. Note that this applies for maintenance-related deterioration only where we allow such critical emission-related maintenance.

(4) *Dual-fuel and flexible-fuel engines*. In the case of dual-fuel and flexible-fuel engines, apply deterioration factors separately for each fuel type. You may accumulate service hours on a single emission-data engine using the type of fuel or the fuel mixture expected to have the highest combustion and exhaust temperatures; you may ask us to approve a different fuel mixture if you demonstrate that a different criterion is more appropriate.

(5) *Deterioration factor for crankcase emissions*. If engines route crankcase emissions into the ambient atmosphere or into the exhaust downstream of exhaust aftertreatment, you must account for any increase in crankcase emissions throughout the useful life using good engineering judgment. Use separate deterioration factors for crankcase emissions of each pollutant (either multiplicative or additive).

(d) Determine the official emission result for each pollutant to at least one more decimal place than the applicable standard. Apply the deterioration factor to the official emission result, as described in paragraph (c) of this section, then round the adjusted figure to the same number of decimal places as the emission standard. Compare the rounded emission levels to the emission standard for each emission-data engine.

(e) You do not need deterioration factors to demonstrate compliance with off-cycle standards. However, for engines designed to discharge crankcase emissions to the ambient atmosphere, you must determine deteriorated emission levels to represent crankcase emissions at the end of useful life for purposes of demonstrating compliance with off-cycle emission standards. Determine an official brake-specific crankcase emission result for each pollutant based on operation over the FTP duty cycle. Also determine an official crankcase emission result for NO_x in g/hr from the idle portion of any of the duty cycles specified in subpart F of this part. Apply crankcase deterioration factors to all these official crankcase emission results as described in paragraph (c) of this section, then round the adjusted figures to the same number of decimal places as the off-cycle emission standards in § 1036.104(a)(3).

§ 1036.241 Demonstrating compliance with greenhouse gas emission standards.

(a) For purposes of certification, your engine family is considered in compliance with the emission standards in § 1036.108 if all emission-data engines representing the tested configuration of that engine family have test results showing official emission results and deteriorated emission levels at or below the standards. Note that your FCLs are considered to be the applicable emission standards with which you must comply for certification.

(b) Your engine family is deemed not to comply if any emission-data engine representing the tested configuration of that engine family has test results showing an official emission result or a deteriorated emission level for any pollutant that is above an applicable emission standard (generally the FCL). Note that you may increase your FCL if any certification test results exceed your initial FCL.

(c) Apply deterioration factors to the measured emission levels for each pollutant to show compliance with the applicable emission standards. Your deterioration factors must take into account any available data from in-use testing with similar engines. Apply deterioration factors as follows:

(1) *Additive deterioration factor for greenhouse gas emissions*. Except as specified in paragraphs (c)(2) and (3) of this section, use an additive deterioration factor for exhaust

emissions. An additive deterioration factor is the difference between the highest exhaust emissions (typically at the end of the useful life) and exhaust emissions at the low-hour test point. In these cases, adjust the official emission results for each tested engine at the selected test point by adding the factor to the measured emissions. If the factor is less than zero, use zero. Additive deterioration factors must be specified to one more decimal place than the applicable standard.

(2) *Multiplicative deterioration factor for greenhouse gas emissions.* Use a multiplicative deterioration factor for a pollutant if good engineering judgment calls for the deterioration factor for that pollutant to be the ratio of the highest exhaust emissions (typically at the end of the useful life) to exhaust emissions at the low-hour test point. Adjust the official emission results for each tested engine at the selected test point by multiplying the measured emissions by the deterioration factor. If the factor is less than one, use one. A multiplicative deterioration factor may not be appropriate in cases where testing variability is significantly greater than engine-to-engine variability. Multiplicative deterioration factors must be specified to one more significant figure than the applicable standard.

(3) *Sawtooth and other nonlinear deterioration patterns.* The deterioration factors described in paragraphs (c)(1) and (2) of this section assume that the highest useful life emissions occur either at the end of useful life or at the low-hour test point. The provisions of this paragraph (c)(3) apply where good engineering judgment indicates that the highest useful life emissions will occur between these two points. For example, emissions may increase with service accumulation until a certain maintenance step is performed, then return to the low-hour emission levels and begin increasing again. Such a pattern may occur with battery-based ~~electric hybrid engines or hybrid powertrains~~. Base deterioration factors for engines with such emission patterns on the difference between (or ratio of) the point at which the highest emissions occur and the low-hour test point. Note that this applies for maintenance-related deterioration only where we allow such critical emission-related maintenance.

(4) *Dual-fuel and flexible-fuel engines.* In the case of dual-fuel and flexible-fuel engines, apply deterioration factors separately for each fuel type by measuring emissions with each fuel type at each test point. You may accumulate service hours on a single emission-data engine using the type of fuel or the fuel mixture expected to have the highest combustion and exhaust temperatures; you may ask us to approve a different fuel mixture if you demonstrate that a different criterion is more appropriate.

(d) Calculate emission data using measurements to at least one more decimal place than the applicable standard. Apply the deterioration factor to the official emission result, as described in paragraph (c) of this section, then round the adjusted figure to the same number of decimal places as the emission standard. Compare the rounded emission levels to the emission standard for each emission-data engine.

(e) If you identify more than one configuration in § 1036.205(1)(2), we may test (or require you to test) any of the identified configurations. We may also require you to provide an engineering analysis that demonstrates that untested configurations listed in § 1036.205(1)(2) comply with their FCL.

§ 1036.245 Deterioration factors for exhaust emission standards.

This section describes how to determine deterioration factors, either with pre-existing test data or with new emission measurements. Apply these deterioration factors to determine whether your engines will meet the duty-cycle emission standards throughout the useful life as described in § 1036.240. The provisions of this section and the verification provisions of § 1036.246 apply for

all engine families starting in model year 2027; you may optionally use these provisions to determine and verify deterioration factors for earlier model years.

(a) You may ask us to approve deterioration factors for an engine family based on an engineering analysis of emission measurements from similar highway or nonroad engines if you have already given us these data for certifying the other engines in the same or earlier model years. Use good engineering judgment to decide whether the two engines are similar. We will approve your request if you show us that the emission measurements from other engines reasonably represent in-use deterioration for the engine family for which you have not yet determined deterioration factors.

(b) [Reserved]

(c) If you are unable to determine deterioration factors for an engine family under paragraph (a) of this section, select engines, subsystems, or components for testing. Determine deterioration factors based on service accumulation and related testing to represent the deterioration expected from in-use engines over the useful life, including crankcase emissions. You may perform maintenance on emission-data engines as described in § 1036.125 and 40 CFR part 1065, subpart E. Use good engineering judgment for all aspects of the effort to establish deterioration factors under this paragraph (c). Send us your test plan for our preliminary approval under § 1036.210. You may apply deterioration factors based on testing under this paragraph (c) to multiple engine families, consistent with the provisions in paragraph (a) of this section. Determine deterioration factors based on a combination of minimum required engine dynamometer aging hours and accelerated bench-aged aftertreatment as follows:

(1) Select an emission-data engine and aftertreatment devices and systems that can be assembled into a certified configuration to represent the engine family. Stabilize the engine and aftertreatment devices and systems, together or separately, to prepare for emission measurements. Perform low-hour emission measurement once the engine has operated with aftertreatment long enough to stabilize the emission control. Measure emissions of all regulated pollutants while the engine operates over all applicable duty cycles on an engine dynamometer as described in subpart F of this part.

(2) Perform additional service accumulation as described in paragraph (c)(3) of this section on an engine dynamometer meeting at least the following minimum specifications:

TABLE 1 TO PARAGRAPH (c)(2) OF § 1036.245—MINIMUM REQUIRED ENGINE DYNAMOMETER AGING HOURS BY PRIMARY INTENDED SERVICE CLASS

Primary Intended Service Class	Minimum Engine Dynamometer Hours
Spark-ignition HDE	300
Light HDE	1,250
Medium HDE	1,500
Heavy HDE	1,500

(3) Perform service accumulation in the laboratory by operating the engine [or hybrid powertrain](#) repeatedly over one of the following test sequences, or a different test sequence that we approve in advance:

(i) Use duty-cycle sequence 1 for operating any engine on an engine dynamometer, as follows:

(A) Operate at idle for 2 hours.

(B) Operate for 105 ± 1 hours over a repeat sequence of one FTP followed by one RMC.

(C) Operate over one LLC.

- (D) Operate at idle for 2 hours.
- (E) Shut down the engine for cooldown to ambient temperature.
- (ii) Duty-cycle sequence 2 is based on operating over the LLC and the vehicle-based duty cycles from 40 CFR part 1037. Select the vehicle subcategory and vehicle configuration from § 1036.540 or § 1036.545 with the highest reference cycle work for each vehicle-based duty cycle. Operate the engine as follows for duty-cycle sequence 2:
 - (A) Operate at idle for 2 hours.
 - (B) Operate for 105 ± 1 hours over a repeat sequence of one Heavy-duty Transient Test Cycle, then one 55 mi/hr highway cruise cycle, and then one 65 mi/hr highway cruise cycle.
 - (C) Operate over one LLC.
 - (D) Operate at idle for 2 hours.
 - (E) Shut down the engine for cooldown to ambient temperature.
- (4) Perform all the emission measurements described in paragraph (c)(1) of this section when the engine has reached the minimum service accumulation specified in paragraph (c)(2) of this section, and again after you finish service accumulation in the laboratory if your service accumulation exceeds the values specified in paragraph (c)(2) of this section.
- (5) Determine the deterioration factor based on a combination of actual and simulated service accumulation represented by a number of hours of engine operation calculated using the following equation:

$$t_{\text{total}} = \frac{UL \cdot k}{\bar{v}_{\text{agingcycle}}}$$

Eq. 1036.245-1

Where:

UL = useful life mileage from § 1036.104(e).

k = 1.15 for Heavy HDE and 1.0 for all other primary intended service classes.

$\bar{v}_{\text{agingcycle}}$ = average speed of aging cycle in paragraph (c)(3) of this section. Use 40.26 mi/hr for duty-cycle sequence 1 and 44.48 mi/hr for duty-cycle sequence 2.

Example for Heavy HDE for duty-cycle sequence 1:

UL = 650,000 miles

k = 1.15

$\bar{v}_{\text{agingcycle}}$ = 40.26 mi/hr

$$t_{\text{total}} = \frac{650,000 \cdot 1.15}{40.26}$$

t_{total} = 18,567 hr

- (6) Perform accelerated bench aging of aftertreatment devices to represent normal engine operation over the useful life using the service accumulation hours determined in paragraph (c)(5) of this section. Design your bench aging to represent 10,000 hours of in-use engine operation for every 1,000 hours of accelerated bench aging. Use the accelerated bench-aging procedure in 40 CFR 1065.1131 through 1065.1145 or get our advance approval to use a different procedure that adequately that accounts for thermal and chemical degradation. For example, this might involve testing consistent with the analogous procedures that apply for light-duty vehicles under 40 CFR part 86, subpart S.

(7) After bench-aging aftertreatment devices, install or reinstall those aftertreatment devices and systems on an emission-data engine (or an equivalent engine) that has been stabilized without aftertreatment. Ensure that the aftertreatment is installed such that the engine is in a certified configuration to represent the engine family.

(8) Operate the engine with the bench-aged aftertreatment devices to stabilize emission controls for at least 100 hours on an engine dynamometer.

(9) Once stabilization is complete, repeat the low-hour emission measurements.

(10) Calculate deterioration factors by comparing exhaust emissions with the bench-aged aftertreatment and exhaust emissions at the low-hour test point. Create a linear curve fit if testing includes intermediate test points. Calculate deterioration factors based on measured values, without extrapolation.

(d) If you determine deterioration factors as described in paragraph (c) of this section, you may apply those deterioration factors in later years for engine families that qualify for carryover certification as described in § 1036.235(d). You may also apply those deterioration factors for additional engine families as described in paragraph (a) of this section.

(e) Include the following information in your application for certification:

(1) If you use test data from a different engine family, explain why this is appropriate and include all the emission measurements on which you base the deterioration factors. If the deterioration factors for the new engine family are not identical to the deterioration factors for the different engine family, describe your engineering analysis to justify the revised values and state that all your data, analyses, evaluations, and other information are available for our review upon request.

(2) If you determined deterioration factors under paragraph (c) of this section, include the following information in the first year that you use those deterioration factors:

(i) Describe your accelerated bench aging or other procedures to represent full-life service accumulation for the engine's emission controls.

(ii) Describe how you prepared the test engine before and after installing aftertreatment systems to determine deterioration factors.

(iii) Identify the power rating of the emission-data engine used to determine deterioration factors.

§ 1036.246 Verifying deterioration factors.

We may require you to test in-use engines as described in this section to verify that the deterioration factors you determined under § 1036.245 are appropriate.

(a) Select and prepare in-use engines representing the engine family we identify for verification testing under this section as follows:

(1) You may recruit candidate engines any time before testing. This may involve creating a pool of candidate engines and vehicles in coordination with vehicle manufacturers and vehicle purchasers to ensure availability and to confirm a history of proper maintenance. You may meet the testing requirements of this section by repeating tests on a given engine as it ages, or you may test different engines over the course of verification testing; however, you may not choose whether to repeat tests on a given engine at a later stage based on its measured emission levels. We generally require that you describe your plan for selecting engines in advance and justify any departures from that plan.

(2) Selected vehicles must come from independent sources, unless we approve your request to select vehicles that you own or manage. In your request, you must describe how you will ensure that the vehicle operator will drive in a way that represents normal in-use operation for the engine family.

(3) Select vehicles with installed engines from the same engine family and with the same power rating as the emission-data engine used to determine the deterioration factors. However, if the test engine does not have the specified power rating, you may ask for our approval to either test in the as-received condition or modify engines in selected vehicles by reflashing the ECM or replacing parts to change the engines to be in a different certified configuration for proper testing.

(4) Selected engines must meet the screening criteria described in § 1036.410(b)(2) through (4). Selected engines must also have their original aftertreatment components and be in a certified configuration. You may ask us to approve replacing a critical emission-related component with an equivalent part that has undergone a comparable degree of aging.

(5) We may direct you to preferentially select certain types of vehicles, vehicles from certain model years, or vehicles within some range of service accumulation. We will not direct you to select vehicles that are 10 or more years old, or vehicles with an odometer reading exceeding 85 percent of the engine's useful life. We will specify a time frame for completing required testing.

(b) Perform verification testing with one of the following procedures, or with an alternative procedure that you demonstrate to be equally effective:

(1) *Engine dynamometer testing*. Measure emissions from engines equipped with in-use aftertreatment systems on an engine dynamometer as follows:

(i) Test the aftertreatment system from at least two engines using the procedures specified in subpart F of this part and 40 CFR part 1065. Install the aftertreatment system from the selected in-use vehicle, including all associated wiring, sensors, and related hardware and software, on one of the following partially complete engines:

(A) The in-use engine from the same vehicle.

(B) The emission-data engine used to determine the deterioration factors.

(C) A different emission-data engine from the same engine family that has been stabilized as described in 40 CFR 1065.405(c).

(ii) Perform testing on all certification duty cycles with brake-specific emission standards (g/hp·hr) to determine whether the engine meets all the duty-cycle emission standards, including any compliance allowance, for criteria pollutants. Apply infrequent regeneration adjustment factors as included in your application for certification or develop new factors if we request it.

(iii) Evaluate verification testing for each pollutant independently. You pass the verification test if at least 70 percent of tested engines meet standards for each pollutant over all duty cycles. You fail the verification test if fewer than 70 percent of engines meet standards for a given pollutant over all duty cycles.

(2) *PEMS testing*. Measure emissions using PEMS with in-use engines that remain installed in selected vehicles as follows:

(i) Test at least five engines using the procedures specified in § 1036.555 and 40 CFR part 1065, subpart J.

(ii) Measure emissions of NO_x, HC, and CO as the test vehicle's normal operator drives over a regular shift-day to determine whether the engine meets all the off-cycle emission standards that applied for the engine's original certification. Apply infrequent regeneration adjustment factors as included in your application for certification. For Spark-ignition HDE, calculate off-cycle emission standards for purposes of this subpart by multiplying the FTP duty-cycle standards in § 1036.104(a) by 1.5 and rounding to the same number of decimal places.

(iii) Evaluate verification testing for each pollutant independently. You pass the verification test if at least 70 percent of tested engines meet the off-cycle standards

including any compliance allowance and accuracy margin, for each pollutant. You fail the verification test if fewer than 70 percent of tested engines do not meet standards for a given pollutant.

(iv) You may reverse a fail determination under paragraph (b)(2)(iii) of this section by restarting and successfully completing the verification test for that year using the procedures specified in paragraph (b)(1) of this section. If you do this, you must use the verification testing procedures specified in paragraph (b)(1) of this section for all remaining verification testing for the engine family.

(c) You may stop testing under the verification test program and concede a fail result before you meet all the testing requirements of this section.

(d) Prepare a report to describe your verification testing each year. Include at least the following information:

(1) Identify whether you tested using the procedures specified in paragraph (b)(1) or (2) of this section.

(2) Describe how the test results support a pass or fail decision for the verification test. For in-field measurements, include continuous 1 Hz data collected over the shift-day and binned emission values determined under § 1036.530.

(3) If your testing included invalid test results, describe the reasons for invalidating the data. Give us the invalid test results if we ask for them.

(4) Describe the types of vehicles selected for testing. If you determined that any selected vehicles with enough mileage accumulation were not suitable for testing, describe why you chose not to test them.

(5) For each tested engine, identify the vehicle's VIN, the engine's serial number, the engine's power rating, and the odometer reading and the engine's lifetime operating hours at the start of testing (or engine removal).

(6) State that the tested engines have been properly maintained and used and describe any noteworthy aspects of each vehicle's maintenance history. Describe the steps you took to prepare the engines for testing.

(7) For testing with engines that remain installed in vehicles, identify the date and location of testing. Also describe the ambient conditions and the driving route over the course of the shift-day.

(e) Send electronic reports to the Designated Compliance Officer using an approved information format. If you want to use a different format, send us a written request with justification.

(1) You may send us reports as you complete testing for an engine instead of waiting until you complete testing for all engines.

(2) We may ask you to send us less information in your reports than we specify in this section.

(3) We may require you to send us more information to evaluate whether your engine family meets the requirements of this part.

(4) Once you send us information under this section, you need not send that information again in later reports.

(5) We will review your test report to evaluate the results of the verification testing at each stage. We will notify you if we disagree with your conclusions, if we need additional information, or if you need to revise your testing plan for future testing.

§ 1036.250 Reporting and recordkeeping for certification.

(a) By September 30 following the end of the model year, send the Designated Compliance Officer a report including the total ~~nationwide~~-U.S.-directed production volume of engines you

produced in each engine family during the model year (based on information available at the time of the report). Report the production by serial number and engine configuration. You may combine this report with reports required under subpart H of this part. We may waive the reporting requirements of this paragraph (a) for small manufacturers.

(b) Organize and maintain the following records:

- (1) A copy of all applications and any summary information you send us.
- (2) Any of the information we specify in § 1036.205 that you were not required to include in your application.
- (3) A detailed history of each emission-data engine. For each engine, describe all of the following:
 - (i) The emission-data engine's construction, including its origin and buildup, steps you took to ensure that it represents production engines, any components you built specially for it, and all the components you include in your application for certification.
 - (ii) How you accumulated engine operating hours (service accumulation), including the dates and the number of hours accumulated.
 - (iii) All maintenance, including modifications, parts changes, and other service, and the dates and reasons for the maintenance.
 - (iv) All your emission tests, including documentation on routine and standard tests, as specified in part 40 CFR part 1065, and the date and purpose of each test.
 - (v) All tests to diagnose engine or emission control performance, giving the date and time of each and the reasons for the test.
 - (vi) Any other significant events.
- (4) Production figures for each engine family divided by assembly plant.
- (5) Engine identification numbers for all the engines you produce under each certificate of conformity.

(c) Keep routine data from emission tests required by this part (such as test cell temperatures and relative humidity readings) for one year after we issue the associated certificate of conformity.

Keep all other information specified in this section for eight years after we issue your certificate.

(d) Store these records in any format and on any media, as long as you can promptly send us organized, written records in English if we ask for them. You must keep these records readily available. We may review them at any time.

§ 1036.255 EPA oversight on certificates of conformity.

(a) If we determine an application is complete and shows that the engine family meets all the requirements of this part and the Act, we will issue a certificate of conformity for the engine family for that model year. We may make the approval subject to additional conditions.

(b) We may deny an application for certification if we determine that an engine family fails to comply with emission standards or other requirements of this part or the Clean Air Act. We will base our decision on all available information. If we deny an application, we will explain why in writing.

(c) In addition, we may deny your application or suspend or revoke a certificate of conformity if you do any of the following:

- (1) Refuse to comply with any testing or reporting requirements in this part.
- (2) Submit false or incomplete information. This includes doing anything after submitting an application that causes submitted information to be false or incomplete.
- (3) Cause any test data to become inaccurate.
- (4) Deny us from completing authorized activities (see 40 CFR 1068.20). This includes a failure to provide reasonable assistance.

(5) Produce engines for importation into the United States at a location where local law prohibits us from carrying out authorized activities.

(6) Fail to supply requested information or amend an application to include all engines being produced.

(7) Take any action that otherwise circumvents the intent of the Act or this part.

(d) We may void a certificate of conformity if you fail to keep records, send reports, or give us information as required under this part or the Act. Note that these are also violations of 40 CFR 1068.101(a)(2).

(e) We may void a certificate of conformity if we find that you intentionally submitted false or incomplete information. This includes doing anything after submitting an application that causes submitted information to be false or incomplete after submission.

(f) If we deny an application or suspend, revoke, or void a certificate, you may ask for a hearing (see § 1036.820).

Subpart D— Testing Production Engines and Hybrid Powertrains

§ 1036.301 Measurements related to GEM inputs in a selective enforcement audit.

(a) Selective enforcement audits apply for engines as specified in 40 CFR part 1068, subpart E. This section describes how this applies uniquely in certain circumstances.

(b) Selective enforcement audit provisions apply with respect to your fuel maps as follows:

(1) A selective enforcement audit for an engine with respect to fuel maps would consist of performing measurements with production engines to determine fuel-consumption rates as declared for GEM simulations, and running GEM for the vehicle configurations specified in paragraph (b)(2) of this section based on those measured values. The engine is considered passing for a given configuration if the new modeled emission result for each applicable duty cycle is at or below the modeled emission result corresponding to the declared GEM inputs. The engine is considered failing if we determine that its fuel map result is above the modeled emission result corresponding to the result using the manufacturer-declared fuel maps, as specified in § 1036.235(c)(5).

(2) If the audit includes fuel-map testing in conjunction with engine testing relative to exhaust emission standards, the fuel-map simulations for the whole set of vehicles and duty cycles counts as a single test result for purposes of evaluating whether the engine family meets the pass-fail criteria under 40 CFR 1068.420.

(c) If your certification includes powertrain testing as specified in 40 CFR 1036.630, these selective enforcement audit provisions apply with respect to powertrain test results as specified in [§ 1036.545](#) and 40 CFR part 1037, subpart D, ~~and 40 CFR 1037.550~~. We may allow manufacturers to instead perform the engine-based testing to simulate the powertrain test as specified in 40 CFR 1037.551.

(d) We may suspend or revoke certificates for any appropriate configurations within one or more engine families based on the outcome of a selective enforcement audit.

Subpart E—In-Use Testing

§ 1036.401 Testing requirements for in-use engines.

(a) We may perform in-use testing of any engine family subject to the standards of this part, consistent with the Clean Air Act and the provisions of § 1036.235.

(b) This subpart describes a manufacturer-run field-testing program that applies for engines subject to compression-ignition standards under § 1036.104. Note that the testing requirements

of 40 CFR part 86, subpart T, continue to apply for engines subject to exhaust emission standards under 40 CFR part 86.

(c) In-use test procedures for engines subject to spark-ignition standards apply as described in § 1036.530. We won't require routine manufacturer-run field testing for Spark-ignition HDE, but the procedures of this subpart describe how to use field-testing procedures to measure emissions from engines installed in vehicles. Use good engineering judgment to apply the measurement procedures for fuels other than gasoline.

(d) We may void your certificate of conformity for an engine family if you do not meet your obligations under this subpart. We may also void individual tests and require you to retest those vehicles or take other appropriate measures in instances where you have not performed the testing in accordance with the requirements described in this subpart.

§ 1036.405 Overview of the manufacturer-run field-testing program.

(a) You must test in-use engines from the families we select. We may select the following number of engine families for testing, except as specified in paragraph (b) of this section:

(1) We may select up to 25 percent of your engine families in any calendar year, calculated by dividing the number of engine families you certified in the model year corresponding to the calendar year by four and rounding to the nearest whole number. We will consider only engine families with annual ~~U.S.-directed nationwide~~ production volumes above 1,500 units in calculating the number of engine families subject to testing each calendar year under the annual 25 percent engine family limit. If you have only three or fewer families that each exceed an annual ~~U.S.-directed nationwide~~ production volume of 1,500 units, we may select one engine family per calendar year for testing.

(2) Over any four-year period, we will not select more than the average number of engine families that you have certified over that four-year period (the model year when the selection is made and the preceding three model years), based on rounding the average value to the nearest whole number.

(3) We will not select engine families for testing under this subpart from a given model year if your total ~~U.S.-directed nationwide~~ production volume was less than 100 engines.

(b) If there is clear evidence of a nonconformity with regard to an engine family, we may select that engine family without counting it as a selected engine family under paragraph (a) of this section. For example, there may be clear evidence of a nonconformity if you certify an engine family using carryover data after reaching a fail decision under this subpart in an earlier model year without modifying the engine to remedy the problem.

(c) We may select any individual engine family for testing, regardless of its production volume except as described in paragraph (a)(3) of this section, as long as we do not select more than the number of engine families described in paragraph (a) of this section. We may select an engine family from model year 2027 or any later model year.

(d) You must complete all the required testing and reporting under this subpart (for all ten test engines, if applicable), within 18 months after we ~~direct you to test a particular engine family~~receive your proposed plan for recruiting, screening, and selecting vehicles. We will typically select engine families for testing and notify you in writing by June 30 of the applicable calendar year. If you request it, we may allow additional time to send us this information.

(e) If you make a good-faith effort to access enough test vehicles to complete the testing requirements under this subpart for an engine family, but are unable to do so, you must ask us either to modify the testing requirements for the selected engine family or to select a different engine family.

(f) We may select an engine family for repeat testing in a later calendar year. Such a selection for repeat testing would count as an additional engine family for that year under paragraph (a) of this section.

§ 1036.410 Selecting and screening vehicles and engines for testing.

(a) Send us your proposed plan for recruiting, screening, and selecting vehicles. Identify the types of vehicles, location, and any other relevant criteria. We will approve your plan if it supports the objective of measuring emissions to represent a broad range of operating characteristics.

(b) Select vehicles and engines for testing that meet the following criteria:

(1) The vehicles come from at least two independent sources.

(2) Powertrain, drivetrain, emission controls, and other key vehicle and engine systems have been properly maintained and used. See § 1036.125.

(3) The engines have not been tampered with, rebuilt, or undergone major repair that could be expected to affect emissions.

(4) The engines have not been misfueled. Do not consider engines misfueled if they have used fuel meeting the specifications of § 1036.415(c).

(5) The vehicles are likely to operate for at least three hours of non-idle operation over a complete shift-day, as described in § 1036.415(f).

(6) The vehicles have not exceeded the applicable useful life, in miles, hours, or years; you may otherwise not exclude engines from testing based on their age or mileage.

(7) The vehicle has appropriate space for safe and proper mounting of the portable emission measurement system (PEMS) equipment.

(c) You must notify us before disqualifying any vehicle based on illuminated MIL or stored OBD trouble codes as described in § 1036.415(b)(2), or for any other reasons not specified in paragraph (b) of this section. For example, notify us if you disqualify any vehicle because the engine does not represent the engine family or the vehicle's usage is atypical for the particular application. You do not need to notify us in advance if the owner declines to participate in the test program.

§ 1036.415 Preparing and testing engines.

(a) You must limit maintenance to what is in the owners manual for engines with that amount of service and age. For anything we consider an adjustable parameter (see § 1036.115(f)), you may adjust that parameter only if it is outside its adjustable range. You must then set the adjustable parameter to your recommended setting or the mid-point of its adjustable range, unless we approve your request to do otherwise. You must get our approval before adjusting anything not considered an adjustable parameter. You must keep records of all maintenance and adjustments, as required by § 1036.435. You must send us these records, as described in § 1036.430(a)(2)(ix), unless we instruct you not to send them.

(b) You may treat a vehicle with an illuminated MIL or stored trouble code as follows:

(1) If a candidate vehicle has an illuminated MIL or stored trouble code, either test the vehicle as received or repair the vehicle before testing. Once testing is initiated on the vehicle, you accept that the vehicle has been properly maintained and used.

(2) If a MIL illuminates or a trouble code appears on a test vehicle during a field test, stop the test and repair the vehicle. Determine test results as specified in § 1036.530 using one of the following options:

- (i) Restart the testing and use only the portion of the full test results without the MIL illuminated or trouble code set.
 - (ii) Initiate a new test and use only the post-repair test results.
- (3) If you determine that repairs are needed but they cannot be completed in a timely manner, you may disqualify the vehicle and replace it with another vehicle.
- (c) Use appropriate fuels for testing, as follows:
 - (1) You may use any diesel fuel that meets the specifications for S15 in ASTM D975 (incorporated by reference, [see](#) ~~in~~ § 1036.810). You may use any commercially available biodiesel fuel blend that meets the specifications for ASTM D975 or ASTM D7467 (incorporated by reference, [see](#) ~~in~~ § 1036.810) that is either expressly allowed or not otherwise indicated as an unacceptable fuel in the vehicle's owner or operator manual or in the engine manufacturer's published fuel recommendations. You may use any gasoline fuel that meets the specifications in ASTM D4814 (incorporated by reference, [see](#) ~~in~~ § 1036.810). For other fuel types, you may use any commercially available fuel.
 - (2) You may drain test vehicles' fuel tanks and refill them with diesel fuel conforming to the specifications in paragraph (c)(1) of this section.
 - (3) Any fuel that is added to a test vehicle's fuel tanks must be purchased at a local retail establishment near the site of vehicle recruitment or screening, or along the test route. Alternatively, the fuel may be drawn from a central fueling source, as long as the fuel represents commercially available fuel in the area of testing.
 - (4) No post-refinery fuel additives are allowed, except that specific fuel additives may be used during field testing if you can document that the test vehicle has a history of normally using the fuel treatments and they are not prohibited in the owners manual or in your published fuel-additive recommendations.
 - (5) You may take fuel samples from test vehicles to ensure that appropriate fuels were used during field testing. If a vehicle fails the vehicle-pass criteria and you can show that an inappropriate fuel was used during the failed test, that particular test may be voided. You may drain vehicles' fuel tanks and refill them with diesel fuel conforming to the specifications described in paragraph (c)(1) of this section. You must report any fuel tests that are the basis of voiding a test in your report under § 1036.430.
- (d) You must test the selected engines using the test procedure described in § 1036.530 while they remain installed in the vehicle. Testing consists of characterizing emission rates for moving average 300 second windows while driving, with those windows divided into bins representing different types of engine operation over a shift-day. Measure emissions as follows:
 - (1) Perform all testing with PEMS and field-testing procedures referenced in 40 CFR part 1065, subpart J. Measure emissions of NO_x, CO, and CO₂. We may require you to also measure emissions of HC and PM. You may determine HC emissions by any method specified in 40 CFR 1065.660(b).
 - (2) If the engine's crankcase discharges emissions into the ambient atmosphere, as allowed by § 1036.115(a), you must either route all crankcase emissions into the exhaust for a combined measurement or add the crankcase emission values specified in § 1036.240(e) to represent emission levels at full useful life instead of measuring crankcase emissions in the field.
- (e) Operate the test vehicle under conditions reasonably expected during normal operation. For the purposes of this subpart, normal operation generally includes the vehicle's normal routes and loads (including auxiliary loads such as air conditioning in the cab), normal ambient conditions, and the normal driver.
- (f) Once an engine is set up for testing, test the engine for one shift-day, except as allowed in § 1036.420(d). To complete a shift-day's worth of testing, start sampling at the beginning of a shift

and continue sampling for the whole shift, subject to the calibration requirements of the PEMS. A shift-day is the period of a normal workday for an individual employee. Evaluate the emission data as described in § 1036.420 and include the data in the reporting and record keeping requirements specified in §§ 1036.430 and 1036.435.

(g) For stop-start and automatic engine shutdown systems meeting the specifications of 40 CFR 1037.660, override idle-reduction features if they are adjustable under 40 CFR 1037.520(j)(4). If those systems are tamper-resistant under 40 CFR 1037.520(j)(4), set the 1-Hz emission rate to zero for all regulated pollutants when the idle-reduction feature is active. Do not exclude these data points under § 1036.530(c)(3)(ii).

§ 1036.420 Pass criteria for individual engines.

Perform the following steps to determine whether an engine meets the binned emission standards in § 1036.104(a)(3):

(a) Determine the emission standard for each regulated pollutant for each bin by adding the following accuracy margins for PEMS to the off-cycle standards in § 1036.104(a)(3):

TABLE 1 TO PARAGRAPH (a) OF § 1036.420—ACCURACY MARGINS FOR IN-USE TESTING

	NO _x	HC	PM	CO
Bin 1	0.4 g/hr	-	-	-
Bin 2	5 mg/hp·hr	10 mg/hp·hr	6 mg/hp·hr	0.025 g/hp·hr

(b) Calculate the mass emission rate for each pollutant as specified in § 1036.530.

(c) For engines subject to compression-ignition standards, determine the number of windows in each bin. A bin is valid under this section only if it has at least 2,400 windows for bin 1 and 10,000 windows for bin 2.

(d) Continue testing additional shift-days as necessary to achieve the minimum window requirements for each bin. You may idle the engine at the end of the shift day to increase the number of windows in bin 1. If the vehicle has tamper-resistant idle-reduction technology that prevents idling, populate bin 1 with additional windows by setting the 1-Hz emission rate for all regulated pollutants to zero as described in § 1036.415(g) to achieve exactly 2,400 bin 1 windows.

(e) An engine passes if the result for each bin is at or below the standard determined in paragraph (a) of this section. An engine fails if the result for any bin for any pollutant is above the standard determined in paragraph (a) of this section.

§ 1036.425 Pass criteria for engine families.

For testing with PEMS under § 1036.415(d)(1), determine the number of engines you must test from each selected engine family and the family pass criteria as follows:

(a) Start by measuring emissions from five engines using the procedures described in this subpart E and § 1036.530. If all five engines comply fully with the off-cycle bin standards, the engine family passes, and you may stop testing.

(b) If only one of the engines tested under paragraph (a) of this section does not comply fully with the off-cycle bin standards, test one more engine. If this additional engine complies fully with the off-cycle bin standards, the engine family passes, and you may stop testing.

(c) If two or more engines tested under paragraphs (a) and (b) of this section do not comply fully with the off-cycle bin standards, test additional engines until you have tested a total of ten engines. Calculate the arithmetic mean of the bin emissions from the ten engine tests as specified

in § 1036.530(g) for each pollutant. If the mean values are at or below the off-cycle bin standards, the engine family passes. If the mean value for any pollutant is above an off-cycle bin standard, the engine family fails.

(d) You may accept a fail result for the engine family and discontinue testing at any point in the sequence of testing the specified number of engines.

§ 1036.430 Reporting requirements.

(a) *Report content.* Prepare test reports as follows:

(1) Include the following for each engine family:

(i) Describe how you recruited vehicles. Describe how you used any criteria or thresholds to narrow your search or to screen individual vehicles.

(ii) Include a summary of the vehicles you have disqualified and the reasons you disqualified them, whether you base the disqualification on the criteria in § 1036.410(b), owner nonparticipation, or anything else. If you disqualified a vehicle due to misfueling, include the results of any fuel sample tests. If you reject a vehicle due to tampering, describe how you determined that tampering occurred.

(iii) Identify how many engines you have tested from the applicable engine family and how many engines still need to be tested. Identify how many tested engines have passed or failed under § 1036.420.

(iv) After the final test, report the results and state the outcome of testing for the engine family based on the criteria in § 1036.425.

(v) Describe any incomplete or invalid tests that were conducted under this subpart.

(2) Include the following information for the test vehicle:

(i) The EPA engine-family designation, and the engine's model number, total displacement, and power rating.

(ii) The date EPA selected the engine family for testing.

(iii) The vehicle's make and model and the year it was built.

(iv) The vehicle identification number and engine serial number.

(v) The vehicle's type or application (such as delivery, line haul, or dump truck). Also, identify the type of trailer, if applicable.

(vi) The vehicle's maintenance and use history.

(vii) The known status history of the vehicle's OBD system and any actions taken to address OBD trouble codes or MIL illumination over the vehicle's lifetime.

(viii) Any OBD codes or MIL illumination that occur after you accept the vehicle for field testing under this subpart.

(ix) Any steps you take to maintain, adjust, modify, or repair the vehicle or its engine to prepare for or continue testing, including actions to address OBD trouble codes or MIL illumination. Include any steps you took to drain and refill the vehicle's fuel tank(s) to correct misfueling, and the results of any fuel test conducted to identify misfueling.

(3) Include the following data and measurements for each test vehicle:

(i) The date and time of testing, and the test number.

(ii) Number of shift-days of testing (see § 1036.415(f)).

(iii) Route and location of testing. You may base this description on the output from a global-positioning system (GPS).

(iv) The steps you took to ensure that vehicle operation during testing was consistent with normal operation and use, as described in § 1036.415(e).

(v) Fuel test results, if fuel was tested under § 1036.410 or § 1036.415.

- (vi) The vehicle's mileage at the start of testing. Include the engine's total lifetime hours of operation, if available.
- (vii) The number of windows in each bin (see § 1036.420(c)).
- (viii) The bin emission value per vehicle for each pollutant. Describe the method you used to determine HC as specified in 40 CFR 1065.660(b).
- (ix) Recorded 1 Hz test data for at least the following parameters, noting that gaps in the 1 Hz data file over the shift-day are only allowed during analyzer zero and span verifications and during engine shutdown when the engine is keyed off:
 - (A) Ambient temperature.
 - (B) Ambient pressure.
 - (C) Ambient humidity.
 - (D) Altitude.
 - (E) Emissions of HC, CO, CO₂, and NO_x. Report results for PM if it was measured in a manner that provides 1 Hz test data.
 - (F) Differential backpressure of any PEMS attachments to vehicle exhaust.
 - (G) Exhaust flow.
 - (H) Exhaust aftertreatment temperatures.
 - (I) Engine speed.
 - (J) Engine brake torque.
 - (K) Engine coolant temperature
 - (L) Intake manifold temperature.
 - (M) Intake manifold pressure.
 - (N) Throttle position.
 - (O) Any parameter sensed or controlled, available over the Controller Area Network (CAN) network, to modulate the emission control system or fuel-injection timing.
- (4) Include the following summary information after you complete testing with each engine:
 - (i) State whether the engine meets the off-cycle standards for each bin for each pollutant as described in § 1036.420(e).
 - (ii) Describe if any testing or evaluations were conducted to determine why a vehicle failed the off-cycle emission standards described in § 1036.420.
 - (iii) Describe the purpose of any diagnostic procedures you conduct.
 - (iv) Describe any instances in which the OBD system illuminated the MIL or set trouble codes. Also describe any actions taken to address the trouble codes or MIL.
 - (v) Describe any instances of misfueling, the approved actions taken to address the problem, and the results of any associated fuel sample testing.
 - (vi) Describe the number and length of any data gaps in the 1 Hz data file, the reason for the gap(s), and the parameters affected.
- (b) *Submission*. Send electronic reports to the Designated Compliance Officer using an approved information format. If you want to use a different format, send us a written request with justification.
 - (1) You may send us reports as you complete testing for an engine instead of waiting until you complete testing for all engines.
 - (2) We may ask you to send us less information in your reports than we specify in this section.
 - (3) We may require you to send us more information to evaluate whether your engine family meets the requirements of this part.
 - (4) Once you send us information under this section, you need not send that information again in later reports.

(c) *Additional notifications.* Notify the Designated Compliance Officer describing progress toward completing the required testing and reporting under this subpart, as follows:

- (1) Notify us once you complete testing for an engine.
- (2) Notify us if your review of the test data for an engine family indicates that two of the first five tested engines have failed to comply with the vehicle-pass criteria in § 1036.420(e).
- (3) Notify us if your review of the test data for an engine family indicates that the engine family does not comply with the family-pass criteria in § 1036.425(c).
- (4) Describe any voluntary vehicle/engine emission evaluation testing you intend to conduct with PEMS on the same engine families that are being tested under this subpart, from the time that engine family was selected for field testing under § 1036.405 until the final results of all testing for that engine family are reported to us under this section.

§ 1036.435 Recordkeeping requirements.

Keep the following paper or electronic records of your field testing for five years after you complete all the testing required for an engine family:

- (a) Keep a copy of the reports described in § 1036.430.
- (b) Keep any additional records, including forms you create, related to any of the following:
 - (1) The recruitment, screening, and selection process described in § 1036.410, including the vehicle owner's name, address, phone number, and e-mail address.
 - (2) Pre-test maintenance and adjustments to the engine performed under § 1036.415.
 - (3) Test results for all void, incomplete, and voluntary testing described in § 1036.430.
 - (4) Evaluations to determine why an engine failed any of the bin standards described in § 1036.420.
- (c) Keep a copy of the relevant calibration results required by 40 CFR part 1065.

§ 1036.440 Warranty obligations related to in-use testing.

Testing under this subpart that finds an engine exceeding emission standards under this subpart is not by itself sufficient to show a breach of warranty under 42 U.S.C. 7541(a)(1). A breach of warranty would also require that engines fail to meet one or both of the conditions specified in § 1036.120(a).

Subpart F—Test Procedures

§ 1036.501 General testing provisions.

- (a) Use the equipment and procedures specified in this subpart and 40 CFR part 1065 to determine whether engines meet the emission standards in §§ 1036.104 and 1036.108.
- (b) Use the fuels specified in 40 CFR part 1065 to perform valid tests, as follows:
 - (1) For service accumulation, use the test fuel or any commercially available fuel that is representative of the fuel that in-use engines will use.
 - (2) For diesel-fueled engines, use the ultra-low-sulfur diesel fuel specified in 40 CFR part 1065.703 and 40 CFR 1065.710(b)(3) for emission testing.
 - (3) For gasoline-fueled engines, use the appropriate E10 fuel specified in 40 CFR part 1065.
- (c) For engines that use aftertreatment technology with infrequent regeneration events, apply infrequent regeneration adjustment factors for each duty cycle as described in § 1036.580.
- (d) If your engine is intended for installation in a vehicle equipped with stop-start technology meeting the specifications of 40 CFR 1037.660 to qualify as tamper-resistant under 40 CFR 1037.520(j)(4), you may shut the engine down during idle portions of the duty cycle to represent

in-use operation. We recommend installing a production engine starter motor and letting the engine's ECM manipulate the starter motor to control the engine stop and start events. Use good engineering judgment to address the effects of dynamometer inertia on restarting the engine by, for example, using a larger starter motor or declutching the engine from the dynamometer during restart.

(e) You may disable any AECDs that have been approved solely for emergency vehicle applications under § 1036.115(h)(4). Note that the emission standards do not apply when any of these AECDs are active.

(ef) You may use special or alternate procedures to the extent we allow them under 40 CFR 1065.10.

(fg) This subpart is addressed to you as a manufacturer, but it applies equally to anyone who does testing for you, and to us when we perform testing to determine if your engines meet emission standards.

(gh) For testing engines that use regenerative braking through the crankshaft to only to power an electric heater for aftertreatment devices, you may use the fuel mapping procedure in § 1036.505(b)(1) or (2) and the nonhybrid engine testing procedures in §§ 1036.510, 1036.512, and 1036.514, as long as the recovered energy is less than 10 percent of the total positive work for each applicable transient duty cycle and you may also or instead use the fuel mapping procedure in § 1036.505(b)(1) or (2). You may use this allowance only if the recovered energy is less than 10 percent of the total positive work for each applicable test interval. Otherwise, use powertrain testing procedures specified for hybrid engines or hybrid powertrains to create fuel maps and measure emissions and create fuel maps. For engines that power an electric heater with a battery, you must meet the requirements related to charge-sustaining operation as described in 40 CFR 1066.501(a)3).

§ 1036.505 Engine data and information to support vehicle certification.

You must give vehicle manufacturers information as follows so they can certify their vehicles to greenhouse gas emission standards under 40 CFR part 1037:

(a) Identify engine make, model, fuel type, combustion type, engine family name, calibration identification, and engine displacement. Also identify whether the engines meet CO₂ standards for tractors, vocational vehicles, or both. When certifying vehicles with GEM, for any fuel type not identified in Table 1 to § 1036.550, identify the select fuel type as diesel fuel for engines subject to compression-ignition standards, and select fuel type as gasoline for engines subject to spark-ignition standards.

(b) This paragraph (b) describes four different methods to generate engine fuel maps. For engines without hybrid components and for mild hybrid engines where you do not include hybrid components in the test, generate fuel maps using either paragraph (b)(1) or (2) of this section. For other hybrid engines, generate fuel maps using paragraph (b)(3) of this section. For hybrid powertrains and nonhybrid powertrains and for vehicles where the transmission is not automatic, automated manual, manual, or dual-clutch, generate fuel maps using paragraph (b)(4) of this section.

(1) Determine steady-state engine fuel maps as described in § 1036.535(b). Determine fuel consumption at idle as described in § 1036.535(c). Determine cycle-average engine fuel maps as described in § 1036.540, excluding cycle-average fuel maps for highway cruise cycles.

(2) Determine steady-state fuel maps as described in either § 1036.535(b) or (d). Determine fuel consumption at idle as described in § 1036.535(c). Determine cycle-average engine fuel maps as described in § 1036.540, including cycle-average engine fuel maps for highway

cruise cycles. We may do confirmatory testing by creating cycle-average fuel maps from steady-state fuel maps created in paragraph (b)(1) of this section for highway cruise cycles. In § 1036.540 we define the vehicle configurations for testing; we may add more vehicle configurations to better represent your engine’s operation for the range of vehicles in which your engines will be installed (see 40 CFR 1065.10(c)(1)).

(3) Determine fuel consumption at idle as described in § 1036.535(c) and (d) and determine cycle-average engine fuel maps as described in ~~§ 1036.54540-CFR-1037.550~~, including cycle-average engine fuel maps for highway cruise cycles. Set up the test to apply accessory load for all operation by primary intended service class as described in the following table:

TABLE 1 TO PARAGRAPH (b)(3) OF § 1036.505—ACCESSORY LOAD

Primary Intended Service Class	Power Representing Accessory Load (kW)
Light HDV	1.5
Medium HDV	2.5
Heavy HDV	3.5

(4) Generate powertrain fuel maps as described in ~~§ 1036.54540-CFR-1037.550~~ instead of fuel mapping under § 1036.535 or § 1036.540. Note that the option in ~~§ 1036.54540-CFR-1037.550(b)(2)~~ is allowed only for hybrid engine testing. Disable stop-start systems and automatic engine shutdown systems when conducting powertrain fuel map testing using ~~§ 1036.54540-CFR-1037.550~~.

(c) Provide the following information if you generate engine fuel maps using either paragraph (b)(1), (2), or (3) of this section:

(1) Full-load torque curve for installed engines and the full-load torque curve of the engine (parent engine) with the highest fueling rate that shares the same engine hardware, including the turbocharger, as described in 40 CFR 1065.510. You may use 40 CFR 1065.510(b)(5)(i) for Spark-ignition HDE. Measure the torque curve for hybrid engines that have an RESS as described in 40 CFR 1065.510(g)(2) with the hybrid system active. Test hybrid engines with no RESS as described in 40 CFR 1065.510(b)(5)(ii).

(2) Motoring torque curve as described in 40 CFR 1065.510(c)(2) and (5) for nonhybrid and hybrid engines, respectively. For engines with a low-speed governor, remove data points where the low-speed governor is active. If you don’t know when the low-speed governor is active, we recommend removing all points below 40 r/min above the warm low-idle speed.

(3) Declared engine idle speed. For vehicles with manual transmissions, this is the engine speed with the transmission in neutral. For all other vehicles, this is the engine’s idle speed when the transmission is in drive.

(4) The engine idle speed during the transient cycle-average fuel map.

(5) The engine idle torque during the transient cycle-average fuel map.

(d) If you generate powertrain fuel maps using paragraph (b)(4) of this section, determine the system continuous rated power according to § 1036.520.

§ 1036.510 Supplemental Emission Test.

(a) Measure emissions using the steady-state SET duty cycle as described in this section. Note that the SET duty cycle is operated as a ramped-modal cycle rather than discrete steady-state test points.

(b) [Procedures apply differently for testing certain kinds of engines and powertrains as follows: Perform SET testing with one of the following procedures:](#)

(1) For testing nonhybrid engines, the SET duty cycle is based on normalized speed and torque values relative to certain maximum values. Denormalize speed as described in 40 CFR 1065.512. Denormalize torque as described in 40 CFR 1065.610(d). Note that idle points are to be run at conditions simulating neutral or park on the transmission.

(2) Test ~~hybrid engines and~~ hybrid powertrains as described in ~~§ 1036.54540 CFR 1037.550~~, except as specified in this paragraph (b)(2). Do not compensate the duty cycle for the distance driven as described in ~~§ 1036.54540 CFR 1037.550~~(g)(4). For hybrid engines, select the transmission from ~~Table 1 of § 1036.540(c)(2)~~, substituting “engine” for “vehicle” and “highway cruise cycle” for “SET”. Disregard duty cycles in ~~§ 1036.54540 CFR 1037.550~~(j). For cycles that begin with idle, leave the transmission in neutral or park for the full initial idle segment. Place the transmission into drive no earlier than 5 seconds before the first nonzero vehicle speed setpoint. For SET testing only, place the transmission into park or neutral when the cycle reaches the final idle segment. Use the following vehicle parameters instead of those in ~~§ 1036.54540 CFR 1037.550~~ to define the vehicle model in ~~§ 1036.54540 CFR 1037.550~~(a)(3):

(i) Determine the vehicle test mass, M , as follows:

$$M = 15.1 \cdot P_{\text{contrated}}^{1.31}$$

Eq. 1036.510-1

Where:

$P_{\text{contrated}}$ = the continuous rated power of the hybrid system determined in § 1036.520.

Example:

$$P_{\text{contrated}} = 350.1 \text{ kW}$$

$$M = 15.1 \cdot 350.1^{1.31}$$

$$M = 32499 \text{ kg}$$

(ii) Determine the vehicle frontal area, A_{front} , as follows:

(A) For $M \leq 18050$ kg:

$$A_{\text{front}} = -1.69 \cdot 10^{-8} \cdot M^2 + 6.33 \cdot 10^{-4} \cdot M + 1.67$$

Eq. 1036.510-2

Example:

$$M = 16499 \text{ kg}$$

$$A_{\text{front}} = -1.69 \cdot 10^{-8} \cdot 16499^2 + 6.33 \cdot 10^{-4} \cdot 16499 + 1.67$$

$$A_{\text{front}} = 7.51 \text{ m}^2$$

(B) For $M > 18050$ kg, $A_{\text{front}} = 7.59 \text{ m}^2$

(iii) Determine the vehicle drag area, $C_d A$, as follows:

$$C_d A = \frac{(0.00299 \cdot A_{\text{front}} - 0.000832) \cdot 2 \cdot g \cdot 3.6^2}{\rho}$$

Eq. 1036.510-3

Where:

g = gravitational constant = 9.80665 m/s².

ρ = air density at reference conditions. Use $\rho = 1.1845 \text{ kg/m}^3$.

Example:

$$C_d A = \frac{(0.00299 \cdot 7.59 - 0.000832) \cdot 2 \cdot 9.80665 \cdot 3.6^2}{1.1845}$$
$$C_d A = 3.08 \text{ m}^2$$

(iv) Determine the coefficient of rolling resistance, C_{rr} , as follows:

$$C_{rr} = 5.13 + \frac{17600}{M}$$

Eq. 1036.510-4

Example:

$$C_{rr} = 5.13 + \frac{17600}{32499}$$
$$C_{rr} = 5.7 \text{ N/kN} = 0.0057 \text{ N/N}$$

(v) Determine the vehicle curb mass, M_{curb} , as follows:

$$M_{\text{curb}} = -0.000007376537 \cdot M^2 + 0.6038432 \cdot M$$

Eq. 1036.510-5

Example:

$$M_{\text{curb}} = -0.000007376537 \cdot 32499^2 + 0.6038432 \cdot 32499$$
$$M_{\text{curb}} = 11833 \text{ kg}$$

(vi) Determine the linear equivalent mass of rotational moment of inertias, M_{rotating} , as follows:

$$M_{\text{rotating}} = 0.07 \cdot M_{\text{curb}}$$

Eq. 1036.510-6

Example:

$$M_{\text{rotating}} = 0.07 \cdot 11833$$
$$M_{\text{rotating}} = 828.3 \text{ kg}$$

(vii) Select a combination of drive axle ratio, k_a , and a tire radius, r , that represents the worst-case combination of final-top gear ratio, drive axle ratio, and tire size for CO₂ expected for vehicles in which the hybrid powertrain-engine or hybrid engine-powertrain will be installed. This is typically the highest axle ratio and smallest tire radius. Disregard configurations or settings corresponding to a maximum vehicle speed below 60 mi/hr if selecting a drive axle ratio and tire radius, unless you can demonstrate that in-use vehicles will not exceed that speed. if representative, ensure that the maximum vehicle speed is no less than 60 mi/hr. Manufacturers- You may request preliminary approval for selected drive axle ratio and tire radius consistent with the provisions of § 1036.210. If the hybrid engine or hybrid powertrain is used exclusively in vehicles which are not capable of reaching 60 mi/hr, you may request that we approve an alternate test cycle and cycle-validation criteria as described in follow the provisions of 40 CFR 1066.425(b)(5).

Note for that hybrid engines rely on a specified transmission that is different for each duty cycle; the transmission's final top gear ratio therefore can change depending on the duty cycle, which will in turn change the selection of the drive axle ratio and tire size. For example, § 1036.520 prescribes a different top gear ratio than this paragraph (b)(2) of this section.

(viii) ~~Select a tire radius, r , that represents the worst case pair of tire size and drive axle ratio for CO₂ expected for vehicles in which the hybrid powertrain or hybrid engine will be installed. This is typically the smallest tire radius.~~

~~(ix)~~ If you are certifying a hybrid engine, use a default transmission efficiency of 0.95 and create the vehicle model along with its default transmission shift strategy as described in ~~§ 1036.54540 CFR 1037.550~~(a)(3)(ii). Use the transmission parameters defined in ~~Table 1 of~~ § 1036.540(c)(2) to determine transmission type and gear ratio. For Light HDV and Medium HDV, use the Light HDV and Medium HDV parameters for FTP, LLC, and SET duty cycles. For Tractors and Heavy HDVs, use the Tractor and Heavy HDV transient cycle parameters for the FTP and LLC duty cycles and the Tractor and Heavy HDV highway cruise cycle parameters for the SET duty cycle.

(c) Measure emissions using the SET duty cycle shown in Table 1 of this section to determine whether engines meet the steady-state compression-ignition standards specified in subpart B of this part. Table 1 of this section specifies test settings, as follows:

(1) The duty cycle for testing nonhybrid engines involves a schedule of normalized engine speed and torque values. Note that nonhybrid powertrains are generally tested as engines, so this section does not describe separate procedures for that configuration.

(2) The duty cycle for testing ~~hybrid engines and~~ hybrid powertrains involves a schedule of vehicle speeds and road grade as follows:

(i) Determine road grade at each point based on the continuous rated power of the hybrid powertrain ~~system~~, $P_{\text{contrated}}$, in kW determined in § 1036.520, the vehicle speed (A, B, or C) in mi/hr for a given SET mode, $v_{\text{ref[speed]}}$, and the specified road-grade coefficients using the following equation:

$$\text{Roadgrade} = a \cdot P_{\text{contrated}}^3 + b \cdot P_{\text{contrated}}^2 \cdot v_{\text{ref[speed]}} + c \cdot P_{\text{contrated}}^2 + d \cdot v_{\text{ref[speed]}}^2 + e \cdot P_{\text{contrated}} \cdot v_{\text{ref[speed]}} + f \cdot P_{\text{contrated}} + g \cdot v_{\text{ref[speed]}} + h$$

Eq. 1036.510-7

Example for SET mode 3a in Table 1 of this section:

$$P_{\text{contrated}} = 345.2 \text{ kW}$$

$$v_{\text{refB}} = 59.3 \text{ mi/hr}$$

$$\begin{aligned} \text{Road grade} = & 8.296 \cdot 10^{-9} \cdot 345.2^3 + (-4.752 \cdot 10^{-7}) \cdot 345.2^2 \cdot 59.3 + 1.291 \\ & \cdot 10^{-5} \cdot 345.2^2 + 2.88 \cdot 10^{-4} \cdot 59.3^2 + 4.524 \cdot 10^{-4} \cdot 345.2 \cdot 59.3 \\ & + (-1.802 \cdot 10^{-2}) \cdot 345.2 + (-1.83 \cdot 10^{-1}) \cdot 59.3 + 8.81 \end{aligned}$$

$$\text{Road grade} = 0.53\%$$

(ii) Use the vehicle C speed determined in § 1036.520. Determine vehicle A and B speeds as follows:

(A) Determine vehicle A speed using the following equation:

$$v_{\text{refA}} = v_{\text{refC}} \cdot \frac{55.0}{75.0}$$

Eq. 1036.510-8

Example:

$$v_{\text{refC}} = 68.42 \text{ mi/hr}$$
$$v_{\text{refA}} = 68.4 \cdot \frac{55.0}{75.0}$$
$$v_{\text{refA}} = 50.2 \text{ mi/hr}$$

(B) Determine vehicle B speed using the following equation:

$$v_{\text{refB}} = v_{\text{refC}} \cdot \frac{65.0}{75.0}$$

Eq. 1036.510-9

Example:

$$v_{\text{refB}} = 68.4 \cdot \frac{65.0}{75.0}$$
$$v_{\text{refB}} = 59.3 \text{ mi/hr}$$

(3) Table 1 follows:

TABLE 1 TO PARAGRAPH (c)(3) OF § 1036.510—SUPPLEMENTAL EMISSION TEST

SET mode	Engine testing			Hybrid powertrain testing								
	Time in mode (seconds)	Engine speed ^{a b}	Torque (percent) ^{b c}	Vehicle speed (mi/hr)	Road-grade coefficients							
					a	b	c	d	e	f	g	h
1a Steady-state	124	Warm Idle	0	0	0	0	0	0	0	0	0	0
1b Transition ^d	20	Linear Transition	Linear Transition	Linear Transition	-1.898E-08	-5.895E-07	3.780E-05	4.706E-03	6.550E-04	-2.679E-02	1.027E+00	1.542E+01
2a Steady-state	196	A	100	v _{refA}	-1.227E-08	-5.504E-07	3.946E-05	1.212E-03	5.289E-04	-3.116E-02	-3.227E-01	1.619E+01
2b Transition ^d	20	Linear Transition	Linear Transition	Linear Transition	-2.305E-09	-4.873E-07	2.535E-05	8.156E-04	4.730E-04	-2.383E-02	-2.975E-01	1.277E+01
3a Steady-state	220	B	50	v _{refB}	8.296E-09	-4.752E-07	1.291E-05	2.880E-04	4.524E-04	-1.802E-02	-1.830E-01	8.810E+00
3b Transition	20	B	Linear Transition	v _{refB}	4.642E-09	-5.143E-07	1.991E-05	3.556E-04	4.873E-04	-2.241E-02	-2.051E-01	1.068E+01
4a Steady-state	220	B	75	v _{refB}	1.818E-10	-5.229E-07	2.579E-05	5.575E-04	5.006E-04	-2.561E-02	-2.399E-01	1.287E+01
4b Transition ^d	20	Linear Transition	Linear Transition	Linear Transition	5.842E-10	-4.992E-07	2.244E-05	4.700E-04	4.659E-04	-2.203E-02	-1.761E-01	1.072E+01
5a Steady-state	268	A	50	v _{refA}	3.973E-09	-4.362E-07	1.365E-05	4.846E-04	4.158E-04	-1.606E-02	-1.908E-01	8.206E+00
5b Transition	20	A	Linear Transition	v _{refA}	-2.788E-10	-4.226E-07	1.812E-05	6.591E-04	4.158E-04	-1.846E-02	-2.201E-01	1.001E+01
6a Steady-state	268	A	75	v _{refA}	-4.216E-09	-4.891E-07	2.641E-05	8.796E-04	4.692E-04	-2.348E-02	-2.595E-01	1.226E+01
6b Transition	20	A	Linear Transition	v _{refA}	3.979E-09	-4.392E-07	1.411E-05	2.079E-04	4.203E-04	-1.658E-02	-1.655E-01	7.705E+00
7a Steady-state	268	A	25	v _{refA}	1.211E-08	-3.772E-07	6.209E-07	1.202E-04	3.578E-04	-8.420E-03	-1.248E-01	4.189E+00
7b Transition ^d	20	Linear Transition	Linear Transition	Linear Transition	1.659E-09	-4.954E-07	2.103E-05	4.849E-04	4.776E-04	-2.194E-02	-2.551E-01	1.075E+01
8a Steady-state	196	B	100	v _{refB}	-8.232E-09	-5.707E-07	3.900E-05	8.150E-04	5.477E-04	-3.325E-02	-2.956E-01	1.689E+01
8b Transition	20	B	Linear Transition	v _{refB}	4.286E-09	-5.150E-07	2.070E-05	5.214E-04	4.882E-04	-2.291E-02	-2.271E-01	1.157E+01

9a Steady-state	196	B	25	v_{refB}	1.662E-08	-4.261E-07	-2.705E-07	2.098E-05	4.046E-04	-1.037E-02	-1.263E-01	4.751E+00
9b Transition ^d	20	Linear Transition	Linear Transition	Linear Transition	7.492E-09	-5.451E-07	1.950E-05	2.243E-04	5.114E-04	-2.331E-02	-2.270E-01	1.062E+01
10a Steady-state	28	C	100	v_{refC}	-1.073E-09	-5.904E-07	3.477E-05	5.069E-04	5.647E-04	-3.354E-02	-2.648E-01	1.651E+01
10b Transition	20	C	Linear Transition	v_{refC}	9.957E-09	-5.477E-07	1.826E-05	2.399E-04	5.196E-04	-2.410E-02	-2.010E-01	1.128E+01
11a Steady-state	4	C	25	v_{refC}	1.916E-08	-5.023E-07	3.715E-06	3.634E-05	4.706E-04	-1.539E-02	-1.485E-01	6.827E+00
11b Transition	20	C	Linear Transition	v_{refC}	1.474E-08	-5.176E-07	1.027E-05	1.193E-04	4.911E-04	-1.937E-02	-1.713E-01	8.872E+00
12a Steady-state	4	C	75	v_{refC}	6.167E-09	-5.577E-07	2.354E-05	3.524E-04	5.319E-04	-2.708E-02	-2.253E-01	1.313E+01
12b Transition	20	C	Linear Transition	v_{refC}	1.039E-08	-5.451E-07	1.756E-05	2.257E-04	5.165E-04	-2.366E-02	-1.978E-01	1.106E+01
13a Steady-state	4	C	50	v_{refC}	6.209E-09	-5.292E-07	2.126E-05	3.475E-04	5.132E-04	-2.552E-02	-2.212E-01	1.274E+01
13b Transition ^d	20	Linear Transition	Linear Transition	Linear Transition	4.461E-09	-6.452E-07	1.301E-05	1.420E-03	5.779E-04	-1.564E-02	1.949E-01	7.998E+00
14 Steady-state	144	Warm Idle	0	0	0	0	0	0	0	0	0	0

^aEngine speed terms are defined in 40 CFR part 1065.

^bAdvance from one mode to the next within a 20 second transition phase. During the transition phase, command a linear progression from the settings of the current mode to the settings of the next mode.

^cThe percent torque is relative to maximum torque at the commanded engine speed.

^dUse the average vehicle speed during each transition for v_{ref} in Eq. 1036.510-7 for calculating road grade for all points during the transition.

(d) Determine criteria pollutant emissions for ~~plug-in hybrid engines and~~ plug-in hybrid powertrains as follows:

(1) Carry out a charge-sustaining test as described in paragraph (b)(2) of this section. Precondition the engine or powertrain in charge-sustaining mode. Perform testing as described in this section for hybrid engines and or hybrid powertrains in charge-sustaining mode.

(2) Carry out a charge-depleting test as described in paragraph ~~(db)~~(42) of this section, except as follows:

(i) Fully charge the RESS after preconditioning.

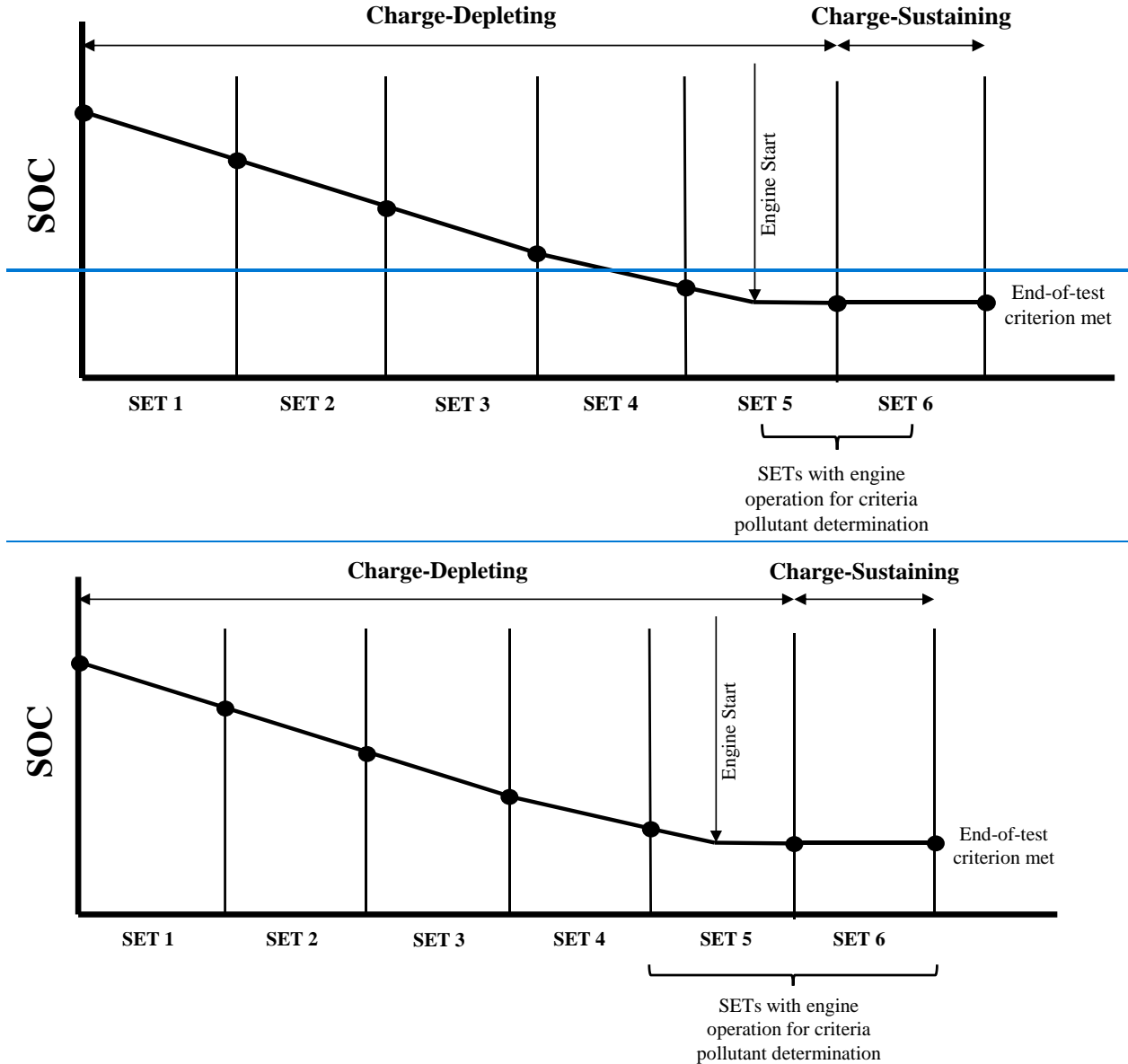
(ii) Operate the ~~hybrid~~ engine or powertrain continuously over repeated SET duty cycles until you reach the end-of-test criterion defined in 40 CFR 1066.501(a)(3).

(iii) Calculate emission results for each SET duty cycle. Figure 1 of this section provides an example of a charge-depleting test sequence where there are two test intervals that contain engine operation.

(3) Report the highest emission result for each criteria pollutant from all tests in paragraphs (d)(1) and (2) of this section, even if those individual results come from different test intervals.

(4) The following figure illustrates an example of an SET charge-depleting test sequence ~~Figure 1 follows:~~

FIGURE 1 TO PARAGRAPH (d)(4) OF § 1036.510—SET CHARGE-DEPLETING CRITERIA POLLUTANT TEST SEQUENCE:-



(e) Determine greenhouse gas pollutant emissions for plug-in hybrid engines and plug-in hybrid powertrains using the emissions results for all the SET test intervals for both charge-depleting and charge-sustaining operation from paragraph (d)(2) of this section. Calculate the utility factor-weighted composite mass of emissions from the charge-depleting and charge-sustaining test results, $e_{UF[emission]comp}$, using the following equation:

$$e_{UF[emission]comp} = \frac{\sum_{i=1}^N [e_{[emission][int]CDi} \cdot (UF_{DCDi} - UF_{DCDi-1})] + \sum_{j=1}^M [e_{[emission][int]CSj}]}{(1 - UF_{RCD}) \cdot M}$$

Eq. 1036.510-10

Where:

i = an indexing variable that represents one test interval.

N = total number of charge-depleting test intervals.

$e_{\text{[emission][int]CD}i}$ = total mass of emissions in the charge-depleting portion of the test for each test interval, i , starting from $i = 1$, including the test interval(s) from the transition phase.

$UF_{\text{DCD}i}$ = utility factor fraction at distance $D_{\text{CD}i}$ from Eq. 1036.510-11, as determined by interpolating the approved utility factor curve for each test interval, i , starting from $i = 1$. Let $UF_{\text{DCD}0} = 0$.

j = an indexing variable that represents one test interval.

M = total number of charge-sustaining test intervals.

$e_{\text{[emission][int]CS}j}$ = total mass of emissions in the charge-sustaining portion of the test for each test interval, j , starting from $j = 1$.

UF_{RCD} = utility factor fraction at the full charge-depleting distance, R_{CD} , as determined by interpolating the approved utility factor curve. R_{CD} is the cumulative distance driven over N charge-depleting test intervals.

$$D_{\text{CD}i} = \sum_{k=1}^Q (v_k \cdot \Delta t)$$

Eq. 1036.510-11

Where:

k = an indexing variable that represents one recorded velocity value.

Q = total number of measurements over the test interval.

v = vehicle velocity at each time step, k , starting from $k = 1$. For tests completed under this section, v is the vehicle velocity from the vehicle model in [§ 1036.54540-CFR-1037.550](#). Note that this should include charge-depleting test intervals that start when the engine is not yet operating.

$$\Delta t = 1/f_{\text{record}}$$

f_{record} = the record rate.

Example using the charge-depletion test in Figure 1 of § 1036.510 for the SET for CO₂ emission determination:

$$Q = 24000$$

$$v_1 = 0 \text{ mi/hr}$$

$$v_2 = 0.8 \text{ mi/hr}$$

$$v_3 = 1.1 \text{ mi/hr}$$

$$f_{\text{record}} = 10 \text{ Hz}$$

$$\Delta t = 1/10 \text{ Hz} = 0.1 \text{ s}$$

$$D_{\text{CD}1} = \sum_{k=1}^{24000} (0 \cdot 0.1 + 0.8 \cdot 0.1 + 1.1 \cdot 0.1 + v_{24000} \cdot \Delta t)$$

$$D_{\text{CD}1} = 30.1 \text{ mi}$$

$$D_{\text{CD}2} = 30.0 \text{ mi}$$

$$D_{\text{CD}3} = 30.1 \text{ mi}$$

$$D_{\text{CD}4} = 30.2 \text{ mi}$$

$$D_{\text{CD}5} = 30.1 \text{ mi}$$

$$N = 5$$

$$UF_{\text{DCD}1} = 0.11$$

$$UF_{DCD2} = 0.23$$

$$UF_{DCD3} = 0.34$$

$$UF_{DCD4} = 0.45$$

$$UF_{DCD5} = 0.53$$

$$e_{CO2SETCD1} = 0 \text{ g/hp}\cdot\text{hr}$$

$$e_{CO2SETCD2} = 0 \text{ g/hp}\cdot\text{hr}$$

$$e_{CO2SETCD3} = 0 \text{ g/hp}\cdot\text{hr}$$

$$e_{CO2SETCD4} = 0 \text{ g/hp}\cdot\text{hr}$$

$$e_{CO2SETCD5} = 174.4 \text{ g/hp}\cdot\text{hr}$$

$$M = 1$$

$$e_{CO2SETCS} = 428.1 \text{ g/hp}\cdot\text{hr}$$

$$UF_{RCD} = 0.53$$

$$e_{UFCO2comp} = [0 \cdot (0.11 - 0) + 0 \cdot (0.23 - 0.11) + 0 \cdot (0.34 - 0.23) + 0 \cdot (0.45 - 0.34) + 174.4 \cdot (0.53 - 0.45)] + 428.1 \cdot \frac{(1 - 0.53)}{1}$$

$$e_{UFCO2comp} = 215.2 \text{ g/hp}\cdot\text{hr}$$

(f) Calculate and evaluate cycle ~~validation criteria statistics~~ as specified in 40 CFR 1065.514 for nonhybrid engines and ~~§ 1036.545-40 CFR 1037.550~~ for ~~hybrid engines and~~ hybrid powertrains.

(g) ~~Calculate the total emission mass of each constituent, m , over the test interval as described in 40 CFR 1065.650. For nonhybrid engines, cCalculate the total work, W , over the test interval as described in 40 CFR 1065.650(d). For hybrid engines and hybrid powertrains, cCalculate W_{total} positive cycle work over the test interval for powertrain testing using system power, P_{sys} . Determine P_{sys} , using as described in § 1036.520(f).~~

§ 1036.512 Federal Test Procedure.

(a) Measure emissions using the transient Federal Test Procedure (FTP) as described in this section to determine whether engines meet the emission standards in subpart B of this part.

Operate the engine or hybrid powertrain over one of the following transient duty cycles:

(1) For engines subject to spark-ignition standards, use the transient test interval described in paragraph (b) of appendix B of this part.

(2) For engines subject to compression-ignition standards, use the transient test interval described in paragraph (c) of appendix B of this part.

(b) ~~The following p~~Procedures apply differently for ~~testing testing certain kinds of~~ engines and ~~hybrid~~ powertrains ~~as follows~~:

(1) The transient test intervals for nonhybrid engine testing are based on normalized speed and torque values. Denormalize speed as described in 40 CFR 1065.512. Denormalize torque as described in 40 CFR 1065.610(d).

(2) Test ~~hybrid engines and~~ hybrid powertrains as described in § 1036.510(b)(2), with the following exceptions:

(i) Replace $P_{contrated}$ with P_{rated} , which is the peak rated power determined in § 1036.520.

(ii) Keep the transmission in drive for all idle segments after the initial idle segment.

~~(iii) For hybrid engines, select the transmission from Table 1 of § 1036.540, substituting “engine” for “vehicle”.~~

~~(iviii)~~ For hybrid engines, you may request to change the engine-commanded torque at idle to better represent curb idle transmission torque (CITT).

(iv) For ~~plug-in hybrid engines and~~ plug-in hybrid powertrains, test over the FTP in both charge-sustaining and charge-depleting operation for both criteria and greenhouse gas pollutant determination.

(c) Except as specified in paragraph (d) of this section for ~~The plug-in hybrid powertrains, the~~ FTP duty cycle consists of an initial run through the test interval from a cold start as described in 40 CFR part 1065, subpart F, followed by a (20 ±1) minute hot soak with no engine operation, and then a final hot start run through the same transient test interval. Engine starting is part of both the cold-start and hot-start test intervals. Calculate the total emission mass of each constituent, m , and the total work, W , over each test interval as described in 40 CFR 1065.650. Calculate the total work, W , over the test interval as described in 40 CFR 1065.650(d). For ~~hybrid engines and~~ hybrid powertrains, cCalculate W total positive work over each test interval for powertrain testing using system power, P_{sys} as described in § 1036.520(f). Determine P_{sys} using § 1036.520(f). For powertrains with automatic transmissions, account for and include the work produced by the engine from the CITT load. Calculate the official transient emission result from the cold-start and hot-start test intervals using the following equation:

$$\text{Official transient emission result} = \frac{\text{cold start emissions (g)} + 6 \cdot \text{hot start emissions (g)}}{\text{cold start work (hp} \cdot \text{hr)} + 6 \cdot \text{hot start work (hp} \cdot \text{hr)}}$$

Eq. 1036.512-1

(d) Determine criteria pollutant emissions for ~~plug-in hybrid engines and~~ plug-in hybrid powertrains as follows:

(1) Carry out a charge-sustaining test as described in paragraph (b)(2) of this section. Precondition the engine or powertrain in charge-sustaining mode. Perform testing as described in this section for hybrid engines and or hybrid powertrains in charge-sustaining mode.

(2) Carry out a charge-depleting test as described in paragraph (d)(1) of this section, except as follows:

(i) Fully charge the battery after preconditioning.

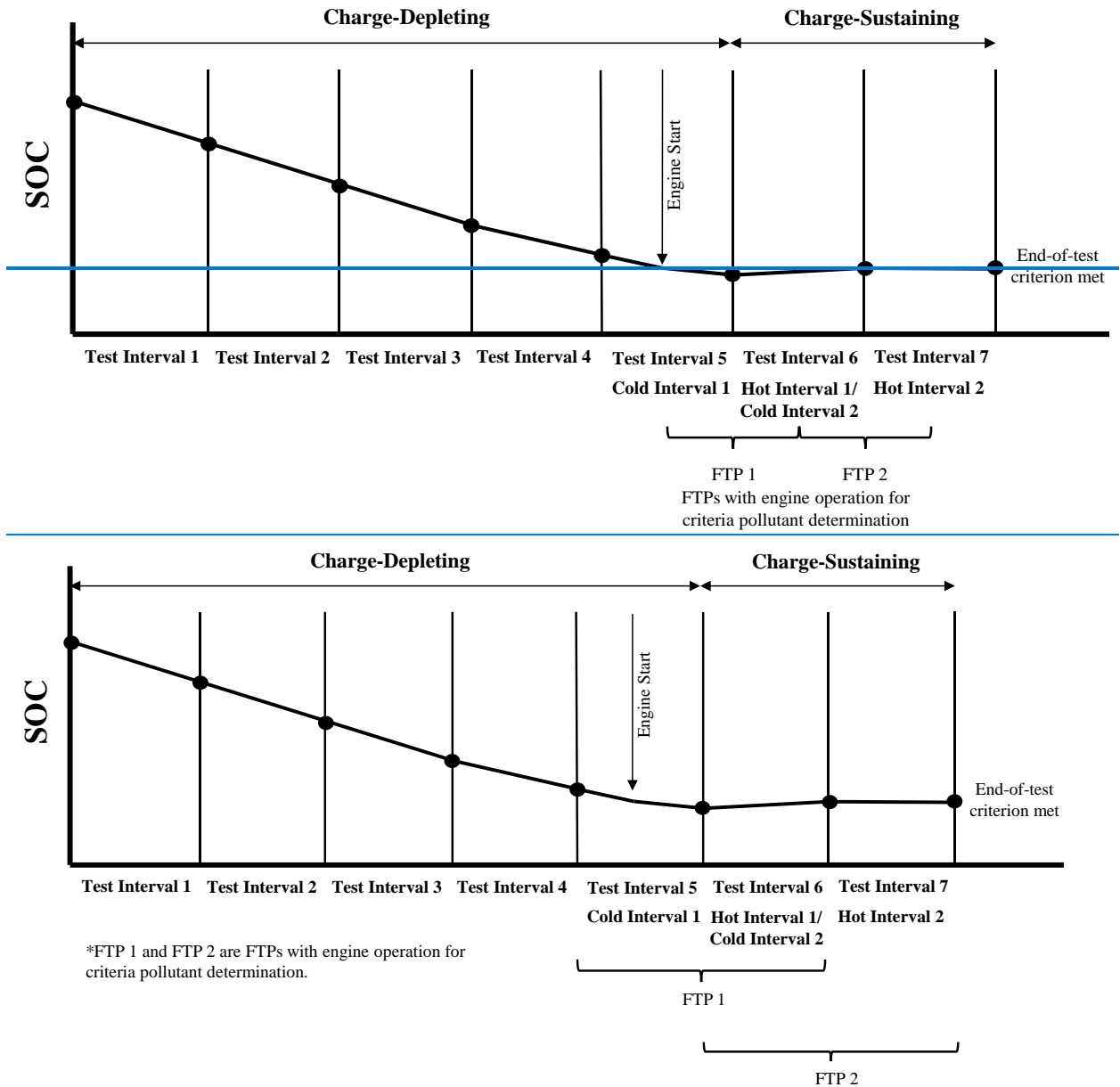
(ii) Operate the ~~hybrid~~ engine or powertrain over one FTP duty cycle followed by alternating repeats of a 20-minute soak and a hot start test interval until you reach the end-of-test criteria defined in 40 CFR 1066.501(a)(3).

(iii) Calculate emission results for each successive pair of test intervals. Calculate the emission result by treating the first of the two test intervals as a cold-start test. Figure 1 of this section § 1036.512 provides an example of a charge-depleting test sequence where there are three test intervals with engine operation for two overlapping FTP duty cycles.

(3) Report the highest emission result for each criteria pollutant from all tests in paragraphs (d)(1) and (2) of this section, even if those individual results come from different test intervals.

(4) The following figure illustrates an example of an FTP charge-depleting test sequence. Figure 1 follows:

FIGURE 1 TO PARAGRAPH (d)(4) OF § 1036.512—FTP CHARGE-DEPLETING CRITERIA POLLUTANT TEST SEQUENCE:



- (e) Determine greenhouse gas pollutant emissions for plug-in hybrid engines and powertrains using the emissions results for all the transient duty cycle test intervals described in either paragraph (b) or (c) of appendix B of this part for both charge-depleting and charge-sustaining operation from paragraph (d)(2) of this section. Calculate the utility factor weighted composite mass of emissions from the charge-depleting and charge-sustaining test results, $e_{UF[emission]comp}$, as described in § 1036.510(e), replacing occurrences of “SET” with “transient test interval”. Note this results in composite FTP GHG emission results for plug-in hybrid engines and powertrains without the use of the cold-start and hot-start test interval weighting factors in Eq. 1036.512-1.
- (f) Calculate and evaluate cycle-validation criteria statistics as specified in 40 CFR 1065.514 for nonhybrid engines and § 1036.54540 CFR 1037.550 for hybrid engines and hybrid powertrains.

§ 1036.514 Low Load Cycle.

~~(a)~~ Measure emissions using the transient Low Load Cycle (LLC) as described in this section to determine whether engines meet the LLC emission standards in § 1036.104. ~~(b)~~ The LLC duty cycle is described in paragraph (d) of appendix B of this part. ~~The following p~~Procedures apply differently for testing ~~nonhybrid-certain kinds of~~ engines, ~~hybrid engines,~~ and ~~hybrid~~ powertrains as follows:†

~~(a)~~ ~~Test~~For nonhybrid engines testing, use using the following procedures:

~~(i)~~ Use the ~~duty cycle is based on~~ normalized speed and torque values for engine testing in the LLC duty cycle described in paragraph (d) of appendix B of this part. ~~(ii)~~ Denormalize speed and torque values as described in 40 CFR 1065.512. ~~Denormalize torque as described in 40 CFR and~~ 1065.610 with the following additional requirements for testing at idle: ~~(d)~~

~~(A)~~ Apply ~~t~~The accessory load at idle ~~described in paragraph (c) of this section must be applied using the optional~~ declared idle power as described in 40 CFR 1065.510(f)(6).

Declared idle torque Use of the optional declared idle torque in 40 CFR 1065.510(f)(5)(iii) is not allowed and must be zero.

~~(B)~~ Apply CITT in addition to accessory load as described in this paragraph (a)(1)(ii).

Set reference speed and torque values as described in Replace paragraph 40 CFR 1065.610(d)(3)(vi) for all other idle segments less than or equal to that are 200 s or shorter in length, set the reference speed and torque values to the warm idle in drive values. This is to represent the transmission operating in drive.

(2) For longer idle segments more than 200 s in length, set the reference speed and torque values to the warm-idle-in-drive values for the first three seconds and the last three seconds of the idle segment. For the points in between, all other points in the idle segment set the reference speed and torque values to the warm-idle-in-neutral values. This is to represent the transmission being manually shifted from drive to neutral shortly after the extended idle starts and back to drive shortly before it ends near the beginning of the idle segment and back to drive near the end of the idle segment.

~~(ii)~~ For idle segments more than 200 seconds, set reference torques to the torque needed to meet the accessory loads in Table 1 of this section instead of CITT. This is to represent shifting the transmission to park or neutral at the start of the idle segment. Change the reference torque to CITT no earlier than 5 seconds before the end of the idle segment. This is to represent shifting the transmission to drive.

(2) Calculate and evaluate cycle-validation criteria as described in 40 CFR 1065.514, except as specified in paragraph (e) of this section.

~~(2b)~~ Test ~~hybrid engines and~~ hybrid powertrains as described in § 1036.510(b)(2), with the following exceptions:

~~(1)~~ Replace $P_{\text{contrated}}$ with P_{rated} , which is the peak rated power determined in § 1036.520.

~~(2)~~ Keep the transmission in drive for all idle segments 200 seconds or less. For idle segments more than 200 seconds, leave the transmission in drive for the first 3 seconds of the idle segment, then immediately place the transmission in park or neutral immediately after the 3rd second in at the start of the idle segment, and place-shift the transmission into drive again no earlier than 5 seconds before the end of the idle segment. The end of the idle segment occurs at which is defined by the first nonzero vehicle speed setpoint.

~~(3)~~ For hybrid engines, select the transmission from Table 1 of § 1036.540, substituting “engine” for “vehicle”.

~~(4)~~ For hybrid engines, you may request to change the GEM-generated engine-commanded-reference torque at idle to better represent curb idle transmission torque (CITT).

(4~~v~~) Adjust procedures in this section as described in § 1036.510(d) and (e) fFor plug-in hybrid engines and plug-in hybrid powertrains, to determine criteria pollutant and greenhouse gas emissions as described in § 1036.510(d) and (e), replacing “SET” with “LLC”. Note that the LLC is therefore the preconditioning duty cycle for plug-in hybrid powertrains.

~~(v5i) Calculate and evaluate cycle-validation criteria statistics as specified in § 1036.545.~~

- (c) Include vehicle accessory loading as follows: Set dynamometer torque demand such that
 (1) Apply a vehicle power represents an accessory load for all each idle operation point in the cycle using based on a constant power. Use the power values as described in the following table: Table 1-2 of to paragraph (c)(43) of this section for each based on primary intended service class. (4) Table 1-2 follows:

TABLE 1-2 TO PARAGRAPH (c)(43) OF § 1036.514—ACCESSORY LOAD AT IDLE

Primary intended service class	Power representing accessory load (kW)
Light HDE	1.5
Medium HDE	2.5
Heavy HDE	3.5

- (2) For nonhybrid engine testing, apply vehicle accessory loads this is in addition to any applicable CITT.

(3) Additional provisions related to vehicle accessory load apply for the following special cases:

(1) For engines with stop-start technology and hybrid powertrains where the accessory load is applied to the engine shaft, account for the loss of mechanical work due to the lack of any idle accessory load during engine-off conditions by determining the total loss of mechanical work from idle accessory load during all engine-off power demand intervals over the entire test interval and distributing that load work over the engine-on portions intervals portion of the entire test interval based on a calculated average power. You may determine the engine-off time by running practice cycles or through engineering analysis.

(2) Apply vehicle accessory power loads on idle points for hybrid powertrain testing where torque is measured at the axle input shaft or wheel hubs that includes the transmission either as a mechanical or electrical load.

(3) You may apply the following deviations from specified torque settings for smoother idle (other than idle that includes motoring), or you may develop different procedures for adjusting accessory load at idle consistent with good engineering judgment:

(i) Set the reference torque to correspond to the applicable accessory load for all points with normalized speed at or below zero percent and reference torque from zero up to the torque corresponding to the accessory load.

(ii) Change the reference torques to correspond to the applicable accessory load for consecutive points with reference torques from zero up to the torque corresponding to the accessory load that immediately precedes or follows idle points.

- (4) Except as specified in paragraph (b)(4) of this section for plug-in hybrid powertrains, the
 (d) The test sequence consists of preconditioning the engine by running one or two FTPs with each FTP followed by (20 ±1) minutes with no engine operation and a hot start run through the LLC. You may start any preconditioning FTP with a hot engine. Perform testing as described in 40 CFR 1065.530 for a test interval that includes engine starting. Calculate the total emission mass of each constituent, m , over the test interval and the total work, W , as described in 40 CFR 1065.650. For nonhybrid engines, calculate the total work, W , over the test interval as described

~~in 40 CFR 1065.650(d). For hybrid engines and hybrid powertrains, c~~Calculate total positive work over the test interval ~~for powertrain testing~~ using system power, P_{sys} . Determine P_{sys} using § 1036.520(f). For powertrains with automatic transmissions, account for and include the work produced by the engine from the CITT load. ~~For batch sampling, you may sample background periodically into the bag over the course of multiple test intervals.~~
~~(e) Calculate and evaluate cycle statistics as specified in 40 CFR 1065.514 for nonhybrid engines and 40 CFR 1037.550 for hybrid engines and hybrid powertrains. For gaseous-fueled engine testing with a single-point fuel injection system, you may apply all the statistical criteria in § 1036.540(d)(3) to validate the LLC.~~
 (iii) Calculate and evaluate cycle statistics as described in 40 CFR 1065.514. (d) For testing spark-ignition gaseous-fueled engines with fuel delivery at a single-point in the intake manifold, you may apply the alternative cycle-validation statistical criteria in Table 42 in this section to validate for the LLC.

TABLE 42 TO PARAGRAPH (bd)(1)(iii) OF § 1036.514— ALTERNATIVE LLC CYCLE VALIDATION STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES FOR SPARK-IGNITION GASEOUS-FUELED SPARK-IGNITION ENGINES^a

<u>Parameter</u>	<u>Speed</u>	<u>Torque</u>	<u>Power</u>
<u>Slope, a_1</u>	<u>—</u>	<u>$0.800 \leq a_1 \leq 1.030$</u>	<u>$0.800 \leq a_1 \leq 1.030$</u>
<u>Absolute value of intercept, a_0</u>	<u>—</u>	<u>—</u>	<u>—</u>
<u>Standard error of the estimate, SEE</u>	<u>—</u>	<u>—</u>	<u>$\leq 15\%$ of maximum mapped power</u>
<u>Coefficient of determination, r^2</u>	<u>—</u>	<u>≥ 0.650</u>	<u>≥ 0.650</u>

^aStatistical Cycle-validation criteria apply as specified in 40 CFR 1065.514 unless otherwise specified.

§ 1036.520 Determining power and vehicle speed values for powertrain testing.

This section describes how to determine the system peak power and continuous rated power of hybrid and nonhybrid powertrain systems and the vehicle speed for carrying out duty-cycle testing under this part and ~~§ 1036.54540 CFR 1037.550~~.

- (a) You must map or re-map an engine before a test if any of the following apply:
 - (1) If you have not performed an initial engine map.
 - (2) If the atmospheric pressure near the engine’s air inlet is not within ± 5 kPa of the atmospheric pressure recorded at the time of the last engine map.
 - (3) If the engine or emission-control system has undergone changes that might affect maximum torque performance. This includes changing the configuration of auxiliary work inputs and outputs.
 - (4) If you capture an incomplete map on your first attempt or you do not complete a map within the specified time tolerance. You may repeat mapping as often as necessary to capture a complete map within the specified time.
- (b) Set up the powertrain test according to ~~§ 1036.54540 CFR 1037.550~~, with the following exceptions:
 - (1) Use vehicle parameters, other than power, as specified in § 1036.510(b)(2). Use the applicable automatic transmission as specified in § 1036.540(c)(2).
 - (2) Select a manufacturer-declared value for $P_{contrated}$ to represent system peak power.
- (c) Verify the following before the start of each test interval:

(1) The state-of-charge of the rechargeable energy storage system (RESS) must be at or above 90 % of the operating range between the minimum and maximum RESS energy levels specified by the manufacturer.

(2) The conditions of all hybrid system components must be within their normal operating range as declared by the manufacturer, including ensuring that no features are actively limiting power or vehicle speed.

(d) Carry out the test as described in this paragraph (d). Warm up the powertrain by operating it. We recommend operating the powertrain at any vehicle speed and road grade that achieves approximately 75 % of its expected maximum power. Continue the warm-up until the engine coolant, block, [lubricating oil](#), or head absolute temperature is within ± 2 % of its mean value for at least 2 min or until the engine thermostat controls engine temperature. Within 90 seconds after concluding the warm-up, operate the powertrain over a continuous trace meeting the following specifications:

(1) Bring the vehicle speed to 0 mi/hr and let the powertrain idle at 0 mi/hr for 50 seconds.

(2) Set maximum driver demand for a full load acceleration at 6.0 % road grade with an initial vehicle speed of 0 mi/hr, continuing for 268 seconds. ~~You may decrease the road grade in the first 30 seconds or increase initial vehicle speed up to 5 mi/hr as needed to mitigate minimize clutch slip.~~

(3) Linearly ramp the grade from 6.0 % down to 0.0 % over 300 seconds. Stop the test ~~after the acceleration is less than 0.02 m/s² 30 seconds after the grade setpoint has reached 0.0 %.~~

(e) Record the powertrain system angular speed and torque values measured at the dynamometer at 100 Hz and use these in conjunction with the vehicle model to calculate vehicle system power, $P_{\text{sys,vehicle}}$. Note that P_{sys} is the corresponding value for system power at a location that represents the transmission input shaft on a conventional powertrain.

(f) Calculate the system power, P_{sys} , for each data point as follows:

(1) For testing with the speed and torque measurements at the transmission input shaft, P_{sys} is equal to the calculated vehicle system power, $P_{\text{sys,vehicle}}$, determined in paragraphs (d) and (e) of this section.

(2) For testing with the speed and torque measurements at the axle input shaft or the wheel hubs, determine P_{sys} for each data point using the following equation:

$$P_{\text{sys}} = \frac{P_{\text{sys,vehicle}}}{\epsilon_{\text{trans}} \cdot \epsilon_{\text{axle}}}$$

Eq. 1036.520-1

Where:

$P_{\text{sys,vehicle}}$ = the calculated vehicle system power for each 100-Hz data point.

ϵ_{trans} = the default transmission efficiency = 0.95.

ϵ_{axle} = the default axle efficiency. Set this value to 1 for speed and torque measurement at the axle input shaft or to 0.955 at the wheel hubs.

Example:

$$P_{\text{sys,vehicle}} = 317.6 \text{ kW}$$

$$P_{\text{sys}} = \frac{317.6}{0.95 \cdot 0.955}$$

$$P_{\text{sys}} = 350.1 \text{ kW}$$

(g) For each 200-ms (5-Hz) time step, t , determine the coefficient of variation (COV) of \bar{P}_{sys} as follows:

(1) Calculate the standard deviation, $\sigma(t)$ of the 20 100-Hz data points in each 5-Hz measurement interval using the following equation:

$$\sigma(t) = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^N (P_{\text{sys}i} - \bar{P}_{\text{sys}}(t))^2}$$

Eq. 1036.520-2

Where:

N = the number of data points in each 5-Hz measurement interval = 20.

$P_{\text{sys}i}$ = the 100-Hz values of P_{sys} within each 5-Hz measurement interval.

$\bar{P}_{\text{sys}}(t)$ = the mean power from each 5-Hz measurement interval.

(2) Calculate the 5-Hz values for $COV(t)$ for each time step, t , as follows:

$$COV(t) = \frac{\sigma(t)}{\bar{P}_{\text{sys}}(t)}$$

Eq. 1036.520-3

(h) Determine rated power, P_{rated} , as the maximum measured power from the data collected in paragraph (d)(2) of this section where the COV determined that meets the specifications in paragraph (g) of this section is less than 2 %.

(i) Determine continuous rated power, $P_{\text{contrated}}$, as follows:

(1) For nonhybrid powertrains, $P_{\text{contrated}}$ equals P_{rated} .

(2) For hybrid powertrains, $P_{\text{contrated}}$ is the maximum measured power from the data collected in paragraph (d)(3) of this section where the COV determined that meets the specifications in paragraph (g) of this section is less than 2 %.

(j) Determine vehicle C speed, v_{refC} , as follows:

(1) If the maximum $P_{\text{sys}}(t)$ in the highest gear during the maneuver in paragraph (d)(3) of this section is greater than $0.98 \cdot P_{\text{contrated}}$, v_{refC} is the average of the minimum and maximum vehicle speeds where $P_{\text{sys}}(t)$ is equal to $0.98 \cdot P_{\text{contrated}}$ during the maneuver in paragraph (d)(3) of this section where the transmission is in the highest gear, using linear interpolation, as appropriate. If $P_{\text{sys}}(t)$ at the lowest vehicle speed where the transmission is in the highest gear is greater than $0.98 \cdot P_{\text{contrated}}$, use the lowest vehicle speed where the transmission is in the highest gear as the minimum vehicle speed input for calculating v_{refC} .

(2) Otherwise, v_{refC} is the maximum vehicle speed during the maneuver in paragraph (d)(3) where the transmission is in the highest gear.

(3) You may use a declared v_{refC} instead of measured v_{refC} if the declared v_{refC} is within (97.5 to 102.5) % of the corresponding measured value.

(4) Manufacturers may request approval to use an alternative vehicle C speed in place of the measured vehicle C speed determined in this paragraph (j) for series hybrid applications. Approval will be contingent upon justification that the measured vehicle C speed is not representative of the expected real-world cruise speed.

(k) If $P_{\text{contrated}}$ as determined in paragraph (i) of this section is within ± 3 % of the manufacturer-declared value for $P_{\text{contrated}}$, use the manufacturer-declared value. Otherwise, repeat the procedure

in paragraphs (b) through (j) of this section and use $P_{\text{contrated}}$ from paragraph (i) instead of the manufacturer-declared value.

§ 1036.525 Clean Idle test.

Measure emissions using the procedures described in this section to determine whether engines and hybrid powertrains meet the clean idle emission standards in § 1036.104(b). For ~~plug-in hybrid engines and~~ plug-in hybrid powertrains, perform the test with the hybrid function disabled.

(a) The clean idle test consists of two separate test intervals as follows:

(1) Mode 1 consists of engine operation with a speed setpoint at your recommended warm idle speed. Set the dynamometer torque demand corresponding to vehicle power requirements at your recommended warm idle speed that represent in-use operation.

(2) Mode 2 consists of engine operation with a speed setpoint at 1100 r/min. Set the dynamometer torque demand to account for the sum of the following power loads:

(i) Determine power requirements for idling at 1100 r/min.

(ii) Apply a power demand of 2 kW to account for appliances and accessories the vehicle operator may use during rest periods.

(3) Determine torque demand for testing under this paragraph (a) based on an accessory load that includes the engine cooling fan, alternator, coolant pump, air compressor, engine oil and fuel pumps, and any other engine accessory that operates at the specific test condition. Also include the accessory load from the air conditioning compressor operating at full capacity for Mode 2. Do not include any other load for air conditioning or other cab or vehicle accessories except as specified.

(b) Perform the Clean Idle test as follows:

(1) Warm up the engine by operating it over the FTP or SET duty cycle, or by operating it at any speed above peak-torque speed and at (65 to 85) % of maximum mapped power. The warm-up is complete when the engine thermostat controls engine temperature or when the engine coolant's temperature is within 2 % of its mean value for at least 2 minutes.

(2) Start operating the engine in Mode 1 as soon as practical after the engine warm-up is complete.

(3) Start sampling emissions 10 minutes after reaching the speed and torque setpoints and continue emission sampling and engine operation at those setpoints. Stop emission sampling after 1200 seconds to complete the test interval.

(4) Linearly ramp the speed and torque setpoints over 5 seconds to start operating the engine in Mode 2. Sample emissions during Mode 2 as described in paragraph (b)(3) of this section.

(c) Verify that the test speed stays within ± 50 r/min of the speed setpoint throughout the test. The torque tolerance is ± 2 percent of the maximum mapped torque at the test speed. Verify that measured torque meets the torque tolerance relative to the torque setpoint throughout the test.

(d) Calculate the mean mass emission rate of NO_x , \bar{m}_{NO_x} , over each test interval by calculating the total emission mass m_{NO_x} and dividing by the total time.

§ 1036.530 Test procedures for off-cycle testing.

(a) *General.* This section describes the measurement and calculation procedures to perform field testing and determine whether tested engines and engine families meet emission standards under subpart E of this part. Calculate mass emission rates as specified in 40 CFR part 1065, subpart G. Use good engineering judgment to adapt these procedures for simulating vehicle operation in the laboratory.

- (b) *Vehicle preparation and measurement procedures.* (1) Set up the vehicle for testing with a portable emissions measurement system (PEMS) as specified in 40 CFR part 1065, subpart J. (2) Begin emission sampling and data collection as described in 40 CFR 1065.935(c)(3) before starting the engine at the beginning of the shift-day. Start the engine only after confirming that engine coolant temperature is at or below 40 °C. (3) Measure emissions over one or more shift-days as specified in subpart E of this part. (4) For engines subject to compression-ignition standards, record 1 Hz measurements of ambient temperature near the vehicle.
- (c) *Test Intervals.* Determine the test intervals as follows:
- (1) *Spark-ignition.* Create a single test interval that covers the entire shift-day for engines subject to spark-ignition standards. The test interval starts with the first pair of consecutive data points with no exclusions as described in paragraph (c)(3) of this section after the start of the shift-day and ends with the last pair of consecutive data points with no exclusions before the end of the shift day.
- (2) *Compression-ignition.* Create a series of 300 second test intervals for engines subject to compression-ignition standards (moving-average windows) as follows:
- (i) Begin and end each test interval with a pair of consecutive data points with no exclusions as described in paragraph (c)(3) of this section. Select the last data point of each test interval such that the test interval includes 300 seconds of data with no exclusions, as described in paragraph (d) of this section. The test interval may be a fraction of a second more or less than 300 seconds to account for the precision of the time stamp in recording 1 Hz data. A test interval may include up to 599 seconds of data with continuous exclusions; invalidate any test interval that includes at least 600 seconds of continuous sampling with excluded data.
- (ii) The first 300 second test interval starts with the first pair of consecutive data points with no exclusions. Determine the start of each subsequent 300 second test interval by finding the first pair of consecutive data points with no exclusions after the initial data point of the previous test interval.
- (iii) The last 300 second test interval ends with the last pair of consecutive data points with no exclusions before the end of the shift day.
- (3) *Excluded data.* Exclude data from test intervals for any period meeting one or more of the following conditions:
- (i) An analyzer or flow meter is performing zero and span drift checks or zero and span calibrations, including any time needed for the analyzer to stabilize afterward, consistent with good engineering judgment.
- (ii) The engine is off, except as specified in § 1036.415(g).
- (iii) The engine is performing an infrequent regeneration. Do not exclude data related to any other AECs, except as specified in paragraph (c)(3)(vi) of this section.
- (iv) The recorded ambient air temperature is below 5 °C or above the temperature calculated using the following equation.

$$T_{\max} = -0.0014 \cdot h + 37.78$$

Eq. 1036.530-1

Where:

h = recorded elevation of the vehicle in feet above sea level (h is negative for elevations below sea level).

Example:

$$h = 2679 \text{ ft}$$

$$T_{\max} = -0.0014 \cdot 2679 + 37.78$$

$$T_{\max} = 34.0 \text{ }^{\circ}\text{C}$$

- (v) The vehicle is operating at an elevation more than 5,500 feet above sea level.
 - (vi) An engine has one or more active AECs for emergency vehicles under § 1036.115(h)(4).
 - (vii) A single data point does not meet any of the conditions specified in paragraphs (c)(3)(i) through (vi) of this section, but it is preceded and followed by data points that both meet one or more of the specified exclusion conditions.
- (d) *Assembling test intervals.* A test interval may include multiple subintervals separated by periods with one or more exclusions under paragraph (c)(3) of this section.
- (1) Treat these test subintervals as continuous for calculating duration of the test interval for engines subject to compression-ignition standards.
 - (2) Calculate emission mass during each test subinterval and sum those subinterval emission masses to determine the emission mass over the test interval. Calculate emission mass as described in 40 CFR 1065.650(c)(2)(i), with the following exceptions and clarifications:
 - (i) Correct NO_x emissions for humidity as specified in 40 CFR 1065.670. Calculate corrections relative to ambient air humidity as measured by PEMS.
 - (ii) Disregard the provision in 40 CFR 1065.650(g) for setting negative emission mass to zero for test intervals and subintervals.
 - (iii) Calculation of emission mass in 40 CFR 1065.650 assumes a constant time interval, Δt . If it is not appropriate to assume Δt is constant for testing under this section, use good engineering judgment to record time at each data point and adjust the mass calculation from Eq. 1065.650-4 by treating Δt as a variable.
- (e) *Normalized CO₂ emission mass over a 300 second test interval.* For engines subject to compression-ignition standards, determine the normalized CO₂ emission mass over each 300 second test interval, $m_{\text{CO}_2, \text{norm}, \text{testinterval}}$, to the nearest 0.01 % using the following equation:

$$m_{\text{CO}_2, \text{norm}, \text{testinterval}} = \frac{m_{\text{CO}_2, \text{testinterval}}}{e_{\text{CO}_2 \text{FTPFL}} \cdot P_{\max} \cdot t_{\text{testinterval}}}$$

Eq. 1036.530-2

Where:

$m_{\text{CO}_2, \text{testinterval}}$ = total CO₂ emission mass over the test interval.

$e_{\text{CO}_2 \text{FTPFL}}$ = the engine's FCL for CO₂ over the FTP duty cycle. If the engine family includes no FTP testing, use the engine's FCL for CO₂ over the SET duty cycle.

P_{\max} = the highest value of rated power for all the configurations included in the engine family.

$t_{\text{testinterval}}$ = duration of the test interval. Note that the nominal value is 300 seconds.

Example:

$$m_{\text{CO}_2, \text{testinterval}} = 3948 \text{ g}$$

$$e_{\text{CO}_2 \text{FTPFL}} = 428.2 \text{ g/hp}\cdot\text{hr}$$

$$P_{\max} = 406.5 \text{ hp}$$

$$t_{\text{testinterval}} = 300.01 \text{ s} = 0.08 \text{ hr}$$

$$m_{\text{CO}_2, \text{norm}, \text{testinterval}} = \frac{3948}{428.2 \cdot 406.5 \cdot 0.08}$$

$$m_{\text{CO}_2, \text{norm}, \text{testinterval}} = 0.2722 = 27.22 \%$$

(f) *Binning 300 second test intervals.* For engines subject to compression-ignition standards, identify the appropriate bin for each of the 300 second test intervals based on its normalized CO₂ emission mass, $m_{\text{CO}_2, \text{norm}, \text{testinterval}}$, as follows:

TABLE 1 TO PARAGRAPH (f) OF § 1036.530—CRITERIA FOR OFF-CYCLE BINS

Bin	Normalized CO ₂ emission mass over the 300 second test interval
Bin 1	$m_{\text{CO}_2, \text{norm}, \text{testinterval}} \leq 6.00 \%$.
Bin 2	$m_{\text{CO}_2, \text{norm}, \text{testinterval}} > 6.00 \%$.

(g) *Off-cycle emissions quantities.* Determine the off-cycle emissions quantities as follows:

(1) *Spark-ignition.* For engines subject to spark-ignition standards, the off-cycle emission quantity, $e_{[\text{emission}], \text{offcycle}}$, is the value for CO₂-specific emission mass for a given pollutant over the test interval representing the shift-day converted to a brake-specific value, as calculated for each measured pollutant using the following equation:

$$e_{[\text{emissions}], \text{offcycle}} = \frac{m_{[\text{emission}]}}{m_{\text{CO}_2}} \cdot e_{\text{CO}_2, \text{FTP}, \text{FCL}}$$

Eq. 1036.530-3

Where:

$m_{[\text{emission}]}$ = total emission mass for a given pollutant over the test interval as determined in paragraph (d)(2) of this section.

m_{CO_2} = total CO₂ emission mass over the test interval as determined in paragraph (d)(2) of this section.

$e_{\text{CO}_2, \text{FTP}, \text{FCL}}$ = the engine's FCL for CO₂ over the FTP duty cycle.

Example:

$$m_{\text{NO}_x} = 1.337 \text{ g}$$

$$m_{\text{CO}_2} = 18778 \text{ g}$$

$$e_{\text{CO}_2, \text{FTP}, \text{FCL}} = 505.1 \text{ g/hp}\cdot\text{hr}$$

$$e_{\text{NO}_x, \text{offcycle}} = \frac{1.337}{18778} \cdot 505.1$$

$$e_{\text{NO}_x, \text{offcycle}} = 0.035 \text{ g/hp}\cdot\text{hr} = \underline{35 \text{ mg/hp}\cdot\text{hr}}$$

(2) *Compression-ignition.* For engines subject to compression-ignition standards, determine the off-cycle emission quantity for each bin. When calculating mean bin emissions from ten engines to apply the pass criteria for engine families in § 1036.425(c), set any negative off-cycle emissions quantity to zero before calculating mean bin emissions.

(i) *Off-cycle emissions quantity for bin 1.* The off-cycle emission quantity for bin 1, $\bar{m}_{\text{NO}_x, \text{offcycle}, \text{bin1}}$, is the mean NO_x mass emission rate from all test intervals associated with bin 1 as calculated using the following equation:

$$\bar{m}_{\text{NO}_x, \text{offcycle}, \text{bin1}} = \frac{\sum_{i=1}^N m_{\text{NO}_x, \text{testinterval}, i}}{\sum_{i=1}^N t_{\text{testinterval}, i}}$$

Eq. 1036.530-4

Where:

i = an indexing variable that represents one 300 second test interval.

N = total number of 300 second test intervals in bin 1.

$m_{\text{NO}_x, \text{testinterval}, i}$ = total NO_x emission mass over the test interval i in bin 1 as determined in paragraph (d)(2) of this section.

$t_{\text{testinterval}, i}$ = total time of test interval i in bin 1 as determined in paragraph (d)(1) of this section. Note that the nominal value is 300 seconds.

Example:

$$N = 10114$$

$$m_{\text{NO}_x, \text{testinterval}, 1} = 0.021 \text{ g}$$

$$m_{\text{NO}_x, \text{testinterval}, 2} = 0.025 \text{ g}$$

$$m_{\text{NO}_x, \text{testinterval}, 3} = 0.031 \text{ g}$$

$$t_{\text{testinterval}, 1} = 299.99 \text{ s}$$

$$t_{\text{testinterval}, 2} = 299.98 \text{ s}$$

$$t_{\text{testinterval}, 3} = 300.04 \text{ s}$$

$$\bar{m}_{\text{NO}_x, \text{offcycle}, \text{bin1}} = \frac{(0.021 + 0.025 + 0.031 \dots + m_{\text{NO}_x, \text{testinterval}, 10114})}{(299.99 + 299.98 + 300.04 \dots + t_{\text{testinterval}, 10114})}$$

$$\bar{m}_{\text{NO}_x, \text{offcycle}, \text{bin1}} = 0.000285 \text{ g/s} = 1.026 \text{ g/hr}$$

(ii) *Off-cycle emissions quantity for bin 2.* The off-cycle emission quantity for bin 2, $e_{[\text{emission}], \text{offcycle}, \text{bin2}}$, is the value for CO₂-specific emission mass for a given pollutant of all the 300 second test intervals in bin 2 combined and converted to a brake-specific value, as calculated for each measured pollutant using the following equation:

$$e_{[\text{emissions}], \text{offcycle}, \text{bin2}} = \frac{\sum_{i=1}^N m_{[\text{emission}], \text{testinterval}, i}}{\sum_{i=1}^N m_{\text{CO}_2, \text{testinterval}, i}} \cdot e_{\text{CO}_2, \text{FTP}, \text{FCL}}$$

Eq. 1036.530-5

Where:

i = an indexing variable that represents one 300 second test interval.

N = total number of 300 second test intervals in bin 2.

$m_{[\text{emission}], \text{testinterval}, i}$ = total emission mass for a given pollutant over the test interval i in bin 2 as determined in paragraph (d)(2) of this section.

$m_{\text{CO}_2, \text{testinterval}, i}$ = total CO₂ emission mass over the test interval i in bin 2 as determined in paragraph (d)(2) of this section.

$e_{\text{CO}_2, \text{FTP}, \text{FCL}}$ = the engine's FCL for CO₂ over the FTP duty cycle.

Example:

$$N = 15439$$

$$m_{\text{NO}_x1} = 0.546 \text{ g}$$

$$m_{\text{NO}_x2} = 0.549 \text{ g}$$

$$m_{\text{NO}_x3} = 0.556 \text{ g}$$

$$m_{CO_2,1} = 10950.2 \text{ g}$$

$$m_{CO_2,2} = 10961.3 \text{ g}$$

$$m_{CO_2,3} = 10965.3 \text{ g}$$

$$e_{CO_2,FTP,FCL} = 428.1 \text{ g/hp}\cdot\text{hr}$$

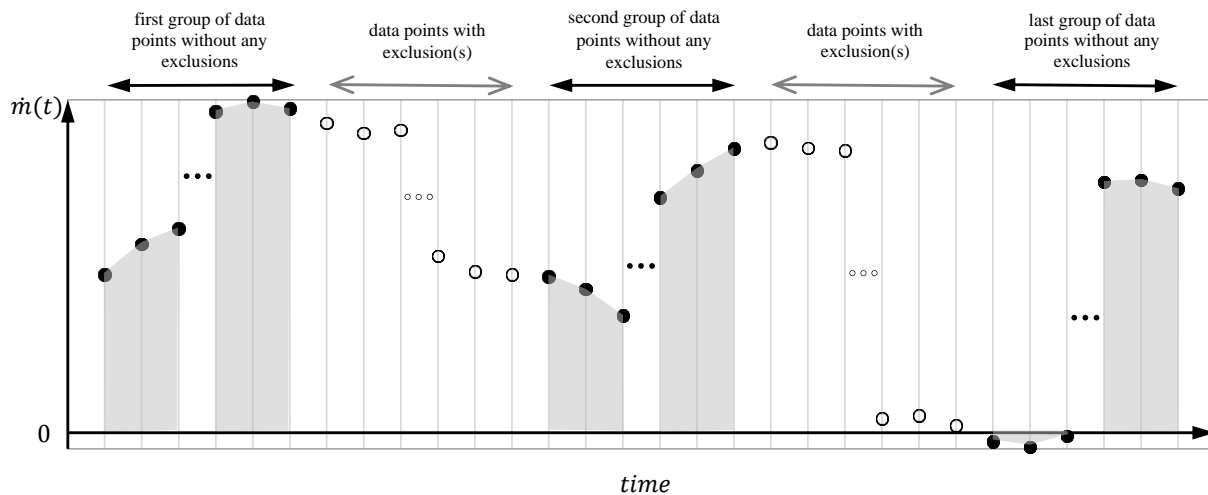
$$e_{NOx,offcycle,bin2} = \frac{(0.546 + 0.549 + 0.556 \dots + m_{NOx,testinterval,15439})}{(10950.2 + 10961.3 + 10965.3 \dots + m_{CO_2,testinterval,15439})} \cdot 428.1$$

$$e_{NOx,offcycle,bin2} = 0.026 \text{ g/hp}\cdot\text{hr} = \underline{26 \text{ mg/hp}\cdot\text{hr}}$$

(h) *Shift-day ambient temperature.* For engines subject to compression-ignition standards, determine the mean shift-day ambient temperature, \bar{T}_{amb} , considering only temperature readings corresponding to data with no exclusions under paragraph (c)(3) of this section.

(i) *Graphical illustration.* Figure 1 of this section illustrates a test interval with interruptions of one or more data points excluded under paragraph (c)(3) of this section. The x-axis is time and the y-axis is the mass emission rate at each data point, $\dot{m}(t)$. The data points coincident with any exclusion are illustrated with open circles. The shaded area corresponding to each group of closed circles represents the total emission mass over that test subinterval. Note that negative values of $\dot{m}(t)$ are retained and not set to zero in the numerical integration calculation. The first group of data points without any exclusions is referred to as the first test subinterval and so on.

FIGURE 1 TO PARAGRAPH (i) OF § 1036.530—ILLUSTRATION OF INTEGRATION OF MASS OF EMISSIONS OVER A TEST INTERVAL WITH EXCLUDE DATA POINTS



(j) *Fuel other than carbon-containing.* The following procedures apply for testing engines using at least one fuel that is not a carbon-containing fuel:

(1) Use the following equation to determine the normalized equivalent CO₂ emission mass over each 300 second test interval $m_{CO_2,norm,testinterval}$ instead of Eq. 1036.530-2:

$$m_{CO_2,norm,equiv,testinterval} = \frac{W_{testinterval}}{P_{max} \cdot t_{testinterval}}$$

Eq. 1036.530-6

Where:

$W_{testinterval}$ = total positive work over the test interval from both the engine and hybrid components, if applicable, as determined in 40 CFR 1065.650.

P_{max} = the highest value of rated power for all the configurations included in the engine family.

$t_{testinterval}$ = duration of the test interval. Note that the nominal value is 300 seconds.

Example:

$$W_{\text{testinterval}} = 8.95 \text{ hp}\cdot\text{hr}$$

$$P_{\text{max}} = 406.5 \text{ hp}$$

$$t_{\text{testinterval}} = 300.01 \text{ s} = 0.08 \text{ hr}$$

$$m_{\text{CO}_2, \text{norm}, \text{testinterval}} = \frac{8.95}{406.5 \cdot 0.08}$$

$$m_{\text{CO}_2, \text{norm}, \text{testinterval}} = 0.2722$$

$$m_{\text{CO}_2, \text{norm}, \text{testinterval}} = 27.22 \%$$

(2) Determine off-cycle emissions quantities as follows:

(i) For engines subject to spark-ignition standards, use the following equation to determine the off-cycle emission quantity instead of Eq. 1036.530-3:

$$e_{[\text{emissions}], \text{offcycle}} = \frac{m_{[\text{emission}]}}{W_{\text{testinterval}}}$$

Eq. 1036.530-7

Where:

$m_{[\text{emission}]}$ = total emission mass for a given pollutant over the test interval as determined in paragraph (d)(2) of this section.

$W_{\text{testinterval}}$ = total positive work over the test interval as determined in 40 CFR 1065.650.

Example:

$$m_{\text{NO}_x} = 1.337 \text{ g}$$

$$W_{\text{testinterval}} = 38.2 \text{ hp}\cdot\text{hr}$$

$$e_{\text{NO}_x, \text{offcycle}} = \frac{1.337}{38.2}$$

$$e_{\text{NO}_x, \text{offcycle}} = 0.035 \text{ g}/\text{hp}\cdot\text{hr} = 35 \text{ mg}/\text{hp}\cdot\text{hr}$$

(ii) For engines subject to compression-ignition standards, use Eq. 1036.530-4 to determine the off-cycle emission quantity for bin 1.

(iii) For engines subject to compression-ignition standards, use the following equation to determine the off-cycle emission quantity for bin 2 instead of Eq. 1036.530-5 to determine the off-cycle emission quantity for bin 2:

$$e_{[\text{emissions}], \text{offcycle}, \text{bin2}} = \frac{\sum_{i=1}^N m_{[\text{emission}], \text{testinterval}, i}}{\sum_{i=1}^N W_{\text{testinterval}, i}}$$

Eq. 1036.530-8

Where:

i = an indexing variable that represents one 300 second test interval.

N = total number of 300 second test intervals in bin 2.

$m_{[\text{emission}], \text{testinterval}, i}$ = total emission mass for a given pollutant over the test interval i in bin 2 as determined in paragraph (d)(2) of this section.

$W_{\text{testinterval}, i}$ = total positive work over the test interval i in bin 2 as determined in 40 CFR 1065.650.

Example:

$$N = 15439$$

$$m_{\text{NOx}1} = 0.546 \text{ g}$$

$$m_{\text{NOx}2} = 0.549 \text{ g}$$

$$m_{\text{NOx}3} = 0.556 \text{ g}$$

$$W_{\text{testinterval}1} = 8.91 \text{ hp}\cdot\text{hr}$$

$$W_{\text{testinterval}2} = 8.94 \text{ hp}\cdot\text{hr}$$

$$W_{\text{testinterval}3} = 8.89 \text{ hp}\cdot\text{hr}$$

$$e_{\text{NOx,offcycle,bin2}} = \frac{(0.546 + 0.549 + 0.556 \dots + m_{\text{NOx,testinterval},15439})}{(8.91 + 8.94 + 8.89 \dots + W_{\text{testinterval},15439})}$$

$$e_{\text{NOx,offcycle,bin2}} = 0.026 \text{ g/hp}\cdot\text{hr} = 26 \text{ mg/hp}\cdot\text{hr}$$

§ 1036.535 Determining steady-state engine fuel maps and fuel consumption at idle.

The procedures in this section describe how to determine an engine's steady-state fuel map and fuel consumption at idle for model year 2021 and later vehicles; these procedures apply as described in § 1036.505. Vehicle manufacturers may need these values to demonstrate compliance with emission standards under 40 CFR part 1037.

(a) *General test provisions.* Perform fuel mapping using the procedure described in paragraph (b) of this section to establish measured fuel-consumption rates at a range of engine speed and load settings. Measure fuel consumption at idle using the procedure described in paragraph (c) of this section. Paragraph (d) of this section describes how to apply the steady-state mapping from paragraph (b) of this section for the special case of cycle-average mapping for highway cruise cycles as described in § 1036.540. Use these measured fuel-consumption values to declare fuel-consumption rates for certification as described in paragraph (g) of this section.

(1) Map the engine's torque curve and declare engine idle speed as described in § 1036.505(c)(1) and (3). Perform emission measurements as described in 40 CFR 1065.501 and 1065.530 for discrete-mode steady-state testing. This section uses engine parameters and variables that are consistent with 40 CFR part 1065.

(2) Measure NO_x emissions as described in paragraph (f) of this section. Include these measured NO_x values any time you report to us your fuel consumption values from testing under this section.

(3) You may use shared data across engine configurations to the extent that the fuel-consumption rates remain valid.

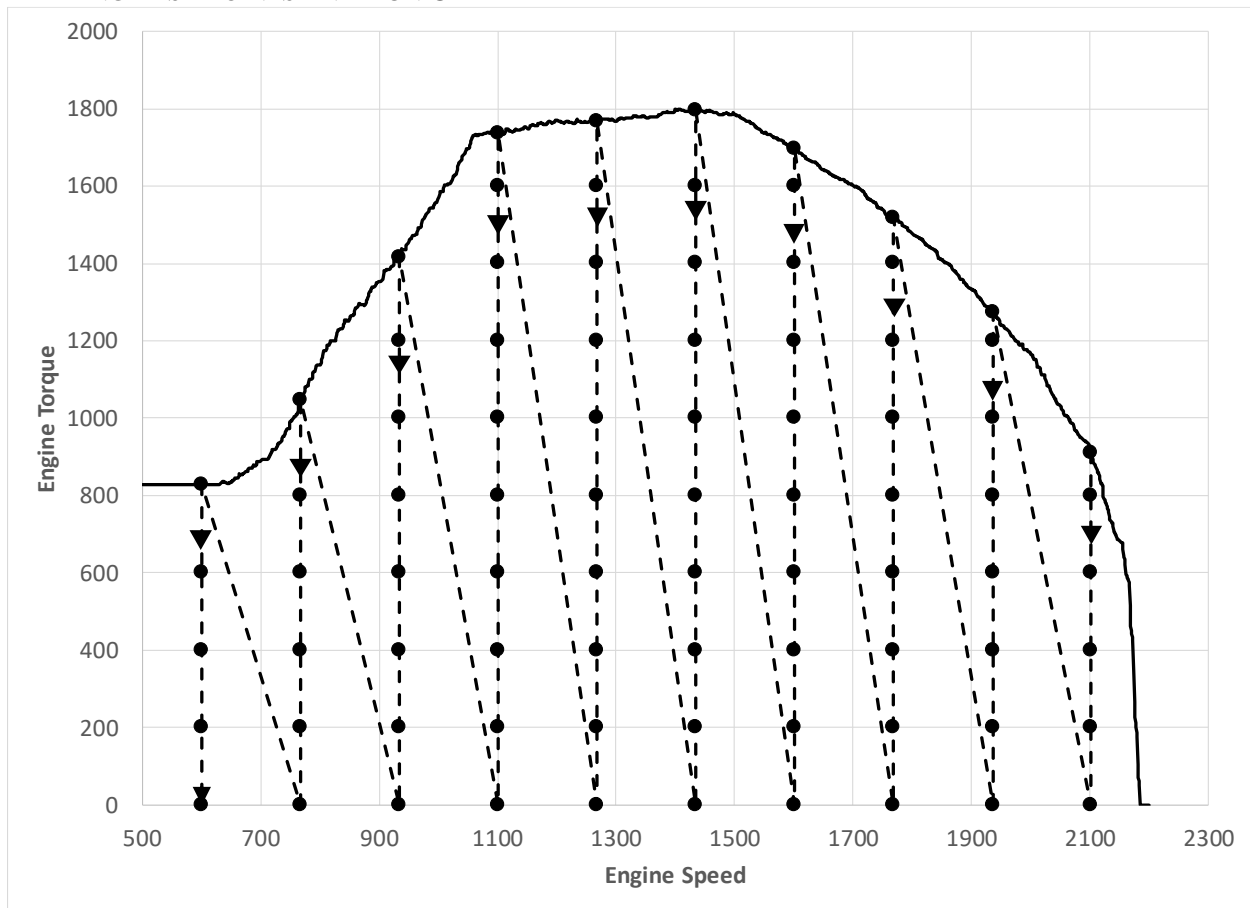
(4) The provisions related to carbon balance error verification in § 1036.543 apply for all testing in this section. These procedures are optional, but we will perform carbon balance error verification for all testing under this section.

(5) Correct fuel mass flow rate to a mass-specific net energy content of a reference fuel as described in paragraph (e) of this section.

(b) *Steady-state fuel mapping.* Determine steady-state fuel-consumption rates for each engine configuration over a series of paired engine speed and torque setpoints as described in this paragraph (b). For example, if you test a high-output (parent) configuration and create a different (child) configuration that uses the same fueling strategy but limits the engine operation to be a subset of that from the high-output configuration, you may use the fuel-consumption rates for the reduced number of mapped points for the low-output configuration, as long as the narrower map includes at least 70 points. Perform fuel mapping as follows:

- (1) Generate the fuel-mapping sequence of engine speed and torque setpoints as follows:
- (i) Select the following required speed setpoints: warm idle speed, f_{idle} , the highest speed above maximum power at which 70 % of maximum power occurs, n_{hi} , and eight (or more) equally spaced points between f_{idle} and n_{hi} . (See 40 CFR 1065.610(c)). For engines with adjustable warm idle speed, replace f_{idle} with minimum warm idle speed f_{idlemin} .
 - (ii) ~~Determine-Select~~ the following ~~default-required~~ torque setpoints at each of the selected speed setpoints: zero ($T = 0$), maximum mapped torque, $T_{\text{max mapped}}$, and eight (or more) equally spaced points between $T = 0$ and $T_{\text{max mapped}}$. Select the maximum torque setpoint at each speed to conform to the torque map as follows:
 - (A) Calculate 5 percent of $T_{\text{max mapped}}$. Subtract this result from the mapped torque at each speed setpoint, T_{max} .
 - (B) Select T_{max} at each speed setpoint as a single torque value to represent all the ~~default-required~~ torque setpoints above the value determined in paragraph (b)(1)(ii)(A) of this section. All ~~of~~ the ~~other~~ default torque setpoints less than T_{max} at a given speed setpoint are required torque setpoints.
 - (iii) You may select any additional speed and torque setpoints consistent with good engineering judgment. For example you may need to select additional points if the engine's fuel consumption is nonlinear across the torque map.- Avoid creating a problem with interpolation between narrowly spaced speed and torque setpoints near T_{max} . For each additional speed setpoint, we recommend including a torque setpoint of T_{max} ; however, you may select torque setpoints that properly represent in-use operation. Increments for torque setpoints between these minimum and maximum values at an additional speed setpoint must be no more than one-ninth of $T_{\text{max,mapped}}$. Note that if the test points were added for the child rating, they should still be reported in the parent fuel map. We will test with at least as many points as you. If you add test points to meet testing requirements for child ratings, include those same test points as reported values for the parent fuel map. For our testing, we will use the same normalized speed and torque test points you use, and we may select additional test points.
 - (iv) Start fuel-map testing at the highest speed setpoint and highest torque setpoint, followed by decreasing torque setpoints at the highest speed setpoint. Continue testing at the next lowest speed setpoint and the highest torque setpoint at that speed setpoint, followed by decreasing torque setpoints at that speed setpoint. Follow this pattern through all the speed and torque points, ending with the lowest speed (f_{idle} or f_{idlemin}) and torque setpoint ($T = 0$). The following figure illustrates an array of test points and the corresponding run order.

FIGURE 1 TO PARAGRAPH (b)(1)(iv) OF § 1036.535—ILLUSTRATION OF STEADY-STATE FUEL-MAPPING TEST POINTS AND RUN ORDER



(v) The highest torque setpoint for each speed setpoint is an optional reentry point to restart fuel mapping after an incomplete test run.

(vi) The lowest torque setpoint at each speed setpoint is an optional exit point to interrupt testing. Paragraph (b)(7) of this section describes how to interrupt testing at other times.

(2) If the engine's warm idle speed is adjustable, set it to its minimum value, f_{idlemin} .

(3) The measurement at each unique combination of speed and torque setpoints constitutes a test interval. Unless we specify otherwise, you may program the dynamometer to control either speed or torque for a given test interval, with operator demand controlling the other parameter. Control speed and torque so that all recorded speed points are within $\pm 1\%$ of n_{hi} from the target speed and all recorded engine torque points are within $\pm 5\%$ of $T_{\text{max mapped}}$ from the target torque during each test interval, except as follows:

(i) For steady-state engine operating points that cannot be achieved, and the operator demand stabilizes at minimum; program the dynamometer to control torque and let the engine govern speed (see 40 CFR 1065.512(b)(1)). Control torque so that all recorded engine torque points are within ± 25 N·m from the target torque. The specified speed tolerance does not apply for the test interval.

(ii) For steady-state engine operating points that cannot be achieved and the operator demand stabilizes at maximum and the speed setpoint is below 90% of n_{hi} even with maximum operator demand, program the dynamometer to control speed and let the engine govern torque (see 40 CFR 1065.512(b)(2)). The specified torque tolerance does not apply for the test interval.

- (iii) For steady-state engine operating points that cannot be achieved and the operator demand stabilizes at maximum and the speed setpoint is at or above 90 % of n_{hi} even with maximum operator demand, program the dynamometer to control torque and let the engine govern speed (see 40 CFR 1065.512(b)(1)). The specified speed tolerance does not apply for the test interval.
- (iv) For the steady-state engine operating points at the minimum speed setpoint and maximum torque setpoint, you may program the dynamometer to control speed and let the engine govern torque. The specified torque tolerance does not apply for this test interval if operator demand stabilizes at its maximum or minimum limit.
- (4) Record measurements using direct and/or indirect measurement of fuel flow as follows:
- (i) *Direct fuel-flow measurement.* Record speed and torque and measure fuel consumption with a fuel flow meter for (30 ± 1) seconds. Determine the corresponding mean values for the test interval. Use of redundant direct fuel-flow measurements requires our advance approval.
- (ii) *Indirect fuel-flow measurement.* Record speed and torque and measure emissions and other inputs needed to run the chemical balance in 40 CFR 1065.655(c) for (30 ± 1) seconds. Determine the corresponding mean values for the test interval. Use of redundant indirect fuel-flow measurements requires our advance approval. Measure background concentration as described in 40 CFR 1065.140, except that you may use one of the following methods to apply a single background reading to multiple test intervals:
- (A) For batch sampling, you may sample periodically into the bag over the course of multiple test intervals and read them as allowed in paragraph (b)(7)(i) of this section. You must determine a single background reading for all affected test intervals if you use the method described in this paragraph (b)(4)(ii)(A).
- (B) You may measure background concentration by sampling from the dilution air during the interruptions allowed in paragraph (b)(7)(i) of this section or at other times before or after test intervals. Measure background concentration within 30 minutes before the first test interval and within 30 minutes before each reentry point. Measure the corresponding background concentration within 30 minutes after each exit point and within 30 minutes after the final test interval. You may measure background concentration more frequently. Correct measured emissions for test intervals between a pair of background readings based on the average of those two values. Once the system stabilizes, collect a background sample over an averaging period of at least 30 seconds.
- (5) Warm up the engine as described in 40 CFR 1065.510(b)(2). Within 60 seconds after concluding the warm-up, linearly ramp the speed and torque setpoints over 5 seconds to the starting test point from paragraph (b)(1) of this section.
- (6) Stabilize the engine by operating at the specified speed and torque setpoints for (70 ± 1) seconds and then start the test interval. Record measurements during the test interval. Measure and report NO_x emissions over each test interval as described in paragraph (f) of this section.
- (7) After completing a test interval, linearly ramp the speed and torque setpoints over 5 seconds to the next test point.
- (i) You may interrupt the fuel-mapping sequence before a reentry point as noted in paragraphs (b)(1)(v) and (vi) of this section. If you zero and span analyzers, read and evacuate background bag samples, or sample dilution air for a background reading during the interruption, the maximum time to stabilize in paragraph (b)(6) of this section does not apply. If you shut off the engine, restart with engine warm-up as described in paragraph (b)(5) of this section.

(ii) You may interrupt the fuel-mapping sequence at a given speed setpoint before completing measurements at that speed. If this happens, you may measure background concentration and take other action as needed to validate test intervals you completed before the most recent reentry point. Void all test intervals after the last reentry point. Restart testing at the appropriate reentry point in the same way that you would start a new test. Operate the engine long enough to stabilize aftertreatment thermal conditions, even if it takes more than 70 seconds. In the case of an infrequent regeneration event, interrupt the fuel-mapping sequence and allow the regeneration event to finish with the engine operating at a speed and load that allows effective regeneration.

(iii) If you void any one test interval, all the testing at that speed setpoint is also void. Restart testing by repeating the fuel-mapping sequence as described in this paragraph (b); include all voided speed setpoints and omit testing at speed setpoints that already have a full set of valid results.

(8) If you determine fuel-consumption rates using emission measurements from the raw or diluted exhaust, calculate the mean fuel mass flow rate, \bar{m}_{fuel} , for each point in the fuel map using the following equation:

$$\bar{m}_{\text{fuel}} = \frac{M_C}{w_{\text{Cmeas}}} \cdot \left(\bar{n} \bar{n}_{\text{exh}} \cdot \frac{\bar{x}_{\text{Ccombdry}}}{1 + \bar{x}_{\text{H}_2\text{Oexhdry}}} - \frac{\bar{m}_{\text{CO}_2\text{DEF}}}{M_{\text{CO}_2}} \right)$$

Eq. 1036.535-1

Where:

\bar{m}_{fuel} = mean fuel mass flow rate for a given fuel map setpoint, expressed to at least the nearest 0.001 g/s.

M_C = molar mass of carbon.

w_{Cmeas} = carbon mass fraction of fuel (or mixture of test fuels) as determined in 40 CFR 1065.655(d), except that you may not use the default properties in [Table 2 of 40 CFR 1065.655\(e\)\(5\)](#) to determine α , β , and w_C . You may not account for the contribution to α , β , γ , and δ of diesel exhaust fluid or other non-fuel fluids injected into the exhaust.

$\bar{n} \bar{n}_{\text{exh}}$ = the mean raw exhaust molar flow rate from which you measured emissions according to 40 CFR 1065.655.

$\bar{x}_{\text{Ccombdry}}$ = the mean concentration of carbon from fuel and any injected fluids in the exhaust per mole of dry exhaust as determined in 40 CFR 1065.655(c).

$\bar{x}_{\text{H}_2\text{Oexhdry}}$ = the mean concentration of H₂O in exhaust per mole of dry exhaust as determined in 40 CFR 1065.655(c).

$\bar{m}_{\text{CO}_2\text{DEF}}$ = the mean CO₂ mass emission rate resulting from diesel exhaust fluid decomposition as determined in paragraph (b)(9) of this section. If your engine does not use diesel exhaust fluid, or if you choose not to perform this correction, set $\bar{m}_{\text{CO}_2\text{DEF}}$ equal to 0.

M_{CO_2} = molar mass of carbon dioxide.

Example:

$M_C = 12.0107$ g/mol

$w_{\text{Cmeas}} = 0.869$

$\bar{n} \bar{n}_{\text{exh}} = 25.534$ mol/s

$\bar{x}_{\text{Ccombdry}} = 0.002805$ mol/mol

$\bar{x}_{\text{H}_2\text{Oexhdry}} = 0.0353$ mol/mol

$$\begin{aligned}\bar{m}_{\text{CO}_2\text{DEF}} &= 0.0726 \text{ g/s} \\ M_{\text{CO}_2} &= 44.0095 \text{ g/mol} \\ \bar{m}_{\text{fuel}} &= \frac{12.0107}{0.869} \cdot \left(25.534 \cdot \frac{0.002805}{1 + 0.0353} - \frac{0.0726}{44.0095} \right) \\ \bar{m}_{\text{fuel}} &= 0.933 \text{ g/s}\end{aligned}$$

(9) If you determine fuel-consumption rates using emission measurements with engines that utilize diesel exhaust fluid for NO_x control and you correct for the mean CO₂ mass emission rate resulting from diesel exhaust fluid decomposition as described in paragraph (b)(8) of this section, perform this correction at each fuel map setpoint using the following equation:

$$\bar{m}_{\text{CO}_2\text{DEF}} = \bar{m}_{\text{DEF}} \cdot \frac{M_{\text{CO}_2} \cdot w_{\text{CH}_4\text{N}_2\text{O}}}{M_{\text{CH}_4\text{N}_2\text{O}}}$$

Eq. 1036.535-2

Where:

\bar{m}_{DEF} = the mean mass flow rate of injected urea solution diesel exhaust fluid for a given sampling period, determined directly from the ECM, or measured separately, consistent with good engineering judgment.

M_{CO_2} = molar mass of carbon dioxide.

$w_{\text{CH}_4\text{N}_2\text{O}}$ = mass fraction of urea in diesel exhaust fluid aqueous solution. Note that the subscript “CH₄N₂O” refers to urea as a pure compound and the subscript “DEF” refers to the aqueous urea diesel exhaust fluid as a solution of urea in water. You may use a default value of 32.5 % or use good engineering judgment to determine this value based on measurement.

$M_{\text{CH}_4\text{N}_2\text{O}}$ = molar mass of urea.

Example:

$$\begin{aligned}\bar{m}_{\text{DEF}} &= 0.304 \text{ g/s} \\ M_{\text{CO}_2} &= 44.0095 \text{ g/mol} \\ w_{\text{CH}_4\text{N}_2\text{O}} &= 32.5 \% = 0.325 \\ M_{\text{CH}_4\text{N}_2\text{O}} &= 60.05526 \text{ g/mol} \\ \bar{m}_{\text{CO}_2\text{DEF}} &= 0.304 \cdot \frac{44.0095 \cdot 0.325}{60.05526} \\ \bar{m}_{\text{CO}_2\text{DEF}} &= 0.0726 \text{ g/s}\end{aligned}$$

(10) Correct the measured or calculated mean fuel mass flow rate, at each of the **engine-idle** operating points to account for mass-specific net energy content as described in paragraph (e) of this section.

(c) *Fuel consumption at idle.* Determine fuel-consumption rates at idle for each engine configuration that is certified for installation in vocational vehicles. Determine fuel-consumption rates at idle by testing engines over a series of paired engine speed and torque setpoints as described in this paragraph (c). Perform measurements as follows:

(1) The idle test sequence consists of measuring fuel consumption at four test points representing each combination of the following speed and torque setpoints in any order.

(i) Speed setpoints for engines with adjustable warm idle speed are minimum warm idle speed, f_{idlemin} , and maximum warm idle speed, f_{idlemax} . Speed setpoints for engines with

no adjustable warm idle speed (with zero torque on the primary output shaft) are f_{idle} and 1.15 times f_{idle} .

(ii) Torque setpoints are 0 and 100 N·m.

(2) Control speed and torque as follows:

(i) *Adjustable warm idle speed.* Set the engine's warm idle speed to the next speed setpoint any time before the engine reaches the next test point. Control both speed and torque when the engine is warming up and when it is transitioning to the next test point. Start to control both speed and torque. At any time prior to reaching the next engine-idle operating point, set the engine's adjustable warm idle speed setpoint to the speed setpoint of the next engine-idle operating point in the sequence. This may be done before or during the warm-up or during the transition. Near the end of the transition period control speed and torque as described in paragraph (b)(3)(i) of this section shortly before reaching each test point. Once the engine is operating at the desired speed and torque setpoints, set the operator demand to minimum; control torque so that all recorded engine torque points are within ± 25 N·m from the target torque.

(ii) *Nonadjustable warm idle speed.* For the lowest speed setpoint, control speed and torque as described in paragraph (c)(2)(i) of this section, except for adjusting the warm idle speed. For the second-lowest speed setpoint, control speed and torque so that all recorded speed points are within ± 1 % of n_{hi} from the target speed and engine torque within ± 5 % of T_{max} mapped from the target torque.

(3) Record measurements using direct and/or indirect measurement of fuel flow as follows:

(i) *Direct fuel flow measurement.* Record speed and torque and measure fuel consumption with a fuel flow meter for (600 ± 1) seconds. Determine the corresponding mean values for the test interval. Use of redundant direct fuel-flow measurements require prior EPA approval.

(ii) *Indirect fuel flow measurement.* Record speed and torque and measure emissions and other inputs needed to run the chemical balance in 40 CFR 1065.655(c) for (600 ± 1) seconds. Determine the corresponding mean values for the test interval. Use of redundant indirect fuel-flow measurements require prior EPA approval. Measure background concentration as described in paragraph (b)(4)(ii) of this section. We recommend setting the CVS flow rate as low as possible to minimize background, but without introducing errors related to insufficient mixing or other operational considerations. Note that for this testing 40 CFR 1065.140(e) does not apply, including the minimum dilution ratio of 2:1 in the primary dilution stage.

(4) Warm up the engine as described in 40 CFR 1065.510(b)(2). Within 60 seconds after concluding the warm-up, linearly ramp the speed and torque over 20 seconds to the first speed and torque setpoint.

(5) The measurement at each unique combination of speed and torque setpoints constitutes a test interval. Operate the engine at the selected speed and torque set points for (180 ± 1) seconds, and then start the test interval. Record measurements during the test interval. Measure and report NO_x emissions over each test interval as described in paragraph (f) of this section.

(6) After completing each test interval, repeat the steps in paragraphs (c)(4) and (5) of this section for all the remaining engine-idle test points.

(7) Each test point represents a stand-alone measurement. You may therefore take any appropriate steps between test intervals to process collected data and to prepare engines and equipment for further testing. Note that the allowances for combining background in paragraph (b)(4)(ii)(B) of this section do not apply. If an infrequent regeneration event

occurs, allow the regeneration event to finish; void the test interval if the regeneration starts during a measurement.

(8) Correct the measured or calculated mean fuel mass flow rate, at each of the engine-idle operating points to account for mass-specific net energy content as described in paragraph (e) of this section.

(d) *Steady-state fuel maps used for cycle-average fuel mapping of the highway cruise cycles.* Determine steady-state fuel-consumption rates for each engine configuration over a series of paired engine speed and torque setpoints near idle as described in this paragraph (d). Perform fuel mapping as described in paragraph (b) of this section with the following exceptions:

(1) Select speed setpoints to cover a range of values to represent in-use operation at idle. Speed setpoints for engines with adjustable warm idle speed must include at least minimum warm idle speed, f_{idlemin} , and a speed at or above maximum warm idle speed, f_{idlemax} . Speed setpoints for engines with no adjustable idle speed must include at least warm idle speed (with zero torque on the primary output shaft), f_{idle} , and a speed at or above $1.15 \cdot f_{\text{idle}}$.

(2) Select the following torque setpoints at each speed setpoint to cover a range of values to represent in-use operation at idle:

(i) The minimum torque setpoint is zero.

(ii) Choose a maximum torque setpoint that is at least as large as the value determined by the following equation:

$$T_{\text{idlemaxest}} = \left(\frac{T_{\text{finstall}} \cdot f_{\text{idle}}^2}{f_{\text{finstall}}^2} + \frac{P_{\text{acc}}}{f_{\text{idle}}} \right) \cdot 1.1$$

Eq. 1036.535-3

Where:

T_{finstall} = the maximum engine torque at f_{finstall} .

f_{idle} = for engines with an adjustable warm idle speed, use the maximum warm idle speed, f_{idlemax} . For engines without an adjustable warm idle speed, use warm idle speed, f_{idle} .

f_{finstall} = the stall speed of the torque converter; use f_{ntest} or 2250 r/min, whichever is lower.

P_{acc} = accessory power for the vehicle class; use 1500 W for Vocational Light HDV, 2500 W for Vocational Medium HDV, and 3500 W for Tractors and Vocational Heavy HDV. If your engine is going to be installed in multiple vehicle classes, perform the test with the accessory power for the largest vehicle class the engine will be installed in.

Example:

$$T_{\text{finstall}} = 1870 \text{ N}\cdot\text{m}$$

$$f_{\text{ntest}} = 1740.8 \text{ r/min} = 182.30 \text{ rad/s}$$

$$f_{\text{finstall}} = 1740.8 \text{ r/min} = 182.30 \text{ rad/s}$$

$$f_{\text{idle}} = 700 \text{ r/min} = 73.30 \text{ rad/s}$$

$$P_{\text{acc}} = 1500 \text{ W}$$

$$T_{\text{idlemaxest}} = \left(\frac{1870 \cdot 73.30^2}{182.30^2} + \frac{1500}{73.30} \right) \cdot 1.1$$

$$T_{\text{idlemaxest}} = 355.07 \text{ N}\cdot\text{m}$$

- (iii) Select one or more equally spaced intermediate torque setpoints, as needed, such that the increment between torque setpoints is no greater than one-ninth of $T_{\max, \text{mapped}}$.
- (e) *Correction for net energy content.* Correct the measured or calculated mean fuel mass flow rate, \bar{m}_{fuel} , for each test interval to a mass-specific net energy content of a reference fuel using the following equation:

$$\bar{m}_{\text{fuelcor}} = \bar{m}_{\text{fuel}} \cdot \frac{E_{\text{mfuelmeas}}}{E_{\text{mfuelCref}} \cdot w_{\text{Cref}}}$$

Eq. 1036.535-4

Where:

$E_{\text{mfuelmeas}}$ = the mass-specific net energy content of the test fuel as determined in § 1036.550(b)(1). Note that dividing this value by w_{Cref} (as is done in this equation) equates to a carbon-specific net energy content having the same units as $E_{\text{mfuelCref}}$.

$E_{\text{mfuelCref}}$ = the reference value of carbon-mass-specific net energy content for the appropriate fuel. Use the values shown in ~~t~~Table 1 in § 1036.550 for the designated fuel types, or values we approve for other fuel types.

w_{Cref} = the reference value of carbon mass fraction for the test fuel as shown in ~~t~~Table 1 of § 1036.550 for the designated fuels. For any fuel not identified in the table, use the reference carbon mass fraction of diesel fuel for engines subject to compression-ignition standards, and use the reference carbon mass fraction of gasoline for engines subject to spark-ignition standards.

Example:

$$\bar{m}_{\text{fuel}} = 0.933 \text{ g/s}$$

$$E_{\text{mfuelmeas}} = 42.7984 \text{ MJ/kg}$$

$$E_{\text{mfuelCref}} = 49.3112 \text{ MJ/kgC}$$

$$w_{\text{Cref}} = 0.874 \text{ kgC/kg}$$

$$\bar{m}_{\text{fuel}} = 0.933 \cdot \frac{42.7984}{49.3112 \cdot 0.874}$$

$$\bar{m}_{\text{fuel}} = 0.927 \text{ g/s}$$

- (f) *Measuring NO_x emissions.* Measure NO_x emissions for each sampling period in g/s. You may perform these measurements using a NO_x emission-measurement system that meets the requirements of 40 CFR part 1065, subpart J. If a system malfunction prevents you from measuring NO_x emissions during a test under this section but the test otherwise gives valid results, you may consider this a valid test and omit the NO_x emission measurements; however, we may require you to repeat the test if we determine that you inappropriately voided the test with respect to NO_x emission measurement.
- (g) *Measured vs. declared fuel consumption.* Determine declared fuel consumption as follows:
- (1) Select fuel consumption rates in g/s to characterize the engine's fuel maps. You must select a declared value for each test point that is at or above the corresponding value determined in paragraphs (b) through (d) of this section, including those from redundant measurements.
 - (2) Declared fuel consumption serves as emission standards under § 1036.108. These are the values that vehicle manufacturers will use for certification under 40 CFR part 1037. Note that production engines are subject to GEM cycle-weighted limits as described in § 1036.301.

(3) If you perform the carbon balance error verification, select declared values that are at or above the following emission measurements:

- (i) If you pass the ϵ_{rC} verification, you may use the average of the values from direct and indirect fuel measurements.
- (ii) If you fail ϵ_{rC} verification, but pass either the ϵ_{aC} or ϵ_{aCrate} verification, use the value from indirect fuel measurement.
- (iii) If you fail all three verifications, you must either void the test interval or use the highest value from direct and indirect fuel measurements. Note that we will consider our test results to be invalid if we fail all three verifications.

§ 1036.540 Determining cycle-average engine fuel maps.

(a) *Overview.* This section describes how to determine an engine's cycle-average fuel maps for model year 2021 and later vehicles. Vehicle manufacturers may need cycle-average fuel maps for transient duty cycles, highway cruise cycles, or both to demonstrate compliance with emission standards under 40 CFR part 1037. Generate cycle-average engine fuel maps as follows:

- (1) Determine the engine's torque maps as described in § 1036.505(c).
- (2) Determine the engine's steady-state fuel map and fuel consumption at idle as described in § 1036.535. If you are applying cycle-average fuel mapping for highway cruise cycles, you may instead use GEM's default fuel map instead of generating the steady-state fuel map in § 1036.535(b).
- (3) Simulate several different vehicle configurations using GEM (see 40 CFR 1037.520) to create new engine duty cycles as described in paragraph (c) of this section. The transient vehicle duty cycles for this simulation are in 40 CFR part 1037, appendix A; the highway cruise cycles with grade are in 40 CFR part 1037, appendix D. Note that GEM simulation relies on vehicle service classes as described in 40 CFR 1037.140.
- (4) Test the engines using the new duty cycles to determine fuel consumption, cycle work, and average vehicle speed as described in paragraph (d) of this section and establish GEM inputs for those parameters for further vehicle simulations as described in paragraph (e) of this section.

(b) *General test provisions.* The following provisions apply for testing under this section:

(1) ~~To perform fuel mapping under this section for hybrid engines, make sure the engine and its hybrid features are appropriately configured to represent the hybrid features in your testing.~~

~~(2)~~ Measure NO_x emissions for each specified sampling period in grams. You may perform these measurements using a NO_x emission-measurement system that meets the requirements of 40 CFR part 1065, subpart J. Include these measured NO_x values any time you report to us your fuel-consumption values from testing under this section. If a system malfunction prevents you from measuring NO_x emissions during a test under this section but the test otherwise gives valid results, you may consider this a valid test and omit the NO_x emission measurements; however, we may require you to repeat the test if we determine that you inappropriately voided the test with respect to NO_x emission measurement.

~~(3)~~ The provisions related to carbon balance error verification in § 1036.543 apply for all testing in this section. These procedures are optional, but we will perform carbon balance error verification for all testing under this section.

~~(4)~~ Correct fuel mass to a mass-specific net energy content of a reference fuel as described in paragraph (d)(13) of this section.

(45) This section uses engine parameters and variables that are consistent with 40 CFR part 1065.

(c) *Create engine duty cycles.* Use GEM to simulate your engine operation with several different vehicle configurations to create transient and highway cruise engine duty cycles corresponding to each vehicle configuration as follows:

(1) Set up GEM to simulate your engine’s operation based on your engine’s torque maps, steady-state fuel maps, warm-idle speed as defined in 40 CFR 1037.520(h)(1), and fuel consumption at idle as described in paragraphs (a)(1) and (2) of this section.

(2) Set up GEM with transmission parameters for different vehicle service classes and vehicle duty cycles. Specify the transmission’s torque limit for each gear as the engine’s maximum torque as determined in 40 CFR 1065.510. Specify the transmission type as Automatic Transmission for all engines and for all engine and vehicle duty cycles, except that the transmission type is Automated Manual Transmission for Heavy HDE operating over the highway cruise cycles or the SET duty cycle. For automatic transmissions set neutral idle to “Y” in the vehicle file. Select gear ratios for each gear as shown in the following table:

TABLE 1 TO PARAGRAPH (c)(2) OF § 1036.540—GEM INPUT FOR GEAR RATIO

Gear Number	Spark-ignition HDE, Light HDE, and Medium HDE— All Engine and Vehicle Duty Cycles	Heavy HDE— Transient and FTP Duty Cycles	Heavy HDE— Cruise and SET Duty Cycles
1	3.10	3.51	12.8
2	1.81	1.91	9.25
3	1.41	1.43	6.76
4	1.00	1.00	4.90
5	0.71	0.74	3.58
6	0.61	0.64	2.61
7	—	—	1.89
8	—	—	1.38
9	—	—	1.00
10	—	—	0.73
Lockup Gear	3	3	—

(3) Run GEM for each simulated vehicle configuration and use the GEM outputs of instantaneous engine speed and engine flywheel torque for each vehicle configuration to generate a 10 Hz transient duty cycle corresponding to each vehicle configuration operating over each vehicle duty cycle. Run GEM for the specified number of vehicle configurations. You may run additional vehicle configurations to represent a wider range of in-use vehicles. Run GEM as follows:

(i) Determining axle ratio and tire size. Set the axle ratio, k_a , and tire size, $\frac{f_{ntire}}{v_{vehicle}}$, for each vehicle configuration based on the corresponding designated engine speed (f_{nrefA} , f_{nrefB} , f_{nrefC} , f_{nrefD} , or f_{ntest} as defined in 40 CFR 1065.610(c)(2)) at 65 mi/hr for the transient duty cycle and for the 65 mi/hr highway cruise cycle. Similarly, set these parameters based on the corresponding designated engine speed at 55 mi/hr for the 55 mi/hr highway cruise cycle. Use one of the following equations to determine $\frac{f_{ntire}}{v_{vehicle}}$ and k_a at each of the defined engine speeds:

(A) Select a value for $\left[\frac{f_{ntire}}{v_{vehicle}}\right]_{[speed]}$ and solve for $k_{a[speed]}$ using the following equation:

$$k_{a[speed]} = \frac{f_{n[speed]}}{\left[\frac{f_{ntire}}{v_{vehicle}}\right]_{[speed]} \cdot k_{topgear} \cdot v_{ref}}$$

Eq. 1036.540-1

Where:

$f_{n[speed]}$ = engine's angular speed as determined in paragraph (c)(3)(ii) or (iii) of this section.

$k_{topgear}$ = transmission gear ratio in the highest available gear from Table 1 of this section.

v_{ref} = reference speed. Use 65 mi/hr for the transient cycle and the 65 mi/hr highway cruise cycle and use 55 mi/hr for the 55 mi/hr highway cruise cycle.

(B) Select a value for $k_{a[speed]}$ and solve for $\left[\frac{f_{ntire}}{v_{vehicle}}\right]_{[speed]}$ using the following equation:

$$\left[\frac{f_{ntire}}{v_{vehicle}}\right]_{[speed]} = \frac{f_{n[speed]}}{k_{a[speed]} \cdot k_{topgear} \cdot v_{ref}}$$

Eq. 1036.540-2

Example for a vocational Light HDV or vocational Medium HDV with a 6-speed automatic transmission at B speed (Test 3 or 4 in Table 3 of this section):

$$f_{nrefB} = 1870 \text{ r/min} = 31.17 \text{ r/s}$$

$$k_{aB} = 4.0$$

$$k_{topgear} = 0.61$$

$$v_{ref} = 65 \text{ mi/hr} = 29.06 \text{ m/s}$$

$$\left[\frac{f_{ntire}}{v_{vehicle}}\right]_B = \frac{31.17}{4.0 \cdot 0.61 \cdot 29.06}$$

$$\left[\frac{f_{ntire}}{v_{vehicle}}\right]_B = 0.4396 \text{ r/m}$$

(ii) *Vehicle configurations for Spark-ignition HDE, Light HDE, and Medium HDE.* Test at least eight different vehicle configurations for engines that will be installed in vocational Light HDV or vocational Medium HDV using vehicles in the following table:

TABLE 2 TO PARAGRAPH (c)(3)(ii) OF § 1036.540—VEHICLE CONFIGURATIONS FOR TESTING SPARK-IGNITION HDE, LIGHT HDE, AND MEDIUM HDE

Parameter	1	2	3	4	5	6	7	8
C_{rr} (N/kN)	6.2	7.7	6.2	7.7	6.2	7.7	6.2	7.7
CI engine speed for $\frac{f_{ntire}}{v_{vehicle}}$ and k_a	f_{nrefA}	f_{nrefA}	f_{nrefB}	f_{nrefB}	f_{nrefC}	f_{nrefC}	f_{ntest}	f_{ntest}
SI engine speed for $\frac{f_{ntire}}{v_{vehicle}}$ and k_a	f_{nrefD}	f_{nrefD}	f_{nrefA}	f_{nrefA}	f_{nrefB}	f_{nrefB}	f_{nrefC}	f_{nrefC}
Drive Axle Configuration	4x2	4x2	4x2	4x2	4x2	4x2	4x2	4x2
GEM Regulatory Subcategory	LHD	MHD	LHD	MHD	LHD	MHD	LHD	MHD

(iii) *Vehicle configurations for Heavy HDE.* Test at least nine different vehicle configurations for engines that will be installed in vocational Heavy HDV and for tractors that are not heavy-haul tractors. Test six different vehicle configurations for engines that will be installed in heavy-haul tractors. Use the settings specific to each vehicle configuration as shown in Table 3 or Table 4 in this section, as appropriate. Engines subject to testing under both Table 3 and Table 4 in this section need not repeat overlapping vehicle configurations, so complete fuel mapping requires testing 12 (not 15) vehicle configurations for those engines. However, the preceding sentence does not apply if you choose to create two separate maps from the vehicle configurations defined in Table 3 and Table 4 in this section. Tables 3 and 4 follow:

TABLE 3 TO PARAGRAPH (c)(3)(iii) OF § 1036.540—VEHICLE CONFIGURATIONS FOR TESTING HEAVY HDE INSTALLED IN GENERAL PURPOSE TRACTORS AND VOCATIONAL HEAVY HDV

Parameter	1	2	3	4	5	6	7	8	9
C_{rr} (N/kN)	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
C_{dA}	5.4	4.7	4.0	5.4	4.7	4.0	5.4	4.7	4.0
Engine speed for $\frac{f_{ntire}}{v_{vehicle}}$ and k_a	f_{nrefD}	f_{nrefD}	f_{nrefD}	f_{nrefB}	f_{nrefB}	f_{nrefB}	f_{nrtest}	f_{nrtest}	f_{nrtest}
Drive Axle Configuration	6x4	6x4	4x2	6x4	6x4	4x2	6x4	6x4	4x2
GEM Regulatory Subcategory	C8_SC_HR	C8_DC_MR	C7_DC_MR	C8_SC_HR	C8_DC_MR	C7_DC_MR	C8_SC_HR	C8_DC_MR	C7_DC_MR
Vehicle Weight Reduction (lbs)	0	13,275	6,147	0	13,275	6,147	0	13,275	6,147

TABLE 4 TO PARAGRAPH (c)(3)(iii) OF § 1036.540—VEHICLE CONFIGURATIONS FOR TESTING HEAVY HDE INSTALLED IN HEAVY-HAUL TRACTORS

Parameter	1	2	3	4	5	6
C_{rr} (N/kN)	6.9	6.9	6.9	6.9	6.9	6.9
C_{dA}	5.0	5.4	5.0	5.4	5.0	5.4
Engine speed for $\frac{f_{ntire}}{v_{vehicle}}$ and k_a	f_{nrefD}	f_{nrefD}	f_{nrefB}	f_{nrefB}	f_{ntest}	f_{ntest}
Drive Axle Configuration	6x4	6x4	6x4	6x4	6x4	6x4
GEM Regulatory Subcategory	C8_HH	C8_SC_HR	C8_HH	C8_SC_HR	C8_HH	C8_SC_HR

(iv) *Vehicle configurations for mixed-use engines.* If the engine will be installed in a combination of vehicles defined in paragraphs (c)(3)(ii) and (iii) of this section, use good engineering judgment to select at least nine vehicle configurations from Table 2 and Table 3 in this section that best represent the range of vehicles your engine will be sold in. This may require you to define additional representative vehicle configurations. For example, if your engines will be installed in vocational Medium HDV and vocational Heavy HDV, you might select Tests 2, 4, 6 and 8 of Table 2 in this section to represent vocational Medium HDV and Tests 3, 6, and 9 of Table 3 in this section to represent vocational Heavy HDV and add two more vehicle configurations that you define.

(v) *Defining GEM inputs.* Use the defined values in Tables 1 through 4 in this section to set up GEM with the correct regulatory subcategory and vehicle weight reduction.

(d) *Test the engine with GEM cycles.* Test the engine over each of the ~~transient~~ engine duty cycles generated in paragraph (c) of this section as follows:

(1) Operate the engine over a sequence of required and optional engine duty cycles as follows:

(i) Sort the list of engine duty cycles into three separate groups by vehicle duty cycle: transient vehicle cycle, 55 mi/hr highway cruise cycle, and 65 mi/hr highway cruise cycle.

(ii) Within each group of engine duty cycles derived from the same vehicle duty cycle, first run the engine duty cycle with the highest reference cycle work, followed by the cycle with the lowest cycle work; followed by the cycle with second-highest cycle work, followed by the cycle with the second-lowest cycle work; continuing through all the cycles for that vehicle duty cycle. The series of engine duty cycles to represent a single vehicle duty cycle is a single fuel-mapping sequence. Each engine duty cycle represents a different interval. Repeat the fuel-mapping sequence for the engine duty cycles derived from the other vehicle duty cycles until testing is complete.

(iii) Operate the engine over two full engine duty cycles to precondition before each interval in the fuel-mapping sequence. Precondition the engine before the first and second engine duty cycle in each fuel-mapping sequence by repeating operation with the engine duty cycle with the highest reference cycle work over the relevant vehicle duty cycle. The preconditioning for the remaining cycles in the fuel-mapping sequence consists of operation over the preceding two engine duty cycles in the fuel-mapping sequence (with or without measurement). For transient vehicle duty cycles, start each engine duty cycle within 10 seconds after finishing the preceding engine duty cycle (with or without measurement). For highway cruise cycles, start each engine duty cycle and interval after linearly ramping to the speed and torque setpoints over 5 seconds and stabilizing for 15 seconds.

(2) If the engine has an adjustable warm idle speed setpoint, set it to the value defined in 40 CFR 1037.520(h)(1).

(3) Control speed and torque to meet the cycle validation criteria in 40 CFR 1065.514 for each interval, except that the standard error of the estimate in ~~Table 2 of~~ 40 CFR

1065.514(f)(3) is the only speed criterion that applies if the range of reference speeds is less than 10 percent of the mean reference speed. For spark-ignition gaseous-fueled engines with fuel delivery at a single point in the intake manifold, you may apply the ~~statistical-alternative~~ [cycle-validation](#) criteria in Table 5 in this section for transient testing. Note that 40 CFR part 1065 does not allow reducing cycle precision to a lower frequency than the 10 Hz reference cycle generated by GEM.

TABLE 5 TO PARAGRAPH (c)(3) OF § 1036.540— ~~ALTERNATIVE FUEL-MAPPING CYCLE-VALIDATION STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES FOR SPARK-IGNITION GASEOUS-FUELED SPARK-IGNITION ENGINES^a~~

Parameter	Speed	Torque	Power
Slope, a_1	—	—	—
Absolute value of intercept, $ a_0 $	—	$\leq 3\%$ of maximum mapped torque	—
Standard error of the estimate, SEE	—	$\leq 15\%$ of maximum mapped torque	$\leq 15\%$ of maximum mapped power
Coefficient of determination, r^2	—	≥ 0.700	≥ 0.750

^a~~Statistical Cycle-validation~~ criteria apply as specified in 40 CFR 1065.514 unless otherwise specified.

- (4) Record measurements using direct and/or indirect measurement of fuel flow as follows:
- (i) *Direct fuel-flow measurement.* Record speed and torque and measure fuel consumption with a fuel flow meter for the interval defined by the engine duty cycle. Determine the corresponding mean values for the interval. Use of redundant direct fuel-flow measurements requires our advance approval.
 - (ii) *Indirect fuel-flow measurement.* Record speed and torque and measure emissions and other inputs needed to run the chemical balance in 40 CFR 1065.655(c) for the interval defined by the engine duty cycle. Determine the corresponding mean values for the interval. Use of redundant indirect fuel-flow measurements requires our advance approval. Measure background concentration as described in 40 CFR 1065.140, except that you may use one of the following methods to apply a single background reading to multiple intervals:
 - (A) If you use batch sampling to measure background emissions, you may sample periodically into the bag over the course of multiple intervals. If you use this provision, you must apply the same background readings to correct emissions from each of the applicable intervals.
 - (B) You may determine background emissions by sampling from the dilution air over multiple engine duty cycles. If you use this provision, you must allow sufficient time for stabilization of the background measurement; followed by an averaging period of at least 30 seconds. Use the average of the two background readings to correct the measurement from each engine duty cycle. The first background reading must be taken no greater than 30 minutes before the start of the first applicable engine duty cycle and the second background reading must be taken no later than 30 minutes after the end of the last applicable engine duty cycle. Background readings may not span more than a full fuel-mapping sequence for a vehicle duty cycle.
- (5) Warm up the engine as described in 40 CFR 1065.510(b)(2). Within 60 seconds after concluding the warm-up, start the linear ramp of speed and torque over 20 seconds to the first speed and torque setpoint of the preconditioning cycle.
- (6) Precondition the engine before the start of testing as described in paragraph (d)(1)(iii) of this section.
- (7) Operate the engine over the first engine duty cycle. Record measurements during the interval. Measure and report NO_x emissions over each interval as described in paragraph (b)(2) of this section.

(8) Continue testing engine duty cycles that are derived from the other vehicle duty cycles until testing is complete.

(9) You may interrupt the fuel-mapping sequence after completing any interval. You may calibrate analyzers, read and evacuate background bag samples, or sample dilution air for measuring background concentration before restarting. Shut down the engine during any interruption. If you restart the sequence within 30 minutes or less, restart the sequence at paragraph (d)(6) of this section and then restart testing at the next interval in the fuel-mapping sequence. If you restart the sequence after more than 30 minutes, restart the sequence at paragraph (d)(5) of this section and then restart testing at the next interval in the fuel-mapping sequence.

(10) The following provisions apply for infrequent regeneration events, other interruptions during intervals, and otherwise voided intervals:

(i) Stop testing if an infrequent regeneration event occurs during an interval or an interval is interrupted for any other reason. Void the interrupted interval and any additional intervals for which you are not able to meet requirements for measuring background concentration. If the infrequent regeneration event occurs between intervals, void completed intervals only if you are not able to meet requirements for measuring background concentration for those intervals.

(ii) If an infrequent regeneration event occurs, allow the regeneration event to finish with the engine operating at a speed and load that allows effective regeneration.

(iii) If you interrupt testing during an interval, if you restart the sequence within 30 minutes or less, restart the sequence at paragraph (d)(6) of this section and then restart testing at the next interval in the fuel-mapping sequence. If you restart the sequence after more than 30 minutes, restart the sequence at paragraph (d)(5) of this section and then restart testing at the next interval in the fuel-mapping sequence.

(iv) If you void one or more intervals, you must perform additional testing to get results for all intervals. You may rerun a complete fuel-mapping sequence or any contiguous part of the fuel-mapping sequence. If you get a second valid measurement for any interval, use only the result from the last valid interval. If you restart the sequence within 30 minutes or less, restart the sequence at paragraph (d)(6) of this section and then restart testing at the first selected interval in the fuel-mapping sequence. If you restart the sequence after more than 30 minutes, restart the sequence at paragraph (d)(5) of this section and then restart testing at the first selected interval in the fuel-mapping sequence. Continue testing until you have valid results for all intervals. The following examples illustrate possible scenarios for a partial run through a fuel-mapping sequence:

(A) If you voided only the interval associated with the fourth engine duty cycle in the sequence, you may restart the sequence using the second and third engine duty cycles as the preconditioning cycles and stop after completing the interval associated with the fourth engine duty cycle.

(B) If you voided the intervals associated with the fourth and sixth engine duty cycles, you may restart the sequence using the second and third engine duty cycles for preconditioning and stop after completing the interval associated with the sixth engine duty cycle.

(11) You may send signals to the engine controller during the test, such as current transmission gear and vehicle speed, if that allows engine operation to better represent in-use operation.

(12) Calculate the fuel mass, m_{fuel} , for each duty cycle using one of the following equations:

(i) Determine fuel-consumption using emission measurements from the raw or diluted exhaust. Calculate the mass of fuel for each duty cycle, $m_{\text{fuel}[\text{cycle}]}$, as follows:

(A) For calculations that use continuous measurement of emissions and continuous CO₂ from urea, calculate $m_{\text{fuel}[\text{cycle}]}$ using the following equation:

$$m_{\text{fuel}[\text{cycle}]} = \frac{M_C}{w_{C\text{meas}}} \cdot \left(\sum_{i=1}^N \left(\dot{n}_{\text{exh}i} \cdot \frac{x_{C\text{combdry}i}}{1 + x_{\text{H}_2\text{Oexhdry}i}} \cdot \Delta t \right) - \frac{1}{M_{\text{CO}_2}} \sum_{i=1}^N (\dot{m}_{\text{CO}_2\text{DEF}i} \cdot \Delta t) \right)$$

Eq. 1036.540-3

Where:

M_C = molar mass of carbon.

$w_{C\text{meas}}$ = carbon mass fraction of fuel (or mixture of fuels) as determined in 40 CFR 1065.655(d), except that you may not use the default properties in [Table 2 of 40 CFR 1065.655\(e\)\(5\)](#) to determine α , β , and w_C . You may not account for the contribution to α , β , γ , and δ of diesel exhaust fluid or other non-fuel fluids injected into the exhaust.

i = an indexing variable that represents one recorded emission value.

N = total number of measurements over the duty cycle.

$\dot{n}_{\text{exh}i}$ = exhaust molar flow rate from which you measured emissions [according to 40 CFR 1065.655](#).

$x_{C\text{combdry}i}$ = amount of carbon from fuel and any injected fluids in the exhaust per mole of dry exhaust as determined in 40 CFR 1065.655(c).

$x_{\text{H}_2\text{Oexhdry}i}$ = amount of H₂O in exhaust per mole of exhaust as determined in 40 CFR 1065.655(c).

$\Delta t = 1/f_{\text{record}}$

M_{CO_2} = molar mass of carbon dioxide.

$\dot{m}_{\text{CO}_2\text{DEF}i}$ = mass emission rate of CO₂ resulting from diesel exhaust fluid decomposition over the duty cycle as determined from § 1036.535(b)(9). If your engine does not utilize diesel exhaust fluid for emission control, or if you choose not to perform this correction, set $\dot{m}_{\text{CO}_2\text{DEF}i}$ equal to 0.

Example:

$M_C = 12.0107$ g/mol

$w_{C\text{meas}} = 0.867$

$N = 6680$

$\dot{n}_{\text{exh}1} = 2.876$ mol/s

$\dot{n}_{\text{exh}2} = 2.224$ mol/s

$x_{C\text{combdry}1} = 2.61 \cdot 10^{-3}$ mol/mol

$x_{C\text{combdry}2} = 1.91 \cdot 10^{-3}$ mol/mol

$x_{\text{H}_2\text{Oexh}1} = 3.53 \cdot 10^{-2}$ mol/mol

$x_{\text{H}_2\text{Oexh}2} = 3.13 \cdot 10^{-2}$ mol/mol

$f_{\text{record}} = 10$ Hz

$\Delta t = 1/10 = 0.1$ s

$M_{\text{CO}_2} = 44.0095$ g/mol

$\dot{m}_{\text{CO}_2\text{DEF}1} = 0.0726$ g/s

$\dot{m}_{\text{CO}_2\text{DEF}2} = 0.0751$ g/s

$$m_{\text{fueltransientTest1}} = \frac{12.0107}{0.867} \cdot \left(\begin{aligned} &2.876 \cdot \frac{2.61 \cdot 10^{-3}}{1 + 3.53 \cdot 10^{-2}} \cdot 0.1 + \\ &2.224 \cdot \frac{1.91 \cdot 10^{-3}}{1 + 3.13 \cdot 10^{-2}} \cdot 0.1 + \\ &\left(\dots + \dot{n}_{\text{exh6680}} \cdot \frac{x_{\text{Ccombdry6680}}}{1 + x_{\text{H2Oexhdry6680}}} \cdot \Delta t_{6680} \right) \\ &\left(-\frac{1}{44.0095} \cdot (0.0726 \cdot 1.0 + 0.0751 \cdot 1.0 + \dots + \dot{m}_{\text{CO2DEF6680}} \cdot \Delta t_{6680}) \right) \end{aligned} \right)$$

$$m_{\text{fueltransientTest1}} = 1619.6 \text{ g}$$

(B) If you measure batch emissions and continuous CO₂ from urea, calculate $m_{\text{fuel[cycle]}}$ using the following equation:

$$m_{\text{fuel[cycle]}} = \frac{M_C}{w_{\text{Cmeas}}} \cdot \left(\frac{\bar{x}_{\text{Ccombdry}}}{1 + \bar{x}_{\text{H2Oexhdry}}} \cdot \sum_{i=1}^N (\dot{n}_{\text{exhi}} \cdot \Delta t) - \frac{1}{M_{\text{CO2}}} \sum_{i=1}^N (\dot{m}_{\text{CO2DEF}i} \cdot \Delta t) \right)$$

Eq. 1036.540-4

(C) If you measure continuous emissions and batch CO₂ from urea, calculate $m_{\text{fuel[cycle]}}$ using the following equation:

$$m_{\text{fuel[cycle]}} = \frac{M_C}{w_{\text{Cmeas}}} \cdot \left(\sum_{i=1}^N \left(\dot{n}_{\text{exhi}} \cdot \frac{x_{\text{Ccombdry}i}}{1 + x_{\text{H2Oexhdry}i}} \cdot \Delta t \right) - \frac{m_{\text{CO2DEF}}}{M_{\text{CO2}}} \right)$$

Eq. 1036.540-5

(D) If you measure batch emissions and batch CO₂ from urea, calculate $m_{\text{fuel[cycle]}}$ using the following equation:

$$m_{\text{fuel[cycle]}} = \frac{M_C}{w_{\text{Cmeas}}} \cdot \left(\frac{\bar{x}_{\text{Ccombdry}}}{1 + \bar{x}_{\text{H2Oexhdry}}} \cdot \sum_{i=1}^N (\dot{n}_{\text{exhi}} \cdot \Delta t) - \frac{m_{\text{CO2DEF}}}{M_{\text{CO2}}} \right)$$

Eq. 1036.540-6

(ii) Manufacturers may choose to measure fuel mass flow rate. Calculate the mass of fuel for each duty cycle, $m_{\text{fuel[cycle]}}$, as follows:

$$m_{\text{fuel}} = \sum_{i=1}^N \dot{m}_{\text{fuel}i} \cdot \Delta t$$

Eq. 1036.540-7

Where:

i = an indexing variable that represents one recorded value.

N = total number of measurements over the duty cycle. For batch fuel mass measurements, set $N = 1$.

$\dot{m}_{\text{fuel}i}$ = the fuel mass flow rate, for each point, i , starting from $i = 1$.

$\Delta t = 1/f_{\text{record}}$

f_{record} = the data recording frequency.

Example:

$N = 6680$

$$\begin{aligned} \dot{m}_{\text{fuel}1} &= 1.856 \text{ g/s} \\ \dot{m}_{\text{fuel}2} &= 1.962 \text{ g/s} \\ f_{\text{record}} &= 10 \text{ Hz} \\ \Delta t &= 1/10 = 0.1 \text{ s} \\ m_{\text{fueltransient}} &= (1.856 + 1.962 + \dots + \dot{m}_{\text{fuel}6680}) \cdot 0.1 \\ m_{\text{fueltransient}} &= 111.95 \text{ g} \end{aligned}$$

(13) Correct the measured or calculated fuel mass, m_{fuel} , for each result to a mass-specific net energy content of a reference fuel as described in § 1036.535(e), replacing \bar{m}_{fuel} with m_{fuel} in Eq. 1036.535-4.

(e) *Determine GEM inputs.* Use the results of engine testing in paragraph (d) of this section to determine the GEM inputs for the transient duty cycle and optionally for each of the highway cruise cycles corresponding to each simulated vehicle configuration as follows:

- (1) Using the calculated fuel mass consumption values, $m_{\text{fuel}[\text{cycle}]}$, described in paragraph (d) of this section, declare values using the methods described in § 1036.535(g)(2) and (3).
- (2) We will determine $m_{\text{fuel}[\text{cycle}]}$ values using the method described in § 1036.535(g)(3).
- (3) For the transient cycle, calculate engine output speed per unit vehicle speed,

$\left[\frac{\bar{f}_{\text{engine}}}{\bar{v}_{\text{vehicle}}} \right]_{[\text{cycle}]}$, by taking the average engine speed measured during the engine test while the vehicle is moving and dividing it by the average vehicle speed provided by GEM. Note that the engine cycle created by GEM has a flag to indicate when the vehicle is moving.

(4) Determine engine idle speed and torque, by taking the average engine speed and torque measured during the engine test while the vehicle is not moving. Note that the engine cycle created by GEM has a flag to indicate when the vehicle is moving.

(5) For the cruise cycles, calculate the average engine output speed, \bar{f}_{engine} , and the average engine output torque (positive torque only), \bar{T}_{engine} , while the vehicle is moving. Note that the engine cycle created by GEM has a flag to indicate when the vehicle is moving.

(6) Determine positive work according to 40 CFR part 1065, $W_{[\text{cycle}]}$, by using the engine speed and engine torque measured during the engine test while the vehicle is moving. Note that the engine cycle created by GEM has a flag to indicate when the vehicle is moving.

(7) The following tables illustrate the GEM data inputs corresponding to the different vehicle configurations for a given duty cycle:

- (i) For the transient cycle:

TABLE 6 TO PARAGRAPH (e)(7)(i) OF § 1036.540—GENERIC EXAMPLE OF AN OUTPUT MATRIX FOR TRANSIENT CYCLE VEHICLE CONFIGURATIONS

Parameter	Configuration					
	1	2	3	4	...	<i>n</i>
$m_{\text{fuel}[\text{cycle}]}$						
$\left[\frac{\bar{f}_{\text{engine}}}{\bar{v}_{\text{vehicle}}} \right]_{[\text{cycle}]}$						
$W_{[\text{cycle}]}$						
\bar{f}_{idle}						
\bar{T}_{idle}						

- (ii) For the cruise cycles:

TABLE 7 TO PARAGRAPH (e)(7)(ii) OF § 1036.540 – GENERIC EXAMPLE OF AN OUTPUT MATRIX FOR CRUISE CYCLE VEHICLE CONFIGURATIONS

Parameter	Configuration					
	1	2	3	4	...	<i>n</i>
$m_{\text{fuel}}[\text{cycle}]$						
$\bar{f}_{\text{engine}}[\text{cycle}]$						
$\bar{T}_{\text{engine}}[\text{cycle}]$						
W_{cycle}						

§ 1036.543 Carbon balance error verification.

The optional carbon balance error verification in 40 CFR 1065.543 compares independent assessments of the flow of carbon through the system (engine plus aftertreatment). This procedure applies for each individual interval in §§ 1036.535(b), (c), and (d), ~~and 1036.540,~~ and ~~1036.545~~[40 CFR 1037.550](#).

§ ~~1036.545~~[1037.550](#) Powertrain testing.

This section describes the procedure to measure fuel consumption and create engine fuel maps by testing a powertrain that includes an engine coupled with a transmission, drive axle, and hybrid components or any assembly with one or more of those hardware elements. Engine fuel maps are part of demonstrating compliance with Phase 2 ~~and Phase 3~~ vehicle standards under ~~this part~~[40 CFR part 1037](#); the powertrain test procedure in this section is one option for generating this fuel-mapping information as described in ~~§40 CFR~~ 1036.505. Additionally, this powertrain test procedure is one option for certifying ~~hybrids, engines, and hybrid powertrains~~ to the engine standards in ~~§§40 CFR~~ [1036.104](#) and 1036.108.

(a) *General test provisions.* The following provisions apply broadly for testing under this section:

- (1) Measure NO_x emissions as described in paragraph (k) of this section. Include these measured NO_x values any time you report to us your greenhouse gas emissions or fuel consumption values from testing under this section.
- (2) The procedures of 40 CFR part 1065 apply for testing in this section except as specified. This section uses engine parameters and variables that are consistent with 40 CFR part 1065.
- (3) Powertrain testing depends on models to calculate certain parameters. You can use the detailed equations in this section to create your own models, or use the GEM HIL model contained within GEM Phase 2, Version 4.0 (incorporated by reference, ~~see in~~ [§40 CFR 10367.810](#)) to simulate vehicle hardware elements as follows:
 - (i) Create driveline and vehicle models that calculate the angular speed setpoint for the test cell dynamometer, $f_{\text{nref,dyno}}$, based on the torque measurement location. Use the detailed equations in paragraph (f) of this section, the GEM HIL model's driveline and vehicle submodels, or a combination of the equations and the submodels. You may use the GEM HIL model's transmission submodel in paragraph (f) of this section to simulate a transmission only if testing hybrid engines. [For hybrid engines intended for vehicles with automatic transmissions, update the driver_in_gear signal within the driver interface block in the GEM HIL model with the transmission state \(in-gear or idle\) as a function of time as defined by the duty cycles in this part.](#)

(ii) Create a driver model or use the GEM HIL model's driver submodel to simulate a human driver modulating the throttle and brake pedals to follow the test cycle as closely as possible.

(iii) Create a cycle-interpolation model or use the GEM HIL model's cycle submodel to interpolate the duty-cycles and feed the driver model the duty-cycle reference vehicle speed for each point in the duty-cycle.

(4) The powertrain test procedure in this section is designed to simulate operation of different vehicle configurations over specific duty cycles. See paragraphs (h) and (j) of this section.

(5) For each test run, record engine speed and torque as defined in 40 CFR 1065.915(d)(5) with a minimum sampling frequency of 1 Hz. These engine speed and torque values represent a duty cycle that can be used for separate testing with an engine mounted on an engine dynamometer under [40 CFR§ 1037.551](#), such as for a selective enforcement audit as described in [40 CFR§ 1037.301](#).

(6) For hybrid powertrains with no plug-in capability, correct for the net energy change of the energy storage device as described in 40 CFR 1066.501(a)(3). For plug-in hybrid electric powertrains, follow 40 CFR 1066.501(a)(3) to determine End-of-Test for charge-depleting operation. You must get our approval in advance for your utility factor curve; we will approve it if you can show that you created it, using good engineering judgment, from sufficient in-use data of vehicles in the same application as the vehicles in which the plug-in hybrid electric powertrain will be installed. You may use methodologies described in SAE J2841 (~~incorporated by reference in § 1037.810~~) to develop the utility factor curve.

(7) The provisions related to carbon balance error verification in ~~§40-CFR~~ 1036.543 apply for all testing in this section. These procedures are optional if you are only performing direct or indirect fuel-flow measurement, but we will perform carbon balance error verification for all testing under this section.

(8) Do not apply accessory loads when conducting a powertrain test to generate inputs to GEM if torque is measured at the axle input shaft or wheel hubs.

(9) If you test a powertrain over the [Low Load Cycle duty cycle](#) specified in ~~§40-CFR~~ 1036.514, control and apply the electrical accessory loads, using one of the following systems:

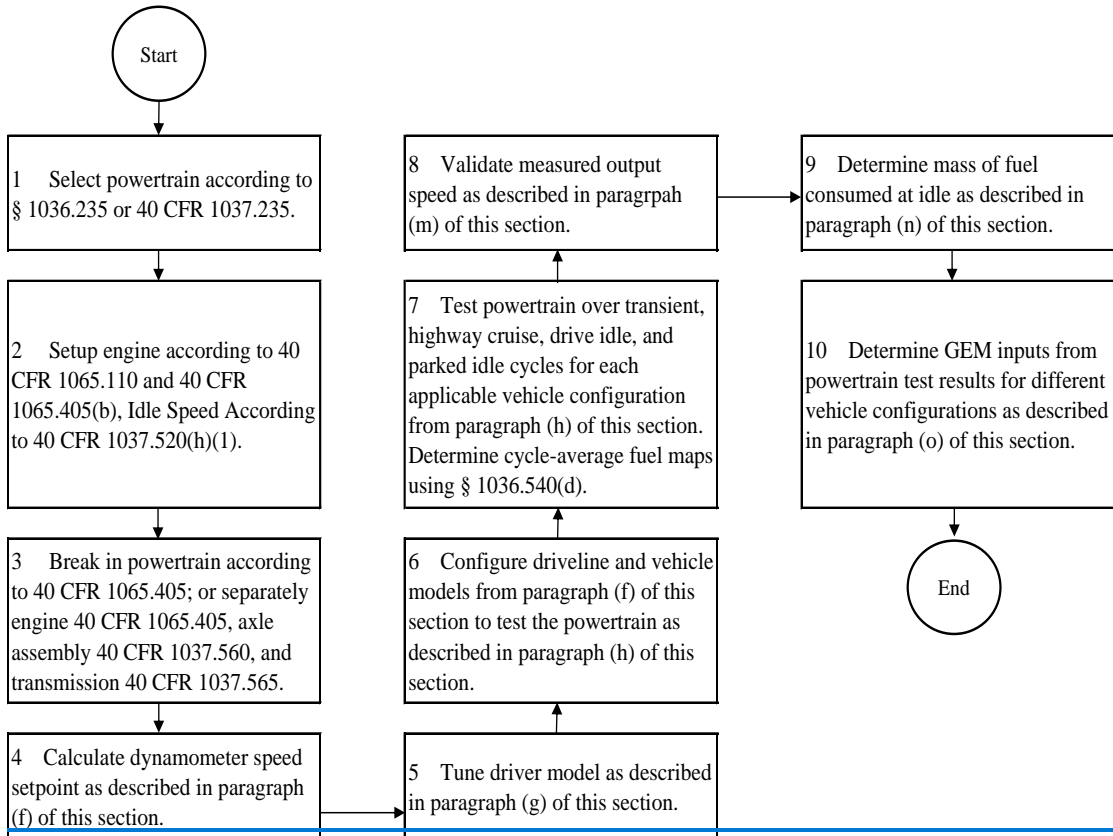
~~(i) We recommend using a load bank connected directly to the powertrain's electrical system. An alternator with dynamic electrical load control.~~ (ii) You may instead use an alternator with dynamic electrical load control. Use good engineering judgment to account for the efficiency of the alternator or the efficiency of the powertrain to convert the mechanical energy to electrical energy. ~~A load bank connected directly to the powertrain's electrical system.~~

(10) The following instruments are required with plug-in hybrid systems to determine required voltages and currents during testing and must be installed on the powertrain to measure these values during testing:

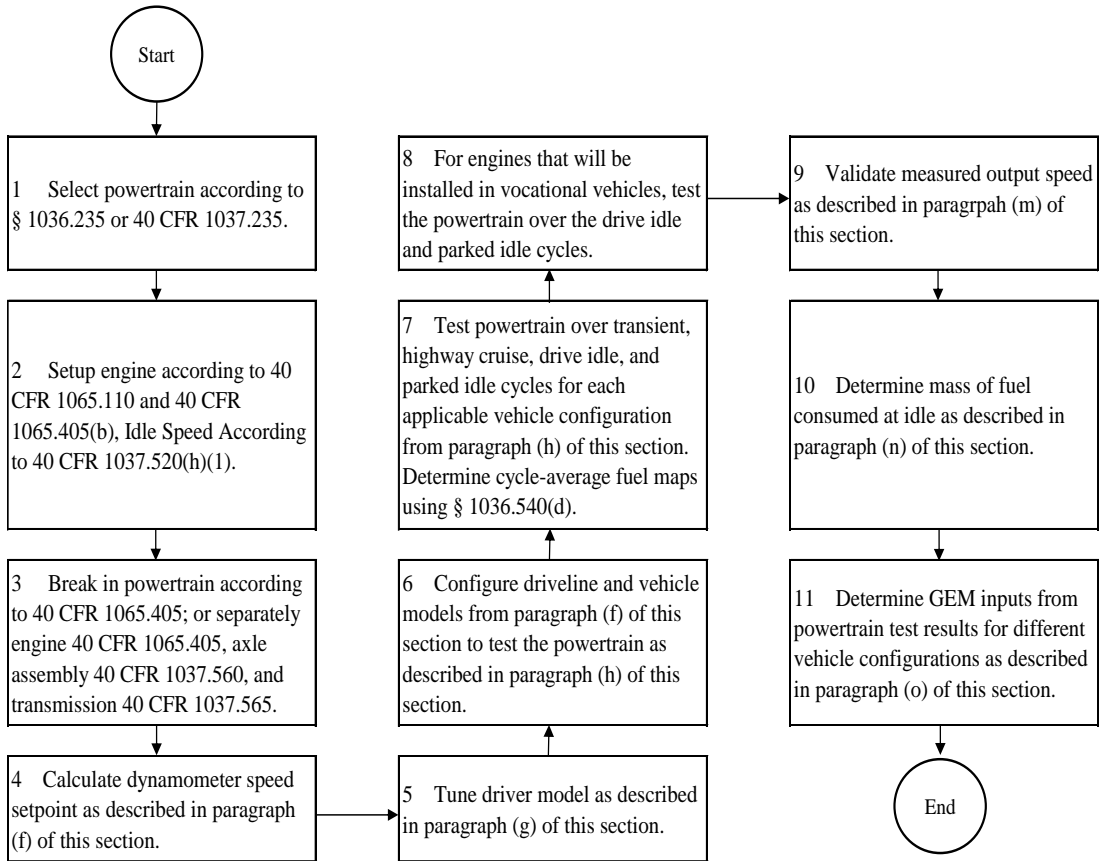
(i) Measure the voltage and current of the battery pack directly with a DC wideband power analyzer to determine power. Measure all current entering and leaving the battery pack. Do not measure voltage upstream of this measurement point. The maximum integration period for determining amp-hours is 0.05 seconds. The power analyzer must have an accuracy for measuring current and voltage of 1 % of point or 0.3 % of maximum, whichever is greater. The power analyzer must not be susceptible to offset errors while measuring current.

(ii) If safety considerations do not allow for measuring voltage, you may determine the voltage directly from the powertrain ECM.

(11) The following figure provides an overview of ~~the steps involved in carrying out testing~~ under this section:



Duty Cycle Exceptions	Note
SET, FTP, LLC	1) Do not compensate the duty cycle for the distance driven in step 5 2) Disregard duty cycles in step 7. 3) For cycles that begin with idle, leave the transmission in neutral or park for the full initial idle segment. Place the transmission into drive no earlier than 5 seconds before the first nonzero vehicle speed setpoint. 4) Use the vehicle parameters in § 1036.505(b)(2)(i) to (ix) to define the vehicle model in § 1036.545(a)(3)
SET Specific	1) For SET testing only, place the transmission into park or neutral when the cycle reaches the final idle segment. 2) Select the transmission from Table 1 of § 1036.540, substituting “engine” for “vehicle” and “highway cruise cycle” for “SET”.
FTP Specific	1) Replace Pcontrated with Prated, which is the peak rated power determined in § 1036.527 2) Keep the transmission in drive for all idle segments after the initial idle segment 3) For hybrid engines, select the transmission from Table 1 of § 1036.540, substituting “engine” for “vehicle”. 4) For hybrid engines, you may request to change the engine-commanded torque at idle to better represent curb idle transmission torque (CITT)
LLC Specific	1) Replace Pcontrated with Prated, which is the peak rated power determined in § 1036.527. 2) Keep the transmission in drive for all idle segments 200 seconds or less. For idle segments more than 200 seconds, place the transmission in park or neutral at the start of the idle segment and place the transmission into drive again no earlier than 5 seconds before the first nonzero vehicle speed setpoint. 3) For hybrid engines, you may request to change the engine-commanded torque at idle to better represent curb idle transmission torque (CITT). 4) For plug-in hybrid engines and powertrains, determine criteria pollutant and greenhouse gas emissions as described in § 1036.505(d) and (e), replacing “SET” with “LLC”.



Duty Cycle Exceptions

SET, FTP, LLC

SET Specific

FTP Specific

LLC Specific

Note

- 1) Do not compensate the duty cycle for the distance driven in step 5.
- 2) Disregard duty cycles in step 7.
- 3) For cycles that begin with idle, leave the transmission in neutral or park for the full initial idle segment. Place the transmission into drive no earlier than 5 seconds before the first nonzero vehicle speed setpoint.
- 4) Use the vehicle parameters in § 1036.505(b)(2)(i) to (viii) to define the vehicle model in § 1036.545(a)(3).

- 1) For SET testing only, place the transmission into park or neutral when the cycle reaches the final idle segment.
- 2) Select the transmission from Table 1 of § 1036.540.

- 1) Replace $P_{\text{contrated}}$ with P_{rated} which is the peak rated power determined in § 1036.520.
- 2) Keep the transmission in drive for all idle segments after the initial idle segment.
- 3) For hybrid engines, select the transmission from Table 1 of § 1036.540.
- 4) For hybrid engines, you may request to change the engine-commanded torque at idle to better represent curb idle transmission torque (CITT).

- 1) Replace $P_{\text{contrated}}$ with P_{rated} which is the peak rated power determined in § 1036.520.
- 2) Keep the transmission in drive for all idle segments 200 seconds or less. For idle segments more than 200 seconds, place the transmission in park or neutral at the start of the idle segment and place the transmission into drive again no earlier than 5 seconds before the first nonzero vehicle speed setpoint.
- 3) For hybrid engines, you may request to change the engine-commanded torque at idle to better represent curb idle transmission torque (CITT).
- 4) For plug-in hybrid engines and powertrains, determine criteria pollutant and greenhouse gas emissions as described in § 1036.510(d) and (e), replacing "SET" with "LLC".

(b) *Test configuration.* Select a powertrain for testing as described in [§ 1036.235](#) or ~~§ 40 CFR 1037.235~~ or ~~§ 40 CFR 1036.235~~ as applicable. Set up the engine according to 40 CFR 1065.110 and ~~40 CFR 1065.405~~(b). Set the engine's idle speed to idle speed defined in [40 CFR § 1037.520\(h\)\(1\)](#).

(1) The default test configuration consists of a powertrain with all components upstream of the axle. This involves connecting the powertrain's output shaft directly to the dynamometer or to a gear box with a fixed gear ratio and measuring torque at the axle input shaft. You may instead set up the dynamometer to connect at the wheel hubs and measure torque at that location. The preceding sentence may apply if your powertrain configuration requires it, such as for hybrid powertrains or if you want to represent the axle performance with powertrain test results. [You may alternatively test the powertrain with a chassis dynamometer if as long as you measure speed and torque at the powertrain's output shaft or wheel hubs.](#)

(2) For testing hybrid engines, connect the engine's crankshaft directly to the dynamometer and measure torque at that location.

(c) *Powertrain temperatures during testing.* Cool the powertrain during testing so temperatures for oil, coolant, block, head, transmission, battery, and power electronics are within the manufacturer's expected ranges for normal operation. You may use electronic control module outputs to comply with this paragraph (c). You may use auxiliary coolers and fans.

(d) *Engine break in.* Break in the engine according to 40 CFR 1065.405, the axle assembly according to [40 CFR § 1037.560](#), and the transmission according to [40 CFR § 1037.565](#). You may instead break in the powertrain as a complete system using the engine break in procedure in 40 CFR 1065.405.

(e) *Dynamometer setup.* Set the dynamometer to operate in speed-control mode (or torque-control mode for hybrid engine testing at idle, including idle portions of transient duty cycles). Record data as described in 40 CFR 1065.202. Command and control the dynamometer speed at a minimum of 5 Hz, or 10 Hz for testing ~~engine~~-hybrid ~~engine~~s. Run the vehicle model to calculate the dynamometer setpoints at a rate of at least 100 Hz. If the dynamometer's command frequency is less than the vehicle model dynamometer setpoint frequency, subsample the calculated setpoints for commanding the dynamometer setpoints.

(f) *Driveline and vehicle model.* Use the GEM HIL model's driveline and vehicle submodels or the equations in this paragraph (f) to calculate the dynamometer speed setpoint, $f_{\text{ref},\text{dyno}}$, based on the torque measurement location. For all powertrains, configure GEM with the accessory load set to zero. For hybrid engines, configure GEM with the applicable accessory load as specified in ~~§ 40 CFR 1036.505~~, ~~and 1036.514~~, and [1036.525](#). For all powertrains and hybrid engines, configure GEM with the tire slip model disabled.

(1) *Driveline model with a transmission in hardware.* For testing with torque measurement at the axle input shaft or wheel hubs, calculate, $f_{\text{ref},\text{dyno}}$, using the GEM HIL model's driveline submodel or the following equation:

$$f_{\text{ref},\text{dyno}} = \frac{k_{\text{a}[\text{speed}]} \cdot v_{\text{ref}i}}{2 \cdot \pi \cdot r_{[\text{speed}]}}$$

Eq. ~~1036.545+1037.550-1~~

Where:

$k_{\text{a}[\text{speed}]}$ = drive axle ratio as determined in paragraph (h) of this section. Set $k_{\text{a}[\text{speed}]}$ equal to 1.0 if torque is measured at the wheel hubs.

$v_{\text{ref}i}$ = simulated vehicle reference speed as calculated in paragraph (f)(3) of this section.

$r_{[\text{speed}]}$ = tire radius as determined in paragraph (h) of this section.

(2) *Driveline model with a simulated transmission.* For testing with the torque measurement at the engine's crankshaft, $f_{nref,dyno}$ is the dynamometer target speed from the GEM HIL model's transmission submodel. You may request our approval to change the transmission submodel, as long as the changes do not affect the gear selection logic. Before testing, initialize the transmission model with the engine's measured torque curve and the applicable steady-state fuel map from the GEM HIL model. You may request our approval to input your own steady-state fuel map. For example, this request for approval could include using a fuel map that represents the combined performance of the engine and hybrid components. Configure the torque converter to simulate neutral idle when using this procedure to generate engine fuel maps in §40-CFR 1036.505 or to perform the Supplemental Emission Test (SET) testing under §40-CFR 1036.510. You may change engine commanded torque at idle to better represent CITT for transient testing under §40-CFR 1036.512. You may change the simulated engine inertia to match the inertia of the engine under test. We will evaluate your requests under this paragraph (f)(2) based on your demonstration that ~~that~~ the adjusted testing better represents in-use operation.

(i) The transmission submodel needs the following model inputs:

- (A) Torque measured at the engine's crankshaft.
- (B) Engine estimated torque determined from the electronic control module or by converting the instantaneous operator demand to an instantaneous torque in N·m.
- (C) Dynamometer mode when idling (speed-control or torque-control).
- (D) Measured engine speed when idling.
- (E) Transmission output angular speed, $f_{ni,transmission}$, calculated as follows:

$$f_{ni,transmission} = \frac{k_{a[speed]} \cdot v_{refi}}{2 \cdot \pi \cdot r_{[speed]}}$$

Eq. ~~1036.545+1037.550-2~~

Where:

$k_{a[speed]}$ = drive axle ratio as determined in paragraph (h) of this section.

v_{refi} = simulated vehicle reference speed as calculated in paragraph (f)(3) of this section.

$r_{[speed]}$ = tire radius as determined in paragraph (h) of this section.

(ii) The transmission submodel generates the following model outputs:

- (A) Dynamometer target speed.
- (B) Dynamometer idle load.
- (C) Transmission engine load limit.
- (D) Engine speed target.

(3) *Vehicle model.* Calculate the simulated vehicle reference speed, v_{refi} , using the GEM HIL model's vehicle submodel or the equations in this paragraph (f)(3):

$$v_{refi} = \left(\frac{k_a \cdot T_{i-1}}{r} \cdot (Eff_{axle}) - \left(M \cdot g \cdot C_{rr} \cdot \cos(\text{atan}(G_{i-1})) + \frac{\rho \cdot C_d A}{2} \cdot v_{ref,i-1}^2 \right) - F_{brake,i-1} - F_{grade,i-1} \right) \cdot \frac{\Delta t_{i-1}}{M + M_{rotating}} + v_{ref,i-1}$$

Eq. ~~1036.545+1037.550-3~~

Where:

i = a time-based counter corresponding to each measurement during the sampling period. Let $v_{\text{ref}1} = 0$; start calculations at $i = 2$. A 10-minute sampling period will generally involve 60,000 measurements.

T = instantaneous measured torque at the axle input, measured at the wheel hubs, or simulated by the GEM HIL model's transmission submodel. For configurations with multiple torque measurements, for example such as when measuring torque at the wheel hubs, T is the sum of all torque measurements.

Eff_{axle} = axle efficiency. Use $\text{Eff}_{\text{axle}} = 0.955$ for $T \geq 0$, and use $\text{Eff}_{\text{axle}} = 1/0.955$ for $T < 0$. Use $\text{Eff}_{\text{axle}} = 1.0$ if torque is measured at the wheel hubs.

M = vehicle mass for a vehicle class as determined in paragraph (h) of this section.

g = gravitational constant = 9.80665 m/s².

C_{rr} = coefficient of rolling resistance for a vehicle class as determined in paragraph (h) of this section.

G_{i-1} = the percent grade interpolated at distance, D_{i-1} , from the duty cycle in [40 CFR part 1037](#), appendix D, ~~to this part~~ corresponding to measurement ($i-1$).

$$D_{i-1} = \sum_{i=1}^N (v_{\text{ref},i-1} \cdot \Delta t_{i-1})$$

Eq. ~~1036.545+1037.550-4~~

ρ = air density at reference conditions. Use $\rho = 1.1845$ kg/m³.

$C_d A$ = drag area for a vehicle class as determined in paragraph (h) of this section.

$F_{\text{brake},i-1}$ = instantaneous braking force applied by the driver model.

$F_{\text{grade},i-1} = M \cdot g \cdot \sin(\text{atan}(G_{i-1}))$

Eq. ~~1036.545+1037.550-5~~

Δt = the time interval between measurements. For example, at 100 Hz, $\Delta t = 0.0100$ seconds.

M_{rotating} = inertial mass of rotating components. Let $M_{\text{rotating}} = 340$ kg for vocational Light HDV or vocational Medium HDV. See paragraph (h) of this section for tractors and for vocational Heavy HDV.

(4) *Example.* The following example illustrates a calculation of $f_{\text{nref,dyno}}$ using paragraph (f)(1) of this section where torque is measured at the axle input shaft. This example is for a vocational Light HDV or vocational Medium HDV with 6 speed automatic transmission at B speed (Test 4 in Table 1 to paragraph (h)(2)(ii) of this section).

$k_{\text{aB}} = 4.0$

$r_{\text{B}} = 0.399$ m

$T_{999} = 500.0$ N·m

$C_{\text{rr}} = 7.7$ N/kN = $7.7 \cdot 10^{-3}$ N/N

$M = 11408$ kg

$C_d A = 5.4$ m²

$G_{999} = 0.39$ % = 0.0039

$$D_{999} = \sum_{i=0}^{998} (19.99 \cdot 0.01 + 20.0 \cdot 0.01 + \dots + v_{\text{ref},998} \cdot \Delta t_{998}) = 1792 \text{ m}$$

$$F_{\text{brake},999} = 0 \text{ N}$$

$$v_{\text{ref},999} = 20.0 \text{ m/s}$$

$$F_{\text{grade},999} = 11408 \cdot 9.81 \cdot \sin(\text{atan}(0.0039)) = 436.5 \text{ N}$$

$$\Delta t = 0.0100 \text{ s}$$

$$M_{\text{rotating}} = 340 \text{ kg}$$

$$v_{\text{ref}1000} =$$

$$\left(\frac{4.0 \cdot 500.0}{0.399} \cdot (0.955) - \left((11408 \cdot 9.80665 \cdot 7.7 \cdot 10^{-3} \cdot \cos(\text{atan}(0.0039))) + \frac{1.1845 \cdot 5.4}{2} \cdot 20.0^2 \right) - 0 - 436.5 \right) \cdot \frac{0.0100}{11408 + 340} + 20.0 v_{\text{ref}1000}$$

$$v_{\text{ref}1000} = 20.00189 \text{ m/s}$$

$$f_{\text{nref}1000,\text{dyno}} = \frac{4.0 \cdot 20.00189}{2 \cdot 3.14 \cdot 0.399}$$

$$f_{\text{nref}1000,\text{dyno}} = 31.93 \text{ r/s} = 1915.8 \text{ r/min}$$

(g) *Driver model.* Use the GEM HIL model's driver submodel or design a driver model to simulate a human driver modulating the throttle and brake pedals. In either case, tune the model to follow the test cycle as closely as possible meeting the following specifications:

(1) The driver model must meet the following speed requirements:

(i) For operation over the highway cruise cycles, the speed requirements described in 40 CFR 1066.425(b) and (c).

(ii) For operation over the [Heavy-Duty Ttransient Test Cycle](#) specified in [40 CFR part 1037](#), appendix A ~~of this part~~, the SET as defined ~~§40-CFR~~ 1036.510, the Federal Test Procedure (FTP) as defined in ~~§40-CFR~~ 1036.512, and the Low Load Cycle (LLC) as defined in ~~§40-CFR~~ 1036.514, the speed requirements described in 40 CFR 1066.425(b) and (c).

(iii) The exceptions in 40 CFR 1066.425(b)(4) apply to the highway cruise cycles, the [Heavy-Duty Ttransient Test Cycle](#) specified in [40 CFR part 1037](#), appendix A ~~of this part~~, SET, FTP, and LLC.

(iv) If the speeds do not conform to these criteria, the test is not valid and must be repeated.

(2) Send a brake signal when operator demand is zero and vehicle speed is greater than the reference vehicle speed from the test cycle. Include a delay before changing the brake signal to prevent dithering, consistent with good engineering judgment.

(3) Allow braking only if operator demand is zero.

(4) Compensate for the distance driven over the duty cycle over the course of the test. Use the following equation to perform the compensation in real time to determine your time in the cycle:

$$t_{\text{cycle}i} = \sum_{i=1}^N \left(\left(\frac{v_{\text{vehicle},i-1}}{v_{\text{cycle},i-1}} \right) \cdot \Delta t_{i-1} \right)$$

Eq. ~~1036.545+1037.550-6~~

Where:

v_{vehicle} = measured vehicle speed.

v_{cycle} = reference speed from the test cycle. If $v_{\text{cycle},i-1} < 1.0 \text{ m/s}$, set $v_{\text{cycle},i-1} = v_{\text{vehicle},i-1}$.

(h) *Vehicle configurations to evaluate for generating fuel maps as defined in §40-CFR 1036.505.* Configure the driveline and vehicle models from paragraph (f) of this section in the test cell to test the powertrain. Simulate multiple vehicle configurations that represent the range of intended vehicle applications using one of the following options:

(1) For known vehicle configurations, use at least three equally spaced axle ratios or tire sizes and three different road loads (nine configurations), or at least four equally spaced axle ratios or tire sizes and two different road loads (eight configurations). Select axle ratios to represent the full range of expected vehicle installations. Select axle ratios and tire sizes such that the ratio of engine speed to vehicle speed covers the range of ratios of minimum and maximum engine speed to vehicle speed when the transmission is in top gear for the vehicles in which the powertrain will be installed. Note that you do not have to use the same axle ratios and tire sizes for each GEM regulatory subcategory. You may determine appropriate C_{rr} , C_{dA} , and mass values to cover the range of intended vehicle applications or you may use the C_{rr} , C_{dA} , and mass values specified in paragraph (h)(2) of this section.

(2) If vehicle configurations are not known, determine the vehicle model inputs for a set of vehicle configurations as described in §40-CFR 1036.540(c)(3) with the following exceptions:

(i) In the equations of §40-CFR 1036.540(c)(3)(i), $k_{topgear}$ is the actual top gear ratio of the powertrain instead of the transmission gear ratio in the highest available gear given in tTable 1 in §40-CFR 1036.540.

(ii) Test at least eight different vehicle configurations for powertrains that will be installed in Spark-ignition HDE, vocational Light HDV, and vocational Medium HDV using the following table instead of tTable 2 in §40-CFR 1036.540:

TABLE 1 TO PARAGRAPH (h)(2)(ii) OF § ~~1036.545~~~~1037.550~~—VEHICLE CONFIGURATIONS FOR TESTING SPARK-IGNITION HDE, LIGHT HDE, AND MEDIUM HDE

Parameter	1	2	3	4	5	6	7	8
C_{rr} (N/kN)	6.2	7.7	6.2	7.7	6.2	7.7	6.2	7.7
C_{dA}	3.4	5.4	3.4	5.4	3.4	5.4	3.4	5.4
CI engine speed for $\frac{f_{ntire}}{v_{vehicle}}$ and k_a	f_{nrefA}	f_{nrefA}	f_{nrefB}	f_{nrefB}	f_{nrefC}	f_{nrefC}	f_{ntest}	f_{ntest}
SI engine speed for $\frac{f_{ntire}}{v_{vehicle}}$ and k_a	f_{nrefD}	f_{nrefD}	f_{nrefA}	f_{nrefA}	f_{nrefB}	f_{nrefB}	f_{nrefC}	f_{nrefC}
M (kg)	7,257	11,408	7,257	11,408	7,257	11,408	7,257	11,408
$M_{rotating}$ (kg)	340	340	340	340	340	340	340	340
Drive axle configuration ^a	4x2	4x2	4x2	4x2	4x2	4x2	4x2	4x2
GEM regulatory subcategory ^a	LHD	MHD	LHD	MHD	LHD	MHD	LHD	MHD

^aDrive axle configuration and GEM regulatory subcategory are not used if using the equations in paragraph (f)(3) of this section.

(iii) Select and test vehicle configurations as described in §40-CFR 1036.540(c)(3)(iii) for powertrains that will be installed in vocational Heavy HDV and tractors using the following tables instead of tTable 3 and tTable 4 in §40-CFR 1036.540:

TABLE 2 TO PARAGRAPH (h)(2)(iii) OF § ~~1036.545~~~~1037.550~~—VEHICLE CONFIGURATIONS FOR TESTING GENERAL PURPOSE TRACTORS AND VOCATIONAL HEAVY HDV

Parameter	1	2	3	4	5	6	7	8	9
C_{rr} (N/kN)	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
C_dA	5.4	4.7	4.0	5.4	4.7	4.0	5.4	4.7	4.0
Engine speed for $\frac{f_{ntire}}{v_{vehicle}}$ and k_a	f_{nrefD}	f_{nrefD}	f_{nrefD}	f_{nrefB}	f_{nrefB}	f_{nrefB}	f_{ntest}	f_{ntest}	f_{ntest}
M (kg)	31,978	25,515	19,051	31,978	25,515	19,051	31,978	25,515	19,051
$M_{rotating}$ (kg)	1,021	794	794	1,021	794	794	1,021	794	794
Drive axle configuration ^a	6x4	6x4	4x2	6x4	6x4	4x2	6x4	6x4	4x2
GEM regulatory subcategory ^a	C8_SC_HR	C8_DC_MR	C7_DC_MR	C8_SC_HR	C8_DC_MR	C7_DC_MR	C8_SC_HR	C8_DC_MR	C7_DC_MR
Vehicle weight reduction (lbs)	0	13,275	6,147	0	13,275	6,147	0	13,275	6,147

^aDrive axle configuration and GEM regulatory subcategory are not used if using the equations in paragraph (f)(3) of this section.

TABLE 3 TO PARAGRAPH (h)(2)(iii) OF § ~~1036.545~~~~1037.550~~—VEHICLE CONFIGURATIONS FOR TESTING HEAVY HDE INSTALLED IN HEAVY-HAUL TRACTORS

Parameter	1	2	3	4	5	6
C_{rr} (N/kN)	6.9	6.9	6.9	6.9	6.9	6.9
C_dA	5.0	5.4	5.0	5.4	5.0	5.4
Engine speed for $\frac{f_{ntire}}{v_{vehicle}}$ and k_a	f_{nrefD}	f_{nrefD}	f_{nrefB}	f_{nrefB}	f_{ntest}	f_{ntest}
M (kg)	53,751	31,978	53,751	31,978	53,751	31,978
$M_{rotating}$ (kg)	1,021	1,021	1,021	1,021	1,021	1,021
Drive axle configuration ^a	6x4	6x4	6x4	6x4	6x4	6x4
GEM regulatory subcategory ^a	C8_HH	C8_SC_HR	C8_HH	C8_SC_HR	C8_HH	C8_SC_HR

^aDrive axle configuration and GEM regulatory subcategory are not used if using the equations in paragraph (f)(3) of this section.

(3) For hybrid powertrain systems where the transmission will be simulated, use the transmission parameters defined in ~~§40-CFR~~ 1036.540(c)(2) to determine transmission type and gear ratio. Use a fixed transmission efficiency of 0.95. The GEM HIL transmission model uses a transmission parameter file for each test that includes the transmission type, gear ratios, lockup gear, torque limit per gear from ~~§40-CFR~~ 1036.540(c)(2), and the values from ~~§40-CFR~~ 1036.505(b)(4) and (c).

(i) [Reserved]

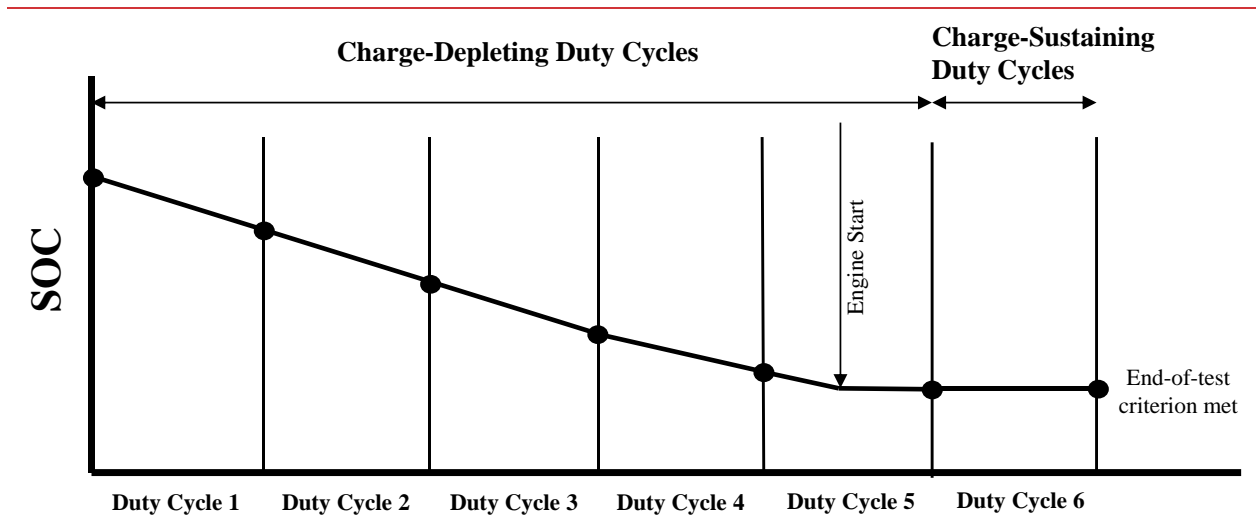
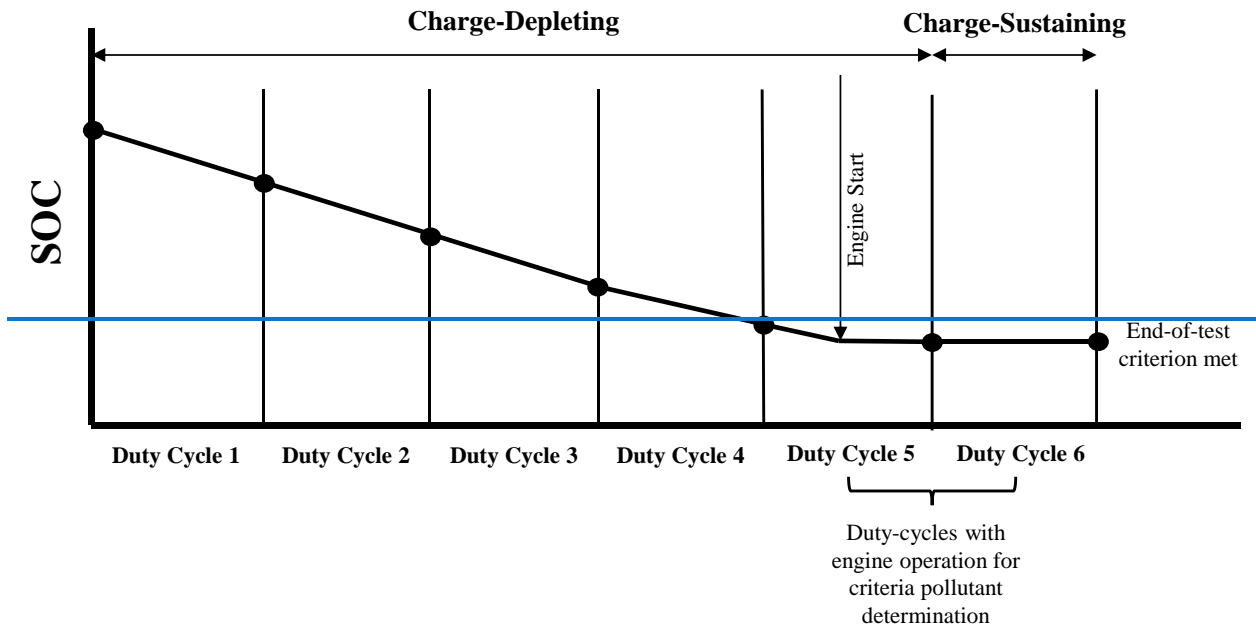
(j) *Duty cycles to evaluate.* Operate the powertrain over each of the duty cycles specified in ~~40 CFR~~ § 1037.510(a)(2), and for each applicable vehicle configuration from paragraph (h) of this section. Determine cycle-average powertrain fuel maps by testing the powertrain using the procedures in ~~§40-CFR~~ 1036.540(d) with the following exceptions:

- (1) Understand “engine” to mean “powertrain”.
- (2) Warm up the powertrain as described in ~~§40-CFR~~ 1036.520(ed)(1).

(3) Within 90 seconds after concluding the warm-up, start the transition to the preconditioning cycle as described in paragraph (j)(5) of this section.

(4) For plug-in hybrid engines, precondition the battery and then complete all back-to-back tests for each vehicle configuration according to 40 CFR 1066.501(a)(3) before moving to the next vehicle configuration. Figure 2 of this section provides an example of The following figure illustrates a charge-depleting test sequence with engine operation during where there are two duty cycles, which are used for criteria pollutant determination test intervals: that contain engine operation. Figure 2 follows:

FIGURE 2 TO PARAGRAPH (j)(4) OF § 1036.545—GENERIC DUTY CYCLE CHARGE-DEPLETING TEST SEQUENCE



(5) If the preceding duty cycle does not end at 0 mi/hr, transition between duty cycles by decelerating at a rate of 2 mi/hr/s at 0 % grade until the vehicle reaches zero speed. Shut off the powertrain. Prepare the powertrain and test cell for the next duty-cycle.

(6) Start the next duty-cycle within 60 to 180 seconds after shutting off the powertrain.

- (i) To start the next duty-cycle, for hybrid powertrains, key on the vehicle and then start the duty-cycle. For conventional powertrains key on the vehicle, start the engine, wait for the engine to stabilize at idle speed, and then start the duty-cycle.
- (ii) If the duty-cycle does not start at 0 mi/hr, transition to the next duty cycle by accelerating at a target rate of 1 mi/hr/s at 0 % grade. Stabilize for 10 seconds at the initial duty cycle conditions and start the duty-cycle.

(7) Calculate cycle work using GEM or the speed and torque from the driveline and vehicle models from paragraph (f) of this section to determine the sequence of duty cycles.

(8) Calculate the mass of fuel consumed for idle duty cycles as described in paragraph (n) of this section.

(k) *Measuring NO_x emissions.* Measure NO_x emissions for each sampling period in grams. You may perform these measurements using a NO_x emission-measurement system that meets the requirements of 40 CFR part 1065, subpart J. If a system malfunction prevents you from measuring NO_x emissions during a test under this section but the test otherwise gives valid results, you may consider this a valid test and omit the NO_x emission measurements; however, we may require you to repeat the test if we determine that you inappropriately voided the test with respect to NO_x emission measurement.

(l) [Reserved]

(m) *Measured output speed validation.* For each test point, validate the measured output speed with the corresponding reference values. ~~For test setups where~~ If speed is measured at multiple more than one locations, the measurements at each location must meet validation requirements~~the requirements in this paragraph (m).~~ If the range of reference speed is less than 10 percent of the mean reference speed, you need to meet only the standard error of the estimate in ~~t~~Table 4 of this section. You may delete points when the vehicle is stopped. If your speed measurement is not at the location of f_{nref} , correct your measured speed using the constant speed ratio between the two locations. Apply cycle-validation criteria for each separate transient or highway cruise cycle based on the following parameters:

TABLE 4 TO PARAGRAPH (m) OF § ~~1036.545~~1037.550— CYCLE-VALIDATION STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES

Parameter ^a	Speed Control
Slope, a_1	$0.990 \leq a_1 \leq 1.010$.
Absolute value of intercept, $ a_0 $	≤ 2.0 % of maximum f_{nref} speed.
Standard error of the estimate, SEE	≤ 2.0 % of maximum f_{nref} speed.
Coefficient of determination, r^2	≥ 0.990 .

^aDetermine values for specified parameters as described in 40 CFR 1065.514(e) by comparing measured and reference values for $f_{nref,dyno}$.

(n) *Fuel consumption at idle.* Record measurements using direct and/or indirect measurement of fuel flow. Determine the fuel-consumption rates at idle for the applicable duty cycles described in 40 CFR § 1037.510(a)(2) as follows:

- (1) *Direct fuel flow measurement.* Determine the corresponding mean values for mean idle fuel mass flow rate, $\bar{m}_{fuelidle}$, for each duty cycle, as applicable. Use of redundant direct fuel-flow measurements require our advance approval.
- (2) *Indirect fuel flow measurement.* Record speed and torque and measure emissions and other inputs needed to run the chemical balance in 40 CFR 1065.655(c). Determine the corresponding mean values for each duty cycle. Use of redundant indirect fuel-flow measurements require our advance approval. Measure background concentration as described in ~~§40 CFR~~ 1036.535(b)(4)(ii). We recommend setting the CVS flow rate as low as possible

to minimize background, but without introducing errors related to insufficient mixing or other operational considerations. Note that for this testing 40 CFR 1065.140(e) does not apply, including the minimum dilution ratio of 2:1 in the primary dilution stage. Calculate the idle fuel mass flow rate for each duty cycle, $\bar{m}_{\text{fuelidle}}$, for each set of vehicle settings, as follows:

$$\bar{m}_{\text{fuelidle}} = \frac{M_C}{w_{C\text{meas}}} \cdot \left(\bar{n}_{\text{exh}} \cdot \frac{\bar{x}_{C\text{combdry}}}{1 + \bar{x}_{\text{H}_2\text{Oexhdry}}} - \frac{\bar{m}_{\text{CO}_2\text{DEF}}}{M_{\text{CO}_2}} \right)$$

Eq. ~~1036.545+1037.550-7~~

Where:

M_C = molar mass of carbon.

$w_{C\text{meas}}$ = carbon mass fraction of fuel (or mixture of test fuels) as determined in 40 CFR 1065.655(d), except that you may not use the default properties in [Table 2 of 40 CFR 1065.655\(e\)\(5\)](#) to determine α , β , and w_C for liquid fuels.

\bar{n}_{exh} = the mean raw exhaust molar flow rate from which you measured emissions according to 40 CFR 1065.655.

$\bar{x}_{C\text{combdry}}$ = the mean concentration of carbon from fuel and any injected fluids in the exhaust per mole of dry exhaust.

$\bar{x}_{\text{H}_2\text{Oexhdry}}$ = the mean concentration of H₂O in exhaust per mole of dry exhaust.

$\bar{m}_{\text{CO}_2\text{DEF}}$ = the mean CO₂ mass emission rate resulting from diesel exhaust fluid decomposition over the duty cycle as determined in ~~§40-CFR~~ 1036.535(b)(9). If your engine does not use diesel exhaust fluid, or if you choose not to perform this correction, set $\bar{m}_{\text{CO}_2\text{DEF}}$ equal to 0.

M_{CO_2} = molar mass of carbon dioxide.

Example:

$$M_C = 12.0107 \text{ g/mol}$$

$$w_{C\text{meas}} = 0.867$$

$$\bar{n}_{\text{exh}} = 25.534 \text{ mol/s}$$

$$\bar{x}_{C\text{combdry}} = 2.805 \cdot 10^{-3} \text{ mol/mol}$$

$$\bar{x}_{\text{H}_2\text{Oexhdry}} = 3.53 \cdot 10^{-2} \text{ mol/mol}$$

$$\bar{m}_{\text{CO}_2\text{DEF}} = 0.0726 \text{ g/s}$$

$$M_{\text{CO}_2} = 44.0095$$

$$\bar{m}_{\text{fuelidle}} = \frac{12.0107}{0.867} \cdot \left(25.534 \cdot \frac{2.805 \cdot 10^{-3}}{1 + 3.53 \cdot 10^{-2}} - \frac{0.0726}{44.0095} \right)$$

$$\bar{m}_{\text{fuelidle}} = 0.405 \text{ g/s} = 1458.6 \text{ g/hr}$$

(o) *Create GEM inputs.* Use the results of powertrain testing to determine GEM inputs for the different simulated vehicle configurations as follows:

(1) Correct the measured or calculated fuel masses, $m_{\text{fuel}[\text{cycle}]}$, and mean idle fuel mass flow rates, $\bar{m}_{\text{fuelidle}}$, if applicable, for each test result to a mass-specific net energy content of a reference fuel as described in ~~§40-CFR~~ 1036.535(e), replacing \bar{m}_{fuel} with $m_{\text{fuel}[\text{cycle}]}$ where applicable in Eq. 1036.535-4.

(2) Declare fuel masses, $m_{\text{fuel}[\text{cycle}]}$ and $\bar{m}_{\text{fuelidle}}$. Determine $m_{\text{fuel}[\text{cycle}]}$ using the calculated fuel mass consumption values described in ~~§40-CFR~~ 1036.540(d)(12). In addition, declare mean

fuel mass flow rate for each applicable idle duty cycle, $\bar{m}_{\text{fuelidle}}$. These declared values may not be lower than any corresponding measured values determined in this section. If you use both direct and indirect measurement of fuel flow, determine the corresponding declared values as described in ~~§40-CFR~~ 1036.535(g)(2) and (3). These declared values, which serve as emission standards, collectively represent the powertrain fuel map for certification.

(3) For engines designed for plug-in hybrid electric vehicles, the mass of fuel for each cycle, $m_{\text{fuel[cycle]}}$, is the utility factor-weighted fuel mass, $m_{\text{fuelUF[cycle]}}$. This is determined by calculating m_{fuel} for the full charge-depleting and charge-sustaining portions of the test and weighting the results, using the following equation:

$$m_{\text{fuelUF[cycle]}} = \sum_{i=1}^N [m_{\text{fuel[cycle]CDi}} \cdot (UF_{\text{DCDi}} - UF_{\text{DCDi-1}})] + \sum_{j=1}^M [m_{\text{fuel[cycle]CSj}}] \cdot \frac{(1 - UF_{\text{RCD}})}{M}$$

Eq. ~~1036.545+1037.550-8~~

Where:

i = an indexing variable that represents one test interval.

N = total number of charge-depleting test intervals.

$m_{\text{fuel[cycle]CDi}}$ = total mass of fuel in the charge-depleting portion of the test for each test interval, i , starting from $i = 1$, including the test interval(s) from the transition phase.

UF_{DCDi} = utility factor fraction at distance D_{CDi} from Eq. ~~40-CFR-10367.51005-119~~ as determined by interpolating the approved utility factor curve for each test interval, i , starting from $i = 1$. Let $UF_{\text{DCD0}} = 0$

j = an indexing variable that represents one test interval.

M = total number of charge-sustaining test intervals.

$m_{\text{fuel[cycle]CSj}}$ = total mass of fuel over the charge-sustaining portion of the test for each test interval, j , starting from $j = 1$.

UF_{RCD} = utility factor fraction at the full charge-depleting distance, R_{CD} , as determined by interpolating the approved utility factor curve. R_{CD} is the cumulative distance driven over N charge-depleting test intervals.

$$D_{\text{CDi}} = \sum_{k=1}^Q (v_k \cdot \Delta t)$$

Eq. ~~1036.545+1037.550-9~~

Where:

k = an indexing variable that represents one recorded velocity value.

Q = total number of measurements over the test interval.

v = vehicle velocity at each time step, k , starting from $k = 1$. For tests completed under this section, v is the vehicle velocity as determined by Eq. ~~1036.545+1037.550-1~~. Note that this should include charge-depleting test intervals that start when the engine is not yet operating.

$\Delta t = 1/f_{\text{record}}$

f_{record} = the record rate.

Example for the 55 mi/hr cruise cycle:

$Q = 8790$

$v_1 = 55.0$ mi/hr

$v_2 = 55.0$ mi/hr

$$v_3 = 55.1 \text{ mi/hr}$$

$$f_{\text{record}} = 10 \text{ Hz}$$

$$\Delta t = 1/10 \text{ Hz} = 0.1 \text{ s}$$

$$D_{\text{CD1}} = \sum_{k=1}^{8790} (55.0 \cdot 0.1 + 55.0 \cdot 0.1 + 55.1 \cdot 0.1 + v_{8790} \cdot \Delta t) = 13.4 \text{ mi}$$

$$D_{\text{CD2}} = 13.4 \text{ mi}$$

$$D_{\text{CD3}} = 13.4 \text{ mi}$$

$$N = 3$$

$$UF_{\text{DCD1}} = 0.05$$

$$UF_{\text{DCD2}} = 0.11$$

$$UF_{\text{DCD3}} = 0.21$$

$$m_{\text{fuel55cruiseCD1}} = 0 \text{ g}$$

$$m_{\text{fuel55cruiseCD2}} = 0 \text{ g}$$

$$m_{\text{fuel55cruiseCD3}} = 1675.4 \text{ g}$$

$$M = 1$$

$$m_{\text{fuel55cruiseCS}} = 4884.1 \text{ g}$$

$$UF_{\text{RCD}} = 0.21$$

$$m_{\text{fuelUF55cruise}} = \frac{[0 \cdot (0.05 - 0) + 0 \cdot (0.11 - 0.05) + 1675.4 \cdot (0.21 - 0.11)] + 4884.1}{(1 - 0.21)}$$

$$m_{\text{fuelUF55cruise}} = 4026.0 \text{ g}$$

(4) For the transient cycle specified in [40 CFR§ 1037.510\(a\)\(2\)\(i\)](#), calculate powertrain output speed per unit of vehicle speed, $\left[\frac{\bar{f}_{\text{powertrain}}}{\bar{v}_{\text{powertrain}}} \right]_{\text{cycle}}$, using one of the following methods:

(i) For testing with torque measurement at the axle input shaft:

$$\left[\frac{\bar{f}_{\text{powertrain}}}{\bar{v}_{\text{powertrain}}} \right]_{\text{cycle}} = \frac{k_a}{2 \cdot \pi \cdot r_{\text{[speed]}}}$$

Eq. [1036.545+1037.550-10](#)

Example:

$$k_a = 4.0$$

$$r_B = 0.399 \text{ m}$$

$$\left[\frac{\bar{f}_{\text{powertrain}}}{\bar{v}_{\text{powertrain}}} \right]_{\text{transienttest4}} = \frac{4.0}{2 \cdot 3.14 \cdot 0.399}$$

$$\left[\frac{\bar{f}_{\text{powertrain}}}{\bar{v}_{\text{powertrain}}} \right]_{\text{transienttest4}} = 1.596 \text{ r/m}$$

(ii) For testing with torque measurement at the wheel hubs, use Eq. [1036.545+1037.550-8](#) setting k_a equal to 1.

(iii) For testing with torque measurement at the engine's crankshaft:

$$\left[\frac{\bar{f}_{\text{powertrain}}}{\bar{v}_{\text{powertrain}}} \right]_{\text{cycle}} = \frac{\bar{f}_{\text{engine}}}{\bar{v}_{\text{ref}}}$$

Eq. [1036.545+1037.550-11](#)

Where:

\bar{f}_{engine} = average engine speed when vehicle speed is at or above 0.100 m/s.

\bar{v}_{ref} = average simulated vehicle speed at or above 0.100 m/s.

Example:

$$\bar{f}_{\text{engine}} = 1870 \text{ r/min} = 31.17 \text{ r/s}$$

$$\bar{v}_{\text{ref}} = 19.06 \text{ m/s}$$

$$\left[\frac{\bar{f}_{\text{powertrain}}}{\bar{v}_{\text{powertrain}}} \right]_{\text{transienttest4}} = \frac{31.17}{19.06}$$

$$\left[\frac{\bar{f}_{\text{powertrain}}}{\bar{v}_{\text{powertrain}}} \right]_{\text{transienttest4}} = 1.635 \text{ r/m}$$

(5) Calculate engine idle speed, by taking the average engine speed measured during the transient cycle test while the vehicle speed is below 0.100 m/s. (Note: Use all the charge-sustaining test intervals when determining engine idle speed for [plug-in hybrid engines and plug-in hybrid](#) powertrains.)

(6) For the cruise cycles specified in [40 CFR§ 1037.510\(a\)\(2\)\(ii\)](#), calculate the average powertrain output speed, $\bar{f}_{\text{powertrain}}$, and the average powertrain output torque (positive torque only), $\bar{T}_{\text{powertrain}}$, at vehicle speed at or above 0.100 m/s. (Note: Use all the charge-sustaining and charge-depleting test intervals when determining $\bar{f}_{\text{powertrain}}$ and $\bar{T}_{\text{powertrain}}$ for [plug-in hybrid engines and plug-in hybrid](#) powertrains.)

(7) Calculate positive work, $W_{[\text{cycle}]}$, as the work over the duty cycle at the axle input shaft, wheel hubs, or the engine's crankshaft, as applicable, when vehicle speed is at or above 0.100 m/s. For [plug-in hybrid engines and plug-in hybrid](#) powertrains, calculate, $W_{[\text{cycle}]}$, by calculating the positive work over each of the charge-sustaining and charge-depleting test intervals and then averaging them together. [If For test setups where speed and torque are measured at more than one multiple locations, determine \$W_{\[\text{cycle}\]}\$ by integrating the sum of the power calculated from measured speed and torque measurements at each location.](#)

(8) The following tables illustrate the GEM data inputs corresponding to the different vehicle configurations for a given duty cycle:

(i) For the transient cycle:

TABLE 5 TO PARAGRAPH (o)(8)(i) OF § ~~1036.545~~[1037.550](#)—EXAMPLE OF OUTPUT MATRIX FOR TRANSIENT CYCLE VEHICLE CONFIGURATIONS

Parameter	Configuration					
	1	2	3	4	...	<i>n</i>
$m_{\text{fuel}[\text{cycle}]}$						
$\left[\frac{\bar{f}_{\text{powertrain}}}{\bar{v}_{\text{powertrain}}} \right]_{[\text{cycle}]}$						
$W_{[\text{cycle}]}$						
\bar{f}_{idle}						

(ii) For the cruise cycles:

TABLE 6 TO PARAGRAPH (o)(8)(ii) OF § ~~1036.545~~1037.550 – GENERIC EXAMPLE OF OUTPUT MATRIX FOR CRUISE CYCLE VEHICLE CONFIGURATIONS

Parameter	Configuration								
	1	2	3	4	5	6	7	...	n
$m_{\text{fuel[cycle]}}$									
$\bar{f}_{\text{npowertrain[cycle]}}$									
$\bar{T}_{\text{powertrain[cycle]}}$									
$W_{\text{[cycle]}}$									

(p) ~~Determining useable battery energy.~~ Determine usable battery energy (UBE) for plug-in hybrid powertrains using one of the following procedures: ~~usable battery energy (UBE) is defined as the total DC discharge energy, E_{DCDtotal} , measured in DC Watt hours, over the charge-depleting portion of the test sequence determined in paragraph (p)(2) of this section for the Heavy-duty Transient Test Cycle in 40 CFR part 1037, appendix A. Select a representative vehicle configuration from paragraph (h) of this section for determination of UBE. UBE represents the total deliverable energy the battery is capable of providing while a powertrain is following a duty cycle on a dynamometer.~~

(1) Select a representative vehicle configuration from paragraph (h) of this section. Measure DC discharge energy, E_{DCD} , in DC watt-hours and measure DC discharge current per hour, C_{D} , for the charge-depleting test intervals of the Heavy-Duty Transient Test Cycle in 40 CFR part 1037, appendix A. ~~The measurement period must include points must capture all the current flowing into and out of the battery pack during the charge-depleting test intervals~~ powertrain operation, including current associated with regenerative braking. Eq. 1036.545-12 shows how to calculate E_{DCD} , but the power analyzer specified in paragraph (a)(10)(i) of this section will typically perform this calculation internally. ~~The equation for calculating powertrain E_{DCD} is given in Eq. 1036.545-12, however, it is expected that this calculation will typically be performed internally by the power analyzer specified in paragraph (a)(10)(i) of this section.~~ Battery voltage measurements made by the powertrain's own on-board sensors (such as those available via with a diagnostic port) may be used for calculating E_{DCD} if ~~these measurements they~~ are equivalent to those produced by from the power analyzer.

$$E_{\text{DCD}} = \sum_{i=0}^N V_i \cdot I_i \cdot \Delta t$$

Eq. 1036.545-12

Where:

i = an indexing variable that represents one individual measurement.

N = total number of measurements.

V = battery DC bus voltage.

I = battery current.

$\Delta t = 1/f_{\text{record}}$

f_{record} = the data recording frequency.

Example:

$N = 13360$

$V_1 = 454.0$

$$V_2 = 454.0$$

$$I_1 = 0$$

$$I_2 = 0$$

$$f_{\text{record}} = 20 \text{ Hz}$$

$$\Delta t = 1/20 = 0.05 \text{ s}$$

$$E_{\text{DCD}} = \sum_{i=0}^{13360} (454.0 \cdot 0 + 454.0 \cdot 0 + \dots + V_{13360} \cdot I_{13360}) \cdot 0.05$$

$$E_{\text{DCD}} = 6540232.7 \text{ W}\cdot\text{s} = 1816.7 \text{ W}\cdot\text{hr}$$

(2) Determine a declared UBE that is at or below the corresponding value determined in paragraph (p)(1) of this section, including those from redundant measurements. This declared UBE serves as the initial-UBE_{certified} determined under 40 CFR 1037.115(f).

§ 1036.550 Calculating greenhouse gas emission rates.

This section describes how to calculate official emission results for CO₂, CH₄, and N₂O.

(a) Calculate brake-specific emission rates for each applicable duty cycle as specified in 40 CFR 1065.650. Apply infrequent regeneration adjustment factors as described in § 1036.580.

(b) Adjust CO₂ emission rates calculated under paragraph (a) of this section for measured test fuel properties as specified in this paragraph (b). This adjustment is intended to make official emission results independent of differences in test fuels within a fuel type. Use good engineering judgment to develop and apply testing protocols to minimize the impact of variations in test fuels.

(1) Determine your test fuel's mass-specific net energy content, $E_{\text{mfuelmeas}}$, also known as lower heating value, in MJ/kg, expressed to at least three decimal places. Determine $E_{\text{mfuelmeas}}$ as follows:

(i) For liquid fuels, determine $E_{\text{mfuelmeas}}$ according to ASTM D4809 (incorporated by reference, see in § 1036.810). Have the sample analyzed by at least three different labs and determine the final value of your test fuel's $E_{\text{mfuelmeas}}$ as the median of all the lab test results you obtained as described in 40 CFR 1065.602(m). If you have results from three different labs, we recommend you screen them to determine if additional observations are needed. To perform this screening, determine the absolute value of the difference between each lab result and the average of the other two lab results. If the largest of these three resulting absolute value differences is greater than 0.297 MJ/kg, we recommend you obtain additional results prior to determining the final value of $E_{\text{mfuelmeas}}$.

(ii) For gaseous fuels, determine $E_{\text{mfuelmeas}}$ according to ASTM D3588 (incorporated by reference, see in § 1036.810).

(2) Determine your test fuel's carbon mass fraction, w_c , as described in 40 CFR 1065.655(d), expressed to at least three decimal places; however, you must measure fuel properties for α and β rather than using the default values specified in Table 1 of 40 CFR 1065.655(e).

(i) For liquid fuels, have the sample analyzed by at least three different labs, determine w_c for each result as described in 40 CFR 1065.655(d), and determine the final value of your test fuel's w_c as the median (as described in 40 CFR 1065.602(m)) of all of the w_c values lab results you obtained as described in 40 CFR 1065.602(m). If you have results from three different labs, we recommend you screen them to determine if additional observations are needed. To perform this screening, determine the absolute value of the difference between each w_c value lab result and the average of the other two w_c values lab results. If the largest of these three resulting absolute value differences is greater than

1.56 percent carbon, we recommend you obtain additional results prior to determining the final value of w_C .

(ii) For gaseous fuels, have the sample analyzed by a single lab and use that result as your test fuel's w_C .

(3) If, over a period of time, you receive multiple fuel deliveries from a single stock batch of test fuel, you may use constant values for mass-specific energy content and carbon mass fraction, consistent with good engineering judgment. To use these constant values, you must demonstrate that every subsequent delivery comes from the same stock batch and that the fuel has not been contaminated.

(4) Correct measured CO₂ emission rates as follows:

$$e_{\text{CO}_2\text{cor}} = e_{\text{CO}_2} \cdot \frac{E_{\text{mfuelmeas}}}{E_{\text{mfuelCref}} \cdot w_{\text{Cmeas}}}$$

Eq. 1036.550-1

Where:

e_{CO_2} = the calculated CO₂ emission result.

$E_{\text{mfuelmeas}}$ = the mass-specific net energy content of the test fuel as determined in paragraph (b)(1) of this section. Note that dividing this value by w_{Cmeas} (as is done in this equation) equates to a carbon-specific net energy content having the same units as $E_{\text{mfuelCref}}$.

$E_{\text{mfuelCref}}$ = the reference value of carbon-mass-specific net energy content for the appropriate fuel type, as determined in Table 1 in this section.

w_{Cmeas} = carbon mass fraction of the test fuel (or mixture of test fuels) as determined in paragraph (b)(2) of this section.

Example:

$$e_{\text{CO}_2} = 630.0 \text{ g/hp}\cdot\text{hr}$$

$$E_{\text{mfuelmeas}} = 42.528 \text{ MJ/kg}$$

$$E_{\text{mfuelCref}} = 49.3112 \text{ MJ/kgC}$$

$$w_{\text{Cmeas}} = 0.870 \text{ kgC/kg}$$

$$e_{\text{CO}_2\text{cor}} = 630.0 \cdot \frac{42.528}{49.3112 \cdot 0.870}$$

$$e_{\text{CO}_2\text{cor}} = 624.5 \text{ g/hp}\cdot\text{hr}$$

TABLE 1 TO PARAGRAPH (b)(4) OF § 1036.550—REFERENCE FUEL PROPERTIES

Fuel type ^a	Reference fuel carbon-mass-specific net energy content, $E_{mfuelCref}$, (MJ/kgC) ^b	Reference fuel carbon mass fraction, w_{Cref} ^b
Diesel fuel	49.3112	0.874
Gasoline	50.4742	0.846
Natural gas	66.2910	0.750
LPG	56.5218	0.820
Dimethyl ether	55.3886	0.521
High-level ethanol-gasoline blends	50.3211	0.576

^aFor fuels that are not listed, you must ask us to approve reference fuel properties.

^bFor multi-fuel streams, such as natural gas with diesel fuel pilot injection, use good engineering judgment to determine blended values for $E_{mfuelCref}$ and w_{Cref} using the values in this table.

(c) Your official emission result for each pollutant equals your calculated brake-specific emission rate multiplied by all applicable adjustment factors, other than the deterioration factor.

§ 1036.555 Test procedures to verify deterioration factors.

Sections 1036.240 through 1036.246 describe certification procedures to determine, verify, and apply deterioration factors. This section describes the measurement procedures for verifying deterioration factors using PEMS with in-use vehicles.

(a) Use PEMS to collect 1 Hz data throughout a shift-day of driving. Collect all the data elements needed to determine brake-specific emissions. Calculate emission results using moving average windows as described in § 1036.530.

(b) Collect data as needed to perform the calculations specified in paragraph (a) of this section and to submit the test report specified in § 1036.246(d).

§ 1036.580 Infrequently regenerating aftertreatment devices.

For engines using aftertreatment technology with infrequent regeneration events that may occur during testing, take one of the following approaches to account for the emission impact of regeneration on criteria pollutant and greenhouse gas emissions:

(a) You may use the calculation methodology described in 40 CFR 1065.680 to adjust measured emission results. Do this by developing an upward adjustment factor and a downward adjustment factor for each pollutant based on measured emission data and observed regeneration frequency as follows:

- (1) Adjustment factors should generally apply to an entire engine family, but you may develop separate adjustment factors for different configurations within an engine family. Use the adjustment factors from this section for all testing for the engine family.
- (2) You may use carryover data to establish adjustment factors for an engine family as described in § 1036.235(d), consistent with good engineering judgment.
- (3) Identify the value of $F_{[cycle]}$ in each application for the certification for which it applies.
- (4) Calculate separate adjustment factors for each required duty cycle.

(b) You may ask us to approve an alternate methodology to account for regeneration events. We will generally limit approval to cases where your engines use aftertreatment technology with extremely infrequent regeneration and you are unable to apply the provisions of this section.

(c) You may choose to make no adjustments to measured emission results if you determine that regeneration does not significantly affect emission levels for an engine family (or configuration) or if it is not practical to identify when regeneration occurs. You may omit adjustment factors under this paragraph (c) for N₂O, CH₄, or other individual pollutants under this paragraph (c) as appropriate. If you choose not to make adjustments under paragraph (a) or (b) of this section, your engines must meet emission standards for all testing, without regard to regeneration.

(d) If your engine family includes engines with one or more emergency AECDs approved under § 1036.115(h)(4), do not consider additional regenerations resulting from those AECDs when developing adjustments to measured values under paragraph (a) or (b) of this section.

Subpart G—Special Compliance Provisions

§ 1036.601 Overview of compliance provisions.

(a) Engine and vehicle manufacturers, as well as owners, operators, and rebuilders of engines subject to the requirements of this part, and all other persons, must observe the provisions of this part, the provisions of 40 CFR part 1068, and the provisions of the Clean Air Act. The provisions of 40 CFR part 1068 apply for heavy-duty highway engines as specified in that part, subject to the following provisions:

(1) The exemption provisions of 40 CFR 1068.201 through 1068.230, 1068.240, and 1068.260 through 265 apply for heavy-duty motor vehicle engines. The other exemption provisions, which are specific to nonroad engines, do not apply for heavy-duty vehicles or heavy-duty engines.

(2) Engine signals to indicate a need for maintenance under § 1036.125(a)(1)(ii) are considered an element of design of the emission control system. Disabling, resetting, or otherwise rendering such signals inoperative without also performing the indicated maintenance procedure is therefore prohibited under 40 CFR 1068.101(b)(1).

(3) The warranty-related prohibitions in section 203(a)(4) of the Act (42 U.S.C. 7522(a)(4)) apply to manufacturers of new heavy-duty highway engines in addition to the prohibitions described in 40 CFR 1068.101(b)(6). We may assess a civil penalty up to \$44,539 for each engine or vehicle in violation.

(b) The following provisions from 40 CFR parts 85 and 86 continue to apply after December 20, 2026 for engines subject to the requirements of this part:

(1) The tampering prohibition in 40 CFR 1068.101(b)(1) applies for alternative fuel conversions as specified in 40 CFR part 85, subpart F.

(2) Engine manufacturers must meet service information requirements as specified in 40 CFR 86.010-38(j).

(3) Provisions related to nonconformance penalties apply as described in 40 CFR part 86, subpart L. Note that nonconformance penalty provisions are not available for current or future emission standards unless we revise the regulation to specify how to apply those provisions.

(4) The manufacturer-run in-use testing program described in 40 CFR part 86, subpart T, continues to apply for engines subject to exhaust emission standards under 40 CFR part 86.

(c) The emergency vehicle field modification provisions of 40 CFR 85.1716 apply with respect to the standards of this part. Emergency vehicle field modifications under 40 CFR 85.1716 may include corresponding changes to diagnostic systems relative to the requirements in §§ 1036.110 and 1036.111. For example, the cab display required under § 1036.110(c)(1) identifying a fault condition may omit information about the timing or extent of a pending derate if an AECD will override the derate.

(d) Subpart C of this part describes how to test and certify dual-fuel and flexible-fuel engines. Some multi-fuel engines may not fit either of those defined terms. For such engines, we will determine whether it is most appropriate to treat them as single-fuel engines, dual-fuel engines, or flexible-fuel engines based on the range of possible and expected fuel mixtures. For example, an engine might burn natural gas but initiate combustion with a pilot injection of diesel fuel. If the engine is designed to operate with a single fueling algorithm (i.e., fueling rates are fixed at a given engine speed and load condition), we would generally treat it as a single-fuel engine. In this context, the combination of diesel fuel and natural gas would be its own fuel type. If the engine is designed to also operate on diesel fuel alone, we would generally treat it as a dual-fuel engine. If the engine is designed to operate on varying mixtures of the two fuels, we would generally treat it as a flexible-fuel engine. To the extent that requirements vary for the different fuels or fuel mixtures, we may apply the more stringent requirements.

§ 1036.605 Alternate emission standards for engines used in specialty vehicles.

Starting in model year 2027, compression-ignition engines at or above 56 kW and spark-ignition engines of any size that will be installed in specialty vehicles as allowed by 40 CFR 1037.605 are exempt from the standards of subpart B of this part if they are certified under this part to alternate emission standards as follows:

- (a) Spark-ignition engines must be of a configuration that is identical to one that is certified under 40 CFR part 1048 to Blue Sky standards under 40 CFR 1048.140.
- (b) Compression-ignition engines must be of a configuration that is identical to one that is certified under 40 CFR part 1039, and meet the following additional standards using the same duty cycles that apply under 40 CFR part 1039:
 - (1) The engines must be certified with a family emission limit for PM of 0.020 g/kW-hr.
 - (2) Diesel-fueled engines using selective catalytic reduction must meet an emission standard of 0.1 g/kW-hr for N₂O.
- (c) Except as specified in this section, engines certified under this section must meet all the requirements that apply under 40 CFR part 1039 or 1048 instead of the comparable provisions in this part. Before shipping engines under this section, you must have written assurance from vehicle manufacturers that they need a certain number of exempted engines under this section. In your annual production report under 40 CFR 1039.250 or 1048.250, count these engines separately and identify the vehicle manufacturers that will be installing them. Treat these engines as part of the corresponding engine family under 40 CFR part 1039 or 1048 for compliance purposes such as testing production engines, in-use testing, defect reporting, and recall.
- (d) The engines must be labeled as described in § 1036.135, with the following statement instead of the one specified in § 1036.135(c)(8): “This engine conforms to alternate standards for specialty vehicles under 40 CFR 1036.605.” Engines certified under this section may not have the label specified for nonroad engines in 40 CFR part 1039 or part 1048 or any other label identifying them as nonroad engines.
- (e) In a separate application for a certificate of conformity, identify the corresponding nonroad engine family, describe the label required under section, state that you meet applicable diagnostic requirements under 40 CFR part 1039 or part 1048, and identify your projected U.S.-directed nationwide production volume.
- (f) No additional certification fee applies for engines certified under this section.
- (g) Engines certified under this section may not generate or use emission credits under this part or under 40 CFR part 1039. The vehicles in which these engines are installed may generate or use emission credits as described in 40 CFR part 1037.

§ 1036.610 Off-cycle technology credits and adjustments for reducing greenhouse gas

emissions.

(a) You may ask us to apply the provisions of this section for CO₂ emission reductions resulting from powertrain technologies that were not in common use with heavy-duty vehicles before model year 2010 that are not reflected in the specified procedure. While you are not required to prove that such technologies were not in common use with heavy-duty vehicles before model year 2010, we will not approve your request if we determine that they do not qualify. We will apply these provisions only for technologies that will result in a measurable, demonstrable, and verifiable real-world CO₂ reduction. Note that prior to model year 2016, these technologies were referred to as “innovative technologies”.

(b) The provisions of this section may be applied as either an improvement factor (used to adjust emission results) or as a separate credit, consistent with good engineering judgment. Note that the term “credit” in this section describes an additive adjustment to emission rates and is not equivalent to an emission credit in the ABT program of subpart H of this part. We recommend that you base your credit/adjustment on A to B testing of pairs of engines/vehicles differing only with respect to the technology in question.

(1) Calculate improvement factors as the ratio of in-use emissions with the technology divided by the in-use emissions without the technology. Adjust the emission results by multiplying by the improvement factor. Use the improvement-factor approach where good engineering judgment indicates that the actual benefit will be proportional to emissions measured over the procedures specified in this part. For example, the benefits from technologies that reduce engine operation would generally be proportional to the engine’s emission rate.

(2) Calculate separate credits based on the difference between the in-use emission rate (g/ton-mile) with the technology and the in-use emission rate without the technology. Subtract this value from your measured emission result and use this adjusted value to determine your FEL. We may also allow you to calculate the credits based on g/hp·hr emission rates. Use the separate-credit approach where good engineering judgment indicates that the actual benefit will not be proportional to emissions measured over the procedures specified in this part.

(3) We may require you to discount or otherwise adjust your improvement factor or credit to account for uncertainty or other relevant factors.

(c) Send your request to the Designated Compliance Officer. We recommend that you do not begin collecting data (for submission to EPA) before contacting us. For technologies for which the vehicle manufacturer could also claim credits (such as transmissions in certain circumstances), we may require you to include a letter from the vehicle manufacturer stating that it will not seek credits for the same technology. Your request must contain the following items:

(1) A detailed description of the off-cycle technology and how it functions to reduce CO₂ emissions under conditions not represented on the duty cycles required for certification.

(2) A list of the engine configurations that will be equipped with the technology.

(3) A detailed description and justification of the selected engines.

(4) All testing and simulation data required under this section, plus any other data you have considered in your analysis. You may ask for our preliminary approval of your plan under § 1036.210.

(5) A complete description of the methodology used to estimate the off-cycle benefit of the technology and all supporting data, including engine testing and in-use activity data. Also include a statement regarding your recommendation for applying the provisions of this section for the given technology as an improvement factor or a credit.

(6) An estimate of the off-cycle benefit by engine model, and the fleetwide benefit based on projected sales of engine models equipped with the technology.

(7) A demonstration of the in-use durability of the off-cycle technology, based on any available engineering analysis or durability testing data (either by testing components or whole engines).

(d) We may seek public comment on your request, consistent with the provisions of 40 CFR 86.1869-12(d). However, we will generally not seek public comment on credits/adjustments based on A to B engine dynamometer testing, chassis testing, or in-use testing.

(e) We may approve an improvement factor or credit for any configuration that is properly represented by your testing.

(1) For model years before 2021, you may continue to use an approved improvement factor or credit for any appropriate engine families in future model years through 2020.

(2) For model years 2021 and later, you may not rely on an approval for model years before 2021. You must separately request our approval before applying an improvement factor or credit under this section for 2021 and later engines, even if we approved an improvement factor or credit for similar engine models before model year 2021. Note that approvals for model year 2021 and later may carry over for multiple years.

§ 1036.615 Engines with Rankine cycle waste heat recovery and hybrid powertrains.

This section specifies how to generate advanced-technology emission credits for hybrid powertrains that include energy storage systems and regenerative braking (including regenerative engine braking) and for engines that include Rankine-cycle (or other bottoming cycle) exhaust energy recovery systems. This section applies only for model year 2020 and earlier engines.

(a) *Pre-transmission hybrid powertrains.* Test pre-transmission hybrid powertrains with the hybrid engine procedures of 40 CFR part 1065 or with the post-transmission procedures in [§ 1036.545](#) ~~40 CFR 1037.550~~. Pre-transmission hybrid powertrains are those engine systems that include features to recover and store energy during engine motoring operation but not from the vehicle's wheels. Engines certified with pre-transmission hybrid powertrains must be certified to meet the diagnostic requirements as specified in § 1036.110 with respect to powertrain components and systems; if different manufacturers produce the engine and the hybrid powertrain, the hybrid powertrain manufacturer may separately certify its powertrain relative to diagnostic requirements.

(b) *Rankine engines.* Test engines that include Rankine-cycle exhaust energy recovery systems according to the procedures specified in subpart F of this part unless we approve alternate procedures.

(c) *Calculating credits.* Calculate credits as specified in subpart H of this part. Credits generated from engines and powertrains certified under this section may be used in other averaging sets as described in § 1036.740(c).

(d) *Off-cycle technologies.* You may certify using both the provisions of this section and the off-cycle technology provisions of § 1036.610, provided you do not double-count emission benefits.

§ 1036.620 Alternate CO₂ standards based on model year 2011 compression-ignition engines.

For model years 2014 through 2016, you may certify your compression-ignition engines to the CO₂ standards of this section instead of the CO₂ standards in § 1036.108. However, you may not certify engines to these alternate standards if they are part of an averaging set in which you carry

a balance of banked credits. You may submit applications for certifications before using up banked credits in the averaging set, but such certificates will not become effective until you have used up (or retired) your banked credits in the averaging set. For purposes of this section, you are deemed to carry credits in an averaging set if you carry credits from advanced technology that are allowed to be used in that averaging set.

(a) The standards of this section are determined from the measured emission rate of the engine of the applicable baseline 2011 engine family or families as described in paragraphs (b) and (c) of this section. Calculate the CO₂ emission rate of the baseline engine using the same equations used for showing compliance with the otherwise applicable standard. The alternate CO₂ standard for light and medium heavy-duty vocational-certified engines (certified for CO₂ using the transient cycle) is equal to the baseline emission rate multiplied by 0.975. The alternate CO₂ standard for tractor-certified engines (certified for CO₂ using the SET duty cycle) and all other Heavy HDE is equal to the baseline emission rate multiplied by 0.970. The in-use FEL for these engines is equal to the alternate standard multiplied by 1.03.

(b) This paragraph (b) applies if you do not certify all your engine families in the averaging set to the alternate standards of this section. Identify separate baseline engine families for each engine family that you are certifying to the alternate standards of this section. For an engine family to be considered the baseline engine family, it must meet the following criteria:

(1) It must have been certified to all applicable emission standards in model year 2011. If the baseline engine was certified to a NO_x FEL above the standard and incorporated the same emission control technologies as the new engine family, you may adjust the baseline CO₂ emission rate to be equivalent to an engine meeting the 0.20 g/hp·hr NO_x standard (or your higher FEL as specified in this paragraph (b)(1)), using certification results from model years 2009 through 2011, consistent with good engineering judgment.

(i) Use the following equation to relate model year 2009-2011 NO_x and CO₂ emission rates (g/hp·hr): $CO_2 = a \times \log(NO_x) + b$.

(ii) For model year 2014-2016 engines certified to NO_x FELs above 0.20 g/hp·hr, correct the baseline CO₂ emissions to the actual NO_x FELs of the 2014-2016 engines.

(iii) Calculate separate adjustments for emissions over the SET duty cycle and the transient cycle.

(2) The baseline configuration tested for certification must have the same engine displacement as the engines in the engine family being certified to the alternate standards, and its rated power must be within five percent of the highest rated power in the engine family being certified to the alternate standards.

(3) The model year 2011 U.S.-directed production volume of the configuration tested must be at least one percent of the total 2011 U.S.-directed production volume for the engine family.

(4) The tested configuration must have cycle-weighted BSFC equivalent to or better than all other configurations in the engine family.

(c) This paragraph (c) applies if you certify all your engine families in the primary intended service class to the alternate standards of this section. For purposes of this section, you may combine Light HDE and Medium HDE into a single averaging set. Determine your baseline CO₂ emission rate as the production-weighted emission rate of the certified engine families you produced in the 2011 model year. If you produce engines for both tractors and vocational vehicles, treat them as separate averaging sets. Adjust the CO₂ emission rates to be equivalent to an engine meeting the average NO_x FEL of new engines (assuming engines certified to the 0.20 g/hp·hr NO_x standard have a NO_x FEL equal to 0.20 g/hp·hr), as described in paragraph (b)(1) of this section.

- (d) Include the following statement on the emission control information label: “THIS ENGINE WAS CERTIFIED TO AN ALTERNATE CO₂ STANDARD UNDER 40 CFR 1036.620.”
- (e) You may not bank CO₂ emission credits for any engine family in the same averaging set and model year in which you certify engines to the standards of this section. You may not bank any advanced-technology credits in any averaging set for the model year you certify under this section (since such credits would be available for use in this averaging set). Note that the provisions of § 1036.745 apply for deficits generated with respect to the standards of this section.
- (f) You need our approval before you may certify engines under this section, especially with respect to the numerical value of the alternate standards. We will not approve your request if we determine that you manipulated your engine families or engine configurations to certify to less stringent standards, or that you otherwise have not acted in good faith. You must keep and provide to us any information we need to determine that your engine families meet the requirements of this section. Keep these records for at least five years after you stop producing engines certified under this section.

§ 1036.625 In-use compliance with CO₂ family emission limits (FELs).

Section 1036.225 describes how to change the FEL for an engine family during the model year. This section, which describes how you may ask us to increase an engine family’s CO₂ FEL after the end of the model year, is intended to address circumstances in which it is in the public interest to apply a higher in-use CO₂ FEL based on forfeiting an appropriate number of emission credits. For example, this may be appropriate where we determine that recalling vehicles would not significantly reduce in-use emissions. We will generally not allow this option where we determine the credits being forfeited would likely have expired.

- (a) You may ask us to increase an engine family’s FEL after the end of the model year if you believe some of your in-use engines exceed the CO₂ FEL that applied during the model year (or the CO₂ emission standard if the family did not generate or use emission credits). We may consider any available information in making our decision to approve or deny your request.
- (b) If we approve your request under this section, you must apply emission credits to cover the increased FEL for all affected engines. Apply the emission credits as part of your credit demonstration for the current production year. Include the appropriate calculations in your final report under § 1036.730.
- (c) Submit your request to the Designated Compliance Officer. Include the following in your request:
- (1) Identify the names of each engine family that is the subject of your request. Include separate family names for different model years
 - (2) Describe why your request does not apply for similar engine models or additional model years, as applicable.
 - (3) Identify the FEL(s) that applied during the model year and recommend a replacement FEL for in-use engines; include a supporting rationale to describe how you determined the recommended replacement FEL.
 - (4) Describe whether the needed emission credits will come from averaging, banking, or trading.
- (d) If we approve your request, we will identify the replacement FEL. The value we select will reflect our best judgment to accurately reflect the actual in-use performance of your engines, consistent with the testing provisions specified in this part. We may apply the higher FELs to other engine families from the same or different model years to the extent they used equivalent emission controls. We may include any appropriate conditions with our approval.

(e) If we order a recall for an engine family under 40 CFR 1068.505, we will no longer approve a replacement FEL under this section for any of your engines from that engine family, or from any other engine family that relies on equivalent emission controls.

§ 1036.630 Certification of engine greenhouse gas emissions for powertrain testing.

For engines included in powertrain families under 40 CFR part 1037, you may choose to include the corresponding engine emissions in your engine families under this part instead of (or in addition to) the otherwise applicable engine fuel maps.

(a) If you choose to certify powertrain fuel maps in an engine family, the declared powertrain emission levels become standards that apply for selective enforcement audits and in-use testing. We may require that you provide to us the engine cycle (not normalized) corresponding to a given powertrain for each of the specified duty cycles.

(b) If you choose to certify only fuel map emissions for an engine family and to not certify emissions over powertrain cycles under ~~§ 1036.54540-CFR-1037.550~~, we will not presume you are responsible for emissions over the powertrain cycles. However, where we determine that you are responsible in whole or in part for the emission exceedance in such cases, we may require that you participate in any recall of the affected vehicles. Note that this provision to limit your responsibility does not apply if you also hold the certificate of conformity for the vehicle.

(c) If you split an engine family into subfamilies based on different fuel-mapping procedures as described in § 1036.230(f)(2), the fuel-mapping procedures you identify for certifying each subfamily also apply for selective enforcement audits and in-use testing.

§ 1036.655 Special provisions for diesel-fueled engines sold in American Samoa or the Commonwealth of the Northern Mariana Islands.

(a) The prohibitions in § 1068.101(a)(1) do not apply to diesel-fueled engines that are intended for use and will be used in American Samoa or the Commonwealth of the Northern Mariana Islands, subject to the following conditions:

(1) The engine meets the emission standards that applied to model year 2006 engines as specified in appendix A of this part.

(2) You meet all the requirements of 40 CFR 1068.265.

(b) If you introduce an engine into U.S. commerce under this section, you must meet the labeling requirements in § 1036.135, but add the following statement instead of the compliance statement in § 1036.135(c)(8):

THIS ENGINE (or VEHICLE, as applicable) CONFORMS TO US EPA EMISSION STANDARDS APPLICABLE TO MODEL YEAR 2006. THIS ENGINE (or VEHICLE, as applicable) DOES NOT CONFORM TO US EPA EMISSION REQUIREMENTS IN EFFECT AT TIME OF PRODUCTION AND MAY NOT BE IMPORTED INTO THE UNITED STATES OR ANY TERRITORY OF THE UNITED STATES EXCEPT AMERICAN SAMOA OR THE COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS.

(c) Introducing into U.S. commerce an engine exempted under this section in any state or territory of the United States other than American Samoa or the Commonwealth of the Northern Mariana Islands, throughout its lifetime, violates the prohibitions in 40 CFR 1068.101(a)(1), unless it is exempt under a different provision.

(d) The exemption provisions in this section also applied for model year 2007 and later engines introduced into commerce in Guam before January 1, 2024.

Subpart H—Averaging, Banking, and Trading for Certification

§ 1036.701 General provisions.

(a) You may average, bank, and trade (ABT) emission credits for purposes of certification as described in this subpart and in subpart B of this part to show compliance with the standards of §§ 1036.104 and 1036.108. Participation in this program is voluntary. Note that certification to NO_x standards in § 1036.104 is based on a family emission limit (FEL) and certification to CO₂ standards in § 1036.108 is based on a Family Certification Level (FCL). This part refers to “FEL/FCL” to simultaneously refer to FELs for NO_x and FCLs for CO₂. Note also that subpart B of this part requires you to assign an FCL to all engine families, whether or not they participate in the ABT provisions of this subpart.

(b) The definitions of subpart I of this part apply to this subpart in addition to the following definitions:

(1) *Actual emission credits* means emission credits you have generated that we have verified by reviewing your final report.

(2) *Averaging set* means a set of engines in which emission credits may be exchanged. See § 1036.740.

(3) *Broker* means any entity that facilitates a trade of emission credits between a buyer and seller.

(4) *Buyer* means the entity that receives emission credits as a result of a trade.

(5) *Reserved emission credits* means emission credits you have generated that we have not yet verified by reviewing your final report.

(6) *Seller* means the entity that provides emission credits during a trade.

(7) *Standard* means the emission standard that applies under subpart B of this part for engines not participating in the ABT program of this subpart.

(8) *Trade* means to exchange emission credits, either as a buyer or seller.

(c) Emission credits may be exchanged only within an averaging set, except as specified in § 1036.740.

(d) You may not use emission credits generated under this subpart to offset any emissions that exceed an FEL/FCL or standard. This paragraph (d) applies for all testing, including certification testing, in-use testing, selective enforcement audits, and other production-line testing. However, if emissions from an engine exceed an FEL/FCL or standard (for example, during a selective enforcement audit), you may use emission credits to recertify the engine family with a higher FEL/FCL that applies only to future production.

(e) You may use either of the following approaches to retire or forego emission credits:

(1) You may retire emission credits generated from any number of your engines. This may be considered donating emission credits to the environment. Identify any such credits in the reports described in § 1036.730. Engines must comply with the applicable FELs even if you donate or sell the corresponding emission credits. Donated credits may no longer be used by anyone to demonstrate compliance with any EPA emission standards.

(2) You may certify an engine family using an FEL/FCL below the emission standard as described in this part and choose not to generate emission credits for that family. If you do this, you do not need to calculate emission credits for those engine families, and you do not need to submit or keep the associated records described in this subpart for that family.

(f) Emission credits may be used in the model year they are generated. Surplus emission credits may be banked for future model years. Surplus emission credits may sometimes be used for past model years, as described in § 1036.745.

(g) You may increase or decrease an FEL/FCL during the model year by amending your application for certification under § 1036.225. The new FEL/FCL may apply only to engines you have not already introduced into commerce.

(h) See § 1036.740 for special credit provisions that apply for greenhouse gas credits generated under 40 CFR 86.1819-14(k)(7) or § 1036.615 or 40 CFR 1037.615.

(i) Unless the regulations in this part explicitly allow it, you may not calculate Phase 1 credits more than once for any emission reduction. For example, if you generate Phase 1 CO₂ emission credits for a hybrid engine under this part for a given vehicle, no one may generate CO₂ emission credits for that same hybrid engine and the associated vehicle under 40 CFR part 1037. However, Phase 1 credits could be generated for identical vehicles using engines that did not generate credits under this part.

(j) Credits you generate with compression-ignition engines in 2020 and earlier model years may be used in model year 2021 and later as follows:

(1) For credit-generating engines certified to the tractor engine standards in § 1036.108, you may use credits calculated relative to the tractor engine standards.

(2) For credit-generating engines certified to the vocational engine standards in § 1036.108, you may optionally carry over adjusted vocational credits from an averaging set, and you may use credits calculated relative to the emission levels in the following table:

TABLE 1 TO PARAGRAPH (j)(2) OF § 1036.701—EMISSION LEVELS FOR CREDIT CALCULATION

Medium HDE	Heavy HDE
558 g/hp·hr	525 g/hp·hr

(k) Engine families you certify with a nonconformance penalty under 40 CFR part 86, subpart L, may not generate emission credits.

§ 1036.705 Generating and calculating emission credits.

(a) The provisions of this section apply separately for calculating emission credits for each pollutant.

(b) For each participating family, calculate positive or negative emission credits relative to the otherwise applicable emission standard. Calculate positive emission credits for a family that has an FEL/FCL below the standard. Calculate negative emission credits for a family that has an FEL/FCL above the standard. Sum your positive and negative credits for the model year before rounding.

(1) Calculate emission credits to the nearest megagram (Mg) for each family or subfamily using the following equation:

$$\text{Emission credits (Mg)} = (\text{Std} - \text{FL}) \cdot \text{CF} \cdot \text{Volume} \cdot \text{UL} \cdot c$$

Eq. 1036.705-1

Where:

Std = the emission standard, in (mg NO_x)/hp·hr or (g CO₂)/hp·hr, that applies under subpart B of this part for engines not participating in the ABT program of this subpart (the “otherwise applicable standard”).

FL = the engine family’s FEL for NO_x, in mg/hp·hr, and FCL for CO₂, in g/hp·hr, rounded to the same number of decimal places as the emission standard.

CF = a transient cycle conversion factor (hp·hr/mile), calculated by dividing the total (integrated) horsepower-hour over the applicable duty cycle by 6.3 miles for engines

subject to spark-ignition standards and 6.5 miles for engines subject to compression-ignition standards. This represents the average work performed over the duty cycle. See paragraph (b)(3) of this section for provisions that apply for CO₂.

Volume = the number of engines eligible to participate in the averaging, banking, and trading program within the given engine family or subfamily during the model year, as described in paragraph (c) of this section.

UL = the useful life for the standard that applies for a given primary intended service class, in miles.

c = use 10⁻⁶ for CO₂ and 10⁻⁹ for NO_x.

Example for model year 2025 Heavy HDE generating CO₂ credits for a model year 2028 Heavy HDE:

Std = 432 g/hp·hr

FL = 401 g/hp·hr

CF = 9.78 hp·hr/mile

Volume = 15,342

UL = 435,000 miles

c = 10⁻⁶

Emission credits = (432 – 401) · 9.78 · 15,342 · 435,000 · 10⁻⁶

Emission credits = 28,131,142 Mg

(2) [Reserved]

(3) The following additional provisions apply for calculating CO₂ credits:

(i) For engine families certified to both the vocational and tractor engine standards, calculate credits separately for the vocational engines and the tractor engines. We may allow you to use statistical methods to estimate the total production volumes where a small fraction of the engines cannot be tracked precisely.

(ii) Calculate the transient cycle conversion factor for vocational engines based on the average of vocational engine configurations weighted by their production volumes. Similarly, calculate the transient cycle conversion factor for tractor engines based on the average of tractor engine configurations weighted by their production volumes. Note that calculating the transient cycle conversion factor for tractors requires you to use the conversion factor even for engines certified to standards based on the SET duty cycle.

(iii) The FCL for CO₂ is based on measurement over the FTP duty cycle for vocational engines and over the SET duty cycle for tractor engines.

(4) You may not generate emission credits for tractor engines (i.e., engines not certified to the transient cycle for CO₂) installed in vocational vehicles (including vocational tractors certified under 40 CFR 1037.630 or exempted under 40 CFR 1037.631). We will waive this provision where you demonstrate that less than five percent of the engines in your tractor family were installed in vocational vehicles. For example, if you know that 96 percent of your tractor engines were installed in non-vocational tractors but cannot determine the vehicle type for the remaining four percent, you may generate credits for all the engines in the family.

(5) You may generate CO₂ emission credits from a model year 2021 or later medium heavy-duty engine family subject to spark-ignition standards for exchanging with other engine families only if the engines in the family are gasoline-fueled. You may generate CO₂ credits from non-gasoline engine families only for the purpose of offsetting CH₄ and/or N₂O emissions within the same engine family as described in paragraph (d) of this section.

~~(c) Compliance with the requirements of this subpart is determined at the end of the model year by calculating emission credits based on actual production volumes, excluding the following engines: As described in § 1036.730, compliance with the requirements of this subpart is determined at the end of the model year based on actual U.S. directed production volumes. Keep appropriate records to document these production volumes. Do not include any of the following engines to calculate emission credits:~~

(1) Engines that you do not certify to the CO₂ standards of this part because they are permanently exempted under subpart G of this part or under 40 CFR part 1068.

(2) Exported engines.

(3) Engines not subject to the requirements of this part, such as those excluded under § 1036.5. For example, do not include engines used in vehicles certified to the greenhouse gas standards of 40 CFR 86.1819.

(4) Engines certified to state emission standards that are different than the emission standards referenced in § 1036.705, and intended for sale in a state that has adopted those emission standards in this part.

(5) Any other engines if we indicate elsewhere in this part that they are not to be included in the calculations of this subpart.

(d) You may use CO₂ emission credits to show compliance with CH₄ and/or N₂O FELs instead of the otherwise applicable emission standards. To do this, calculate the CH₄ and/or N₂O emission credits needed (negative credits) using the equation in paragraph (b) of this section, using the FEL(s) you specify for your engines during certification instead of the FCL. You must use 34 Mg of positive CO₂ credits to offset 1 Mg of negative CH₄ credits for model year 2021 and later engines, and you must use 25 Mg of positive CO₂ credits to offset 1 Mg of negative CH₄ credits for earlier engines. You must use 298 Mg of positive CO₂ credits to offset 1 Mg of negative N₂O credits.

§ 1036.710 Averaging.

(a) Averaging is the exchange of emission credits among your engine families. You may average emission credits only within the same averaging set, except as specified in § 1036.740.

(b) You may certify one or more engine families to an FEL/FCL above the applicable standard, subject to any applicable FEL caps and other the provisions in subpart B of this part, if you show in your application for certification that your projected balance of all emission-credit transactions in that model year is greater than or equal to zero, or that a negative balance is allowed under § 1036.745.

(c) If you certify an engine family to an FEL/FCL that exceeds the otherwise applicable standard, you must obtain enough emission credits to offset the engine family's deficit by the due date for the final report required in § 1036.730. The emission credits used to address the deficit may come from your other engine families that generate emission credits in the same model year (or from later model years as specified in § 1036.745), from emission credits you have banked, or from emission credits you obtain through trading.

§ 1036.715 Banking.

(a) Banking is the retention of surplus emission credits by the manufacturer generating the emission credits for use in future model years for averaging or trading.

(b) You may designate any emission credits you plan to bank in the reports you submit under § 1036.730 as reserved credits. During the model year and before the due date for the final report, you may designate your reserved emission credits for averaging or trading.

- (c) Reserved credits become actual emission credits when you submit your final report. However, we may revoke these emission credits if we are unable to verify them after reviewing your reports or auditing your records.
- (d) Banked credits retain the designation of the averaging set in which they were generated.

§ 1036.720 Trading.

- (a) Trading is the exchange of emission credits between manufacturers. You may use traded emission credits for averaging, banking, or further trading transactions. Traded emission credits remain subject to the averaging-set restrictions based on the averaging set in which they were generated.
- (b) You may trade actual emission credits as described in this subpart. You may also trade reserved emission credits, but we may revoke these emission credits based on our review of your records or reports or those of the company with which you traded emission credits. You may trade banked credits within an averaging set to any certifying manufacturer.
- (c) If a negative emission credit balance results from a transaction, both the buyer and seller are liable, except in cases we deem to involve fraud. See § 1036.255(e) for cases involving fraud. We may void the certificates of all engine families participating in a trade that results in a manufacturer having a negative balance of emission credits. See § 1036.745.

§ 1036.725 Required information for certification.

- (a) You must declare in your application for certification your intent to use the provisions of this subpart for each engine family that will be certified using the ABT program. You must also declare the FEL/FCL you select for the engine family for each pollutant for which you are using the ABT program. Your FELs must comply with the specifications of subpart B of this part, including the FEL caps.
- (b) Include the following in your application for certification:
- (1) A statement that, to the best of your belief, you will not have a negative balance of emission credits for any averaging set when all emission credits are calculated at the end of the year; or a statement that you will have a negative balance of emission credits for one or more averaging sets, but that it is allowed under § 1036.745.
 - (2) ~~Detailed e~~Calculations of projected emission credits (positive or negative) based on projected ~~U.S.-directed~~ production volumes as described in § 1036.705(c). We may require you to include similar calculations from your other engine families to project your net credit balances for the model year. If you project negative emission credits for a family, state the source of positive emission credits you expect to use to offset the negative emission credits.

§ 1036.730 ABT reports.

- (a) If you certify any of your engine families using the ABT provisions of this subpart, you must send us a final report by September 30 following the end of the model year.
- (b) Your report must include the following information for each engine family participating in the ABT program:
- (1) Engine-family designation and averaging set.
 - (2) The emission standards that would otherwise apply to the engine family.
 - (3) The FEL/FCL for each pollutant. If you change the FEL/FCL after the start of production, identify the date that you started using the new FEL/FCL and/or give the engine identification number for the first engine covered by the new FEL/FCL. In this case, identify

each applicable FEL/FCL and calculate the positive or negative emission credits as specified in § 1036.225(f).

(4) The projected and actual ~~U.S.-directed~~ production volumes for calculating emission credits for the model year. If you changed an FEL/FCL during the model year, identify the actual ~~U.S.-directed~~ production volume associated with each FEL/FCL.

(5) The transient cycle conversion factor for each engine configuration as described in § 1036.705.

(6) Useful life.

(7) Calculated positive or negative emission credits for the whole engine family. Identify any emission credits that you traded, as described in paragraph (d)(1) of this section.

(c) Your report must include the following additional information:

(1) Show that your net balance of emission credits from all your participating engine families in each averaging set in the applicable model year is not negative, except as allowed under § 1036.745. Your credit tracking must account for the limitation on credit life under § 1036.740(d).

(2) State whether you will reserve any emission credits for banking.

(3) State that the report's contents are accurate.

(d) If you trade emission credits, you must send us a report within 90 days after the transaction, as follows:

(1) As the seller, you must include the following information in your report:

(i) The corporate names of the buyer and any brokers.

(ii) A copy of any contracts related to the trade.

(iii) The averaging set corresponding to the engine families that generated emission credits for the trade, including the number of emission credits from each averaging set.

(2) As the buyer, you must include the following information in your report:

(i) The corporate names of the seller and any brokers.

(ii) A copy of any contracts related to the trade.

(iii) How you intend to use the emission credits, including the number of emission credits you intend to apply for each averaging set.

(e) Send your reports electronically to the Designated Compliance Officer using an approved information format. If you want to use a different format, send us a written request with justification for a waiver.

(f) Correct errors in your report as follows:

(1) If you notify us by the deadline for submitting the final report or we determine by September 30 after the end of the model year that errors mistakenly decreased your balance of emission credits, you may correct the errors and recalculate the balance of emission credits. If you notify us that errors mistakenly decreased your balance of GHG emission credits after the deadline for submitting the final report, you may correct the errors and recalculate the balance of emission credits after applying a 10 percent discount to the credit correction, but only if you notify us within 24 months after the deadline for submitting the final report. You may not make these corrections for errors that are determined later than September 30 after the end of the model year. If you report a negative balance of emission credits, we may disallow corrections under this paragraph (f)(1).

(2) If you or we determine any time that errors mistakenly increased your balance of emission credits, you must correct the errors and recalculate the balance of emission credits.

§ 1036.735 Recordkeeping.

- (a) You must organize and maintain your records as described in this section. We may review your records at any time.
- (b) Keep the records required by this section for at least eight years after the due date for the end-of-year report. You may not use emission credits for any engines if you do not keep all the records required under this section. You must therefore keep these records to continue to bank valid credits. Store these records in any format and on any media, as long as you can promptly send us organized, written records in English if we ask for them. You must keep these records readily available. We may review them at any time.
- (c) Keep a copy of the reports we require in §§ 1036.725 and 1036.730.
- (d) Keep appropriate records to document production volumes of engines that generate or use emission credits under the ABT program. For example, keep available ~~Keep~~ records of the engine identification number (usually the serial number) for each engine you produce that generates or uses emission credits ~~under the ABT program~~. You may identify these numbers as a range. If you change the FEL/FCL after the start of production, identify the date you started using each FEL/FCL and the range of engine identification numbers associated with each FEL/FCL. You must also identify the purchaser and destination for each engine you produce to the extent this information is available.
- (e) We may require you to keep additional records or to send us relevant information not required by this section in accordance with the Clean Air Act.

§ 1036.740 Restrictions for using emission credits.

The following restrictions apply for using emission credits:

- (a) *Averaging sets*. Except as specified in paragraph (c) of this section, emission credits may be exchanged only within the following averaging sets based on primary intended service class:
- (1) Spark-ignition HDE.
 - (2) Light HDE.
 - (3) Medium HDE.
 - (4) Heavy HDE.
- (b) *Applying credits to prior year deficits*. Where your CO₂ credit balance for the previous year is negative, you may apply credits to that deficit only after meeting your credit obligations for the current year.
- (c) *CO₂ credits from hybrid engines and other advanced technologies*. Phase 1 CO₂ credits you generate under § 1036.615 may be used for any of the averaging sets identified in paragraph (a) of this section; you may also use those credits to demonstrate compliance with the CO₂ emission standards in 40 CFR 86.1819 and 40 CFR part 1037. Similarly, you may use Phase 1 advanced-technology credits generated under 40 CFR 86.1819-14(k)(7) or 40 CFR 1037.615 to demonstrate compliance with the CO₂ standards in this part. In the case of Spark-ignition HDE and Light HDE you may not use more than 60,000 Mg of credits from other averaging sets in any model year.
- (1) The maximum CO₂ credits you may bring into the following service class groups is 60,000 Mg per model year:
 - (i) Spark-ignition HDE, Light HDE, and Light HDV. This group comprises the averaging sets listed in paragraphs (a)(1) and (2) of this section and the averaging set listed in 40 CFR 1037.740(a)(1).
 - (ii) Medium HDE and Medium HDV. This group comprises the averaging sets listed in paragraph (a)(3) of this section and 40 CFR 1037.740(a)(2).

(iii) Heavy HDE and Heavy HDV. This group comprises the averaging sets listed in paragraph (a)(4) of this section and 40 CFR 1037.740(a)(3).

(2) Paragraph (c)(1) of this section does not limit the advanced-technology credits that can be used within a service class group if they were generated in that same service class group.

(d) *NO_x and CO₂ credit life.* NO_x and CO₂ credits may be used only for five model years after the year in which they are generated. For example, credits you generate in model year 2027 may be used to demonstrate compliance with emission standards only through model year 2032.

(e) *Other restrictions.* Other sections of this part specify additional restrictions for using emission credits under certain special provisions.

§ 1036.745 End-of-year CO₂ credit deficits.

Except as allowed by this section, we may void the certificate of any engine family certified to an FCL above the applicable standard for which you do not have sufficient credits by the deadline for submitting the final report.

(a) Your certificate for an engine family for which you do not have sufficient CO₂ credits will not be void if you remedy the deficit with surplus credits within three model years. For example, if you have a credit deficit of 500 Mg for an engine family at the end of model year 2015, you must generate (or otherwise obtain) a surplus of at least 500 Mg in that same averaging set by the end of model year 2018.

(b) You may not bank or trade away CO₂ credits in the averaging set in any model year in which you have a deficit.

(c) You may apply only surplus credits to your deficit. You may not apply credits to a deficit from an earlier model year if they were generated in a model year for which any of your engine families for that averaging set had an end-of-year credit deficit.

(d) You must notify us in writing how you plan to eliminate the credit deficit within the specified time frame. If we determine that your plan is unreasonable or unrealistic, we may deny an application for certification for a vehicle family if its FEL would increase your credit deficit. We may determine that your plan is unreasonable or unrealistic based on a consideration of past and projected use of specific technologies, the historical sales mix of your vehicle models, your commitment to limit production of higher-emission vehicles, and expected access to traded credits. We may also consider your plan unreasonable if your credit deficit increases from one model year to the next. We may require that you send us interim reports describing your progress toward resolving your credit deficit over the course of a model year.

(e) If you do not remedy the deficit with surplus credits within three model years, we may void your certificate for that engine family. We may void the certificate based on your end-of-year report. Note that voiding a certificate applies *ab initio*. Where the net deficit is less than the total amount of negative credits originally generated by the family, we will void the certificate only with respect to the number of engines needed to reach the amount of the net deficit. For example, if the original engine family generated 500 Mg of negative credits, and the manufacturer's net deficit after three years was 250 Mg, we would void the certificate with respect to half of the engines in the family.

(f) For purposes of calculating the statute of limitations, the following actions are all considered to occur at the expiration of the deadline for offsetting a deficit as specified in paragraph (a) of this section:

(1) Failing to meet the requirements of paragraph (a) of this section.

(2) Failing to satisfy the conditions upon which a certificate was issued relative to offsetting a deficit.

(3) Selling, offering for sale, introducing or delivering into U.S. commerce, or importing vehicles that are found not to be covered by a certificate as a result of failing to offset a deficit.

§ 1036.750 Consequences for noncompliance.

(a) For each engine family participating in the ABT program, the certificate of conformity is conditioned upon full compliance with the provisions of this subpart during and after the model year. You are responsible to establish to our satisfaction that you fully comply with applicable requirements. We may void the certificate of conformity for an engine family if you fail to comply with any provisions of this subpart.

(b) You may certify your engine family to an FEL/FCL above an applicable standard based on a projection that you will have enough emission credits to offset the deficit for the engine family. See § 1036.745 for provisions specifying what happens if you cannot show in your final report that you have enough actual emission credits to offset a deficit for any pollutant in an engine family.

(c) We may void the certificate of conformity for an engine family if you fail to keep records, send reports, or give us information we request. Note that failing to keep records, send reports, or give us information we request is also a violation of 42 U.S.C. 7522(a)(2).

(d) You may ask for a hearing if we void your certificate under this section (see § 1036.820).

§ 1036.755 Information provided to the Department of Transportation.

After receipt of each manufacturer's final report as specified in § 1036.730 and completion of any verification testing required to validate the manufacturer's submitted final data, we will issue a report to the Department of Transportation with CO₂ emission information and will verify the accuracy of each manufacturer's equivalent fuel consumption data that required by NHTSA under 49 CFR 535.8. We will send a report to DOT for each engine manufacturer based on each regulatory category and subcategory, including sufficient information for NHTSA to determine fuel consumption and associated credit values. See 49 CFR 535.8 to determine if NHTSA deems submission of this information to EPA to also be a submission to NHTSA.

Subpart I—Definitions and Other Reference Information

§ 1036.801 Definitions.

The following definitions apply to this part. The definitions apply to all subparts unless we note otherwise. All undefined terms have the meaning the Act gives to them. The definitions follow:

Act means the Clean Air Act, as amended, 42 U.S.C. 7401 - 7671q.

Adjustable parameter has the meaning given in 40 CFR 1068.50.

Advanced technology means technology certified under 40 CFR 86.1819-14(k)(7), § 1036.615, or 40 CFR 1037.615.

Aftertreatment means relating to a catalytic converter, particulate filter, or any other system, component, or technology mounted downstream of the exhaust valve (or exhaust port) whose design function is to decrease emissions in the engine exhaust before it is exhausted to the environment. Exhaust gas recirculation (EGR) and turbochargers are not aftertreatment.

Aircraft means any vehicle capable of sustained air travel more than 100 feet above the ground.

Alcohol-fueled engine mean an engine that is designed to run using an alcohol fuel. For purposes of this definition, alcohol fuels do not include fuels with a nominal alcohol content below 25 percent by volume.

Auxiliary emission control device means any element of design that senses temperature, motive speed, engine speed (r/min), transmission gear, or any other parameter for the purpose of activating, modulating, delaying, or deactivating the operation of any part of the emission control system.

Averaging set has the meaning given in § 1036.740.

Calibration means the set of specifications and tolerances specific to a particular design, version, or application of a component or assembly capable of functionally describing its operation over its working range.

Carbon-containing fuel has the meaning given in 40 CFR 1065.1001.

Carryover means relating to certification based on emission data generated from an earlier model year as described in § 1036.235(d).

Certification means relating to the process of obtaining a certificate of conformity for an engine family that complies with the emission standards and requirements in this part.

Certified emission level means the highest deteriorated emission level in an engine family for a given pollutant from the applicable transient and/or steady-state testing, rounded to the same number of decimal places as the applicable standard. Note that you may have two certified emission levels for CO₂ if you certify a family for both vocational and tractor use.

Charge-depleting has the meaning given in 40 CFR 1066.1001.

Charge-sustaining has the meaning given in 40 CFR 1066.1001.

Complete vehicle means a vehicle meeting the definition of complete vehicle in 40 CFR 1037.801 when it is first sold as a vehicle. For example, where a vehicle manufacturer sells an incomplete vehicle to a secondary vehicle manufacturer, the vehicle is not a complete vehicle under this part, even after its final assembly.

Compression-ignition means relating to a type of reciprocating, internal-combustion engine that is not a spark-ignition engine. Note that § 1036.1 also deems gas turbine engines and other engines to be compression-ignition engines.

Crankcase emissions means airborne substances emitted to the atmosphere from any part of the engine crankcase's ventilation or lubrication systems. The crankcase is the housing for the crankshaft and other related internal parts.

~~*Criteria pollutants* means emissions of NO_x, HC, PM, and CO.~~

Critical emission-related component has the meaning given in 40 CFR 1068.30.

Defeat device has the meaning given in § 1036.115(h).

Designated Compliance Officer means one of the following:

- (1) For engines subject to compression-ignition standards, *Designated Compliance Officer* means Director, Diesel Engine Compliance Center, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; complianceinfo@epa.gov; www.epa.gov/ve-certification.
- (2) For engines subject to spark-ignition standards, *Designated Compliance Officer* means Director, Gasoline Engine Compliance Center, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; complianceinfo@epa.gov; www.epa.gov/ve-certification.

Deteriorated emission level means the emission level that results from applying the appropriate deterioration factor to the official emission result of the emission-data engine. Note that where no deterioration factor applies, references in this part to the deteriorated emission level mean the official emission result.

Deterioration factor means the relationship between emissions at the end of useful life (or point of highest emissions if it occurs before the end of useful life) and emissions at the low-hour/low-mileage point, expressed in one of the following ways:

- (1) For multiplicative deterioration factors, the ratio of emissions at the end of useful life (or point of highest emissions) to emissions at the low-hour point.
- (2) For additive deterioration factors, the difference between emissions at the end of useful life (or point of highest emissions) and emissions at the low-hour point.

Diesel exhaust fluid (DEF) means a liquid reducing agent (other than the engine fuel) used in conjunction with selective catalytic reduction to reduce NO_x emissions. *Diesel exhaust fluid* is generally understood to be an aqueous solution of urea conforming to the specifications of ISO 22241.

Dual-fuel means relating to an engine designed for operation on two different types of fuel but not on a continuous mixture of those fuels (see § 1036.601(d)). For purposes of this part, such an engine remains a dual-fuel engine even if it is designed for operation on three or more different fuels.

Electronic control module (ECM) means an engine's electronic device that uses data from engine sensors to control engine parameters.

Emergency vehicle means a vehicle that meets one of the following criteria:

- (1) It is an ambulance or a fire truck.
- (2) It is a vehicle that we have determined will likely be used in emergency situations where emission control function or malfunction may cause a significant risk to human life. For example, we would consider a truck that is certain to be retrofitted with a slip-on firefighting module to become an emergency vehicle, even though it was not initially designed to be a fire truck. Also, a mobile command center that is unable to manually regenerate its DPF while on duty could be an emergency vehicle. In making this determination, we may consider any factor that has an effect on the totality of the actual risk to human life. For example, we may consider how frequently a vehicle will be used in emergency situations or how likely it is that the emission controls will cause a significant risk to human life when the vehicle is used in emergency situations. We would not consider the truck in the example above to be an

emergency vehicle if there is merely a possibility (rather than a certainty) that it will be retrofitted with a slip-on firefighting module.~~has the meaning given in 40 CFR 1037.801.~~

Emission control system means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from an engine.

Emission-data engine means an engine that is tested for certification. This includes engines tested to establish deterioration factors.

Emission-related component has the meaning given in 40 CFR part 1068, appendix A.

Emission-related maintenance means maintenance that substantially affects emissions or is likely to substantially affect emission deterioration.

Engine configuration means a unique combination of engine hardware and calibration (related to the emission standards) within an engine family, which would include hybrid components for engines certified as hybrid engines and hybrid powertrains. Engines within a single engine configuration differ only with respect to normal production variability or factors unrelated to compliance with emission standards.

Engine family has the meaning given in § 1036.230.

Excluded means relating to engines that are not subject to some or all of the requirements of this part as follows:

- (1) An engine that has been determined not to be a heavy-duty engine is excluded from this part.
- (2) Certain heavy-duty engines are excluded from the requirements of this part under § 1036.5.
- (3) Specific regulatory provisions of this part may exclude a heavy-duty engine generally subject to this part from one or more specific standards or requirements of this part.

Exempted has the meaning given in 40 CFR 1068.30.

Exhaust gas recirculation means a technology that reduces emissions by routing exhaust gases that had been exhausted from the combustion chamber(s) back into the engine to be mixed with incoming air before or during combustion. The use of valve timing to increase the amount of residual exhaust gas in the combustion chamber(s) that is mixed with incoming air before or during combustion is not considered exhaust gas recirculation for the purposes of this part.

Family certification level (FCL) means a CO₂ emission level declared by the manufacturer that is at or above emission results for all emission-data engines. The FCL serves as the emission standard for the engine family with respect to certification testing if it is different than the otherwise applicable standard.

Family emission limit (FEL) means one of the following:

- (1) For NO_x emissions, *family emission limit* means a NO_x emission level declared by the manufacturer to serve in place of an otherwise applicable emission standard under the ABT program in subpart H of this part. The FEL serves as the emission standard for the engine family with respect to all required testing.

(2) For greenhouse gas standards, *family emission limit* means an emission level that serves as the standard that applies for testing individual certified engines. The CO₂ FEL is equal to the CO₂ FCL multiplied by 1.03 and rounded to the same number of decimal places as the standard.

Federal Test Procedure (FTP) means the applicable transient duty cycle described in § 1036.512 designed to measure exhaust emissions during urban driving.

Flexible-fuel means relating to an engine designed for operation on any mixture of two or more different types of fuels (see § 1036.601(d)).

Fuel type means a general category of fuels such as diesel fuel, gasoline, or natural gas. There can be multiple grades within a single fuel type, such as premium gasoline, regular gasoline, or gasoline with 10 percent ethanol.

Good engineering judgment has the meaning given in 40 CFR 1068.30. See 40 CFR 1068.5 for the administrative process we use to evaluate good engineering judgment.

~~*Greenhouse gas* means one or more compounds regulated under this part based primarily on their impact on the climate. This generally includes CO₂, CH₄, and N₂O.~~

Greenhouse gas Emissions Model (GEM) means the GEM simulation tool described in 40 CFR 1037.520. Note that an updated version of GEM applies starting in model year 2021.

Gross vehicle weight rating (GVWR) means the value specified by the vehicle manufacturer as the maximum design loaded weight of a single vehicle, consistent with good engineering judgment.

Heavy-duty engine means any engine which the engine manufacturer could reasonably expect to be used for motive power in a heavy-duty vehicle. For purposes of this definition in this part, the term “engine” includes internal combustion engines and other devices that convert chemical fuel into motive power. For example, a gas turbine used in a heavy-duty vehicle is a heavy-duty engine.

Heavy-duty vehicle means any motor vehicle above 8,500 pounds GVWR. An incomplete vehicle is also a heavy-duty vehicle if it has a curb weight above 6,000 pounds or a basic vehicle frontal area greater than 45 square feet. *Curb weight* and *basic vehicle frontal area* have the meaning given in 40 CFR 86.1803-01.

Hybrid means relating to an engine or powertrain that includes a Rechargeable Energy Storage System. Hybrid engines store and recover energy in a way that is integral to the engine or otherwise upstream of the vehicle’s transmission. Examples of hybrid engines include engines with hybrid components connected to the front end of the engine (P0), connected to the crankshaft before the clutch (P1), or connected between the clutch and the transmission where the clutch upstream of the hybrid feature is in addition to the transmission clutch(s) or clutches (P2). Engine-based systems that recover kinetic energy to power an electric heater in the aftertreatment are themselves not sufficient to qualify as a hybrid engine. Provisions that apply for hybrid powertrains apply equally for hybrid engines, except as specified. Note that certain provisions in this part treat hybrid powertrains intended for vehicles that include regenerative braking different than those intended for vehicles that do not include regenerative braking. The

~~definition of hybrid includes plug-in hybrid electric powertrains. an engine or powertrain that includes energy storage features other than a conventional battery system or conventional flywheel. Supplemental electrical batteries and hydraulic accumulators are examples of hybrid energy storage systems. Note that certain provisions in this part treat hybrid engines and hybrid powertrains intended for vehicles that include regenerative braking different than those intended for vehicles that do not include regenerative braking.~~

~~*Hybrid engine* means a hybrid system with features for storing and recovering energy that are integral to the engine or are otherwise upstream of the vehicle's transmission other than a conventional battery system or conventional flywheel. Supplemental electrical batteries and hydraulic accumulators are examples of hybrid energy storage systems. Examples of hybrids that could be considered hybrid engines are P0, P1, and P2 hybrids where hybrid features are connected to the front end of the engine, at the crankshaft, or connected between the clutch and the transmission where the clutch upstream of the hybrid feature is in addition to the transmission clutch(s), respectively. Note other examples of systems that qualify as hybrid engines are systems that recover kinetic energy and use it to power an electric heater in the aftertreatment.~~

~~*Hybrid powertrain* means a powertrain that includes energy storage features other than a conventional battery system or conventional flywheel. Supplemental electrical batteries and hydraulic accumulators are examples of hybrid energy storage systems. Note other examples of systems that qualify as hybrid powertrains are systems that recover kinetic energy and use it to power an electric heater in the aftertreatment.~~

Hydrocarbon (HC) has the meaning given in 40 CFR 1065.1001.

Identification number means a unique specification (for example, a model number/serial number combination) that allows someone to distinguish a particular engine from other similar engines.

Incomplete vehicle means a vehicle meeting the definition of incomplete vehicle in 40 CFR 1037.801 when it is first sold (or otherwise delivered to another entity) as a vehicle.

Innovative technology means technology certified under § 1036.610 (also described as “off-cycle technology”).

Liquefied petroleum gas (LPG) means a liquid hydrocarbon fuel that is stored under pressure and is composed primarily of nonmethane compounds that are gases at atmospheric conditions. Note that, although this commercial term includes the word “petroleum”, LPG is not considered to be a petroleum fuel under the definitions of this section.

Low-hour means relating to an engine that has stabilized emissions and represents the undeteriorated emission level. This would generally involve less than 300 hours of operation for engines with NO_x aftertreatment and 125 hours of operation for other engines.

Manufacture means the physical and engineering process of designing, constructing, and/or assembling a heavy-duty engine or a heavy-duty vehicle.

Manufacturer has the meaning given in 40 CFR 1068.30.

Medium-duty passenger vehicle has the meaning given in 40 CFR 86.1803.

Mild hybrid means relating to a hybrid engine or hybrid powertrain with regenerative braking capability where the system recovers less than 20 percent of the total braking energy over the transient cycle defined in appendix A of 40 CFR part 1037, appendix A.

Model year means the manufacturer's annual new model production period, except as restricted under this definition. It must include January 1 of the calendar year for which the model year is named, may not begin before January 2 of the previous calendar year, and it must end by December 31 of the named calendar year. Manufacturers may not adjust model years to circumvent or delay compliance with emission standards or to avoid the obligation to certify annually.

Motorcoach means a heavy-duty vehicle designed for carrying 30 or more passengers over long distances. Such vehicles are characterized by row seating, rest rooms, and large luggage compartments, and facilities for stowing carry-on luggage.

Motor vehicle has the meaning given in 40 CFR 85.1703.

Natural gas means a fuel whose primary constituent is methane.

Neat has the meaning given in 40 CFR 1065.1001.

New motor vehicle engine has the meaning given in the Act. This generally means a motor vehicle engine meeting any of the following:

- (1) A motor vehicle engine for which the ultimate purchaser has never received the equitable or legal title is a *new motor vehicle engine*. This kind of engine might commonly be thought of as "brand new" although a *new motor vehicle engine* may include previously used parts. Under this definition, the engine is new from the time it is produced until the ultimate purchaser receives the title or places it into service, whichever comes first.
- (2) An imported motor vehicle engine is a *new motor vehicle engine* if it was originally built on or after January 1, 1970.
- (3) Any motor vehicle engine installed in a new motor vehicle.

Noncompliant engine means an engine that was originally covered by a certificate of conformity, but is not in the certified configuration or otherwise does not comply with the conditions of the certificate.

Nonconforming engine means an engine not covered by a certificate of conformity that would otherwise be subject to emission standards.

Nonmethane hydrocarbon (NMHC) means the sum of all hydrocarbon species except methane, as measured according to 40 CFR part 1065.

Nonmethane hydrocarbon equivalent (NMHCE) has the meaning given in 40 CFR 1065.1001.

Nonmethane nonethane hydrocarbon equivalent (NMNEHC) has the meaning given in 40 CFR 1065.1001.

Off-cycle technology means technology certified under § 1036.610 (also described as "innovative technology").

Official emission result means the measured emission rate for an emission-data engine on a given duty cycle before the application of any deterioration factor, but after the applicability of any required regeneration or other adjustment factors.

Owners manual means a document or collection of documents prepared by the engine or vehicle manufacturer for the owner or operator to describe appropriate engine maintenance, applicable warranties, and any other information related to operating or keeping the engine. The owners manual is typically provided to the ultimate purchaser at the time of sale. The owners manual may be in paper or electronic format.

Oxides of nitrogen has the meaning given in 40 CFR 1065.1001.

Percent has the meaning given in 40 CFR 1065.1001. Note that this means percentages identified in this part are assumed to be infinitely precise without regard to the number of significant figures. For example, one percent of 1,493 is 14.93.

Placed into service means put into initial use for its intended purpose, excluding incidental use by the manufacturer or a dealer.

Preliminary approval means approval granted by an authorized EPA representative prior to submission of an application for certification, consistent with the provisions of § 1036.210.

Primary intended service class has the meaning given in § 1036.140.

Rechargeable Energy Storage System (RESS) has the meaning given in 40 CFR 1065.1001.

Relating to as used in this section means relating to something in a specific, direct manner. This expression is used in this section only to define terms as adjectives and not to broaden the meaning of the terms.

Revoke has the meaning given in 40 CFR 1068.30.

Round has the meaning given in 40 CFR 1065.1001.

Sample means the collection of engines selected from the population of an engine family for emission testing. This may include testing for certification, production-line testing, or in-use testing.

Scheduled maintenance means adjusting, removing, disassembling, cleaning, or replacing components or systems periodically to keep a part or system from failing, malfunctioning, or wearing prematurely.

Small manufacturer means a manufacturer meeting the criteria specified in 13 CFR 121.201. The employee and revenue limits apply to the total number of employees and total revenue together for all affiliated companies (as defined in 40 CFR 1068.30). Note that manufacturers with low production volumes may or may not be “small manufacturers”.

Spark-ignition means relating to a gasoline-fueled engine or any other type of engine with a spark plug (or other sparking device) and with operating characteristics significantly similar to the theoretical Otto combustion cycle. Spark-ignition engines usually use a throttle to regulate intake air flow to control power during normal operation.

Steady-state has the meaning given in 40 CFR 1065.1001. This includes fuel mapping and idle testing where engine speed and load are held at a finite set of nominally constant values.

Suspend has the meaning given in 40 CFR 1068.30.

Test engine means an engine in a sample.

Tractor means a vehicle meeting the definition of “tractor” in 40 CFR 1037.801, but not classified as a “vocational tractor” under 40 CFR 1037.630, or relating to such a vehicle.

Tractor engine means an engine certified for use in tractors. Where an engine family is certified for use in both tractors and vocational vehicles, “tractor engine” means an engine that the engine manufacturer reasonably believes will be (or has been) installed in a tractor. Note that the provisions of this part may require a manufacturer to document how it determines that an engine is a tractor engine.

Ultimate purchaser means, with respect to any new engine or vehicle, the first person who in good faith purchases such new engine or vehicle for purposes other than resale.

United States has the meaning given in 40 CFR 1068.30.

Upcoming model year means for an engine family the model year after the one currently in production.

U.S.-directed production volume means the number of engines, subject to the requirements of this part, produced by a manufacturer for which the manufacturer has a reasonable assurance that sale was or will be made to ultimate purchasers in the United States. ~~This does not include Note that this includes engines certified to state emission standards that are different than the emission standards in this part.~~

Vehicle has the meaning given in 40 CFR 1037.801.

Vocational engine means an engine certified for use in vocational vehicles. Where an engine family is certified for use in both tractors and vocational vehicles, “vocational engine” means an engine that the engine manufacturer reasonably believes will be (or has been) installed in a vocational vehicle. Note that the provisions of this part may require a manufacturer to document how it determines that an engine is a vocational engine.

Vocational vehicle means a vehicle meeting the definition of “vocational” vehicle in 40 CFR 1037.801.

Void has the meaning given in 40 CFR 1068.30.

We (us, our) means the Administrator of the Environmental Protection Agency and any authorized representatives.

§ 1036.805 Symbols, abbreviations, and acronyms.

The procedures in this part generally follow either the International System of Units (SI) or the United States customary units, as detailed in NIST Special Publication 811 (incorporated by reference, ~~see~~ § 1036.810). See 40 CFR 1065.20 for specific provisions related to these

conventions. This section summarizes the way we use symbols, units of measure, and other abbreviations.

(a) *Symbols for chemical species.* This part uses the following symbols for chemical species and exhaust constituents:

TABLE 1 TO PARAGRAPH (a) OF § 1036.805—SYMBOLS FOR CHEMICAL SPECIES AND EXHAUST CONSTITUENTS

Symbol	Species
C	carbon.
CH ₄	methane.
CH ₄ N ₂ O	urea.
CO	carbon monoxide.
CO ₂	carbon dioxide.
H ₂ O	water.
HC	hydrocarbon.
NMHC	nonmethane hydrocarbon.
NMHCE	nonmethane hydrocarbon equivalent.
NMNEHC	nonmethane nonethane hydrocarbon.
NO	nitric oxide.
NO ₂	nitrogen dioxide.
NO _x	oxides of nitrogen.
N ₂ O	nitrous oxide.
PM	particulate matter.

(b) *Symbols for quantities.* This part uses the following symbols and units of measure for various quantities:

TABLE 2 TO PARAGRAPH (b) OF § 1036.805—SYMBOLS FOR QUANTITIES

Symbol	Quantity	Unit	Unit Symbol	Unit in Terms of SI Base Units
α	atomic hydrogen-to-carbon ratio	mole per mole	mol/mol	1
A	Area	square meter	m ²	m ²
β	atomic oxygen-to-carbon ratio	mole per mole	mol/mol	1
C_dA	drag area	meter squared	m ²	m ²
C_{rr}	coefficient of rolling resistance	newton per kilonewton	N/kN	10 ⁻³
D	distance	miles or meters	mi or m	m
ε	efficiency			
ϵ	Difference or error quantity			
e	mass weighted emission result	grams/ton-mile	g/ton-mi	g/kg-km
Eff	efficiency			
E_m	mass-specific net energy content	megajoules/kilogram	MJ/kg	m ² ·s ⁻²
f_n	angular speed (shaft)	revolutions per minute	r/min	$\pi \cdot 30 \cdot s^{-1}$
g	gravitational acceleration	meters per second squared	m/s ²	m·s ⁻²
i	indexing variable			
k_a	drive axle ratio			1
$k_{topgear}$	highest available transmission gear			
m	Mass	pound mass or kilogram	lbm or kg	kg
M	molar mass	gram per mole	g/mol	10 ⁻³ ·kg·mol ⁻¹
M	total number in a series			
M	vehicle mass	kilogram	kg	kg
$M_{rotating}$	inertial mass of rotating components	kilogram	kg	kg
N	total number in a series			
Q	total number in a series			
P	Power	kilowatt	kW	10 ³ ·m ² ·kg·s ⁻³
ρ	mass density	kilogram per cubic meter	kg/m ³	m ⁻³ ·kg
r	tire radius	meter	m	m
SEE	standard error of the estimate			
σ	standard deviation			
T	torque (moment of force)	newton meter	N·m	m ² ·kg·s ⁻²
t	Time	second	s	s
Δt	time interval, period, 1/frequency	second	s	s
UF	utility factor			
v	Speed	miles per hour or meters per second	mi/hr or m/s	m·s ⁻¹
W	Work	kilowatt-hour	kW·hr	3.6·m ² ·kg·s ⁻¹
w_C	carbon mass fraction	gram/gram	g/g	1
w_{CH4N2O}	urea mass fraction	gram/gram	g/g	1

x	amount of substance mole fraction	mole per mole	mol/mol	1
x_b	brake energy fraction			
x_{bl}	brake energy limit			

(c) *Superscripts*. This part uses the following superscripts for modifying quantity symbols:

TABLE 3 TO PARAGRAPH (c) OF § 1036.805—SUPERSCRIPTS

Superscript	Meaning
overbar (such as \bar{y})	arithmetic mean.
overdot (such as \dot{y})	quantity per unit time.

(d) *Subscripts*. This part uses the following subscripts for modifying quantity symbols:

TABLE 4 TO PARAGRAPH (d) OF § 1036.805—SUBSCRIPTS

Subscript	Meaning
65	65 miles per hour.
A	A speed.
a	absolute (e.g., absolute difference or error).
acc	accessory.
app	approved.
axle	axle.
B	B speed.
C	C speed.
C	carbon mass.
Ccombdry	carbon from fuel per mole of dry exhaust.
CD	charge-depleting.
CO ₂ DEF	CO ₂ resulting from diesel exhaust fluid decomposition.
comb	combustion.
comp	composite.
cor	corrected.
CS	charge-sustaining.
cycle	cycle.
D	distance.
D	D speed.
DEF	diesel exhaust fluid.
engine	engine.
exh	raw exhaust.
front	frontal.
fuel	fuel.
H ₂ Oexhaustdry	H ₂ O in exhaust per mole of exhaust.
hi	high.
i	an individual of a series.
idle	idle.
int	test interval.
j	an individual of a series.
k	an individual of a series.
m	mass.
max	maximum.
mapped	mapped.
meas	measured quantity.
MY	model year.
neg	negative.
pos	positive.
R	range.
r	relative (e.g., relative difference or error).
rate	rate (divided by time).
rated	rated.
record	record.
ref	reference quantity.
speed	speed.
stall	stall.
test	test.
tire	tire.
transient	transient.
μ	vector.

UF	utility factor.
vehicle	vehicle.

(e) *Other acronyms and abbreviations.* This part uses the following additional abbreviations and acronyms:

TABLE 5 TO PARAGRAPH (e) OF § 1036.805—OTHER ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
ABT	averaging, banking, and trading.
AECD	auxiliary emission control device.
ASTM	American Society for Testing and Materials.
BTU	British thermal units.
CD	charge-depleting.
CFR	Code of Federal Regulations.
CI	compression-ignition.
COV	coefficient of variation.
CS	charge-sustaining.
DEF	diesel exhaust fluid.
DF	deterioration factor.
DOT	Department of Transportation.
E85	gasoline blend including nominally 85 percent denatured ethanol.
ECM	Electronic Control Module.
EGR	exhaust gas recirculation.
EPA	Environmental Protection Agency.
FCL	Family Certification Level.
FEL	family emission limit.
FTP	Federal Test Procedure.
GCWR	<u>gross combined weight rating.</u>
GEM	Greenhouse gas Emissions Model.
g/hp·hr	grams per brake horsepower-hour.
GPS	global positioning system.
GVWR	gross vehicle weight rating.
Heavy HDE	heavy heavy-duty engine (see § 1036.140).
Heavy HDV	heavy heavy-duty vehicle (see 40 CFR 1037.140).
Light HDE	light heavy-duty engine (see § 1036.140).
Light HDV	light heavy-duty vehicle (see 40 CFR 1037.140).
LLC	Low Load Cycle.
LPG	liquefied petroleum gas.
Medium HDE	medium heavy-duty engine (see § 1036.140).
Medium HDV	medium heavy-duty vehicle (see 40 CFR 1037.140).
NARA	National Archives and Records Administration.
NHTSA	National Highway Traffic Safety Administration.
NTE	not-to-exceed.
PEMS	portable emission measurement system.
RESS	rechargeable energy storage system.
SCR	selective catalytic reduction.
SEE	standard error of the estimate.
SET	Supplemental Emission Test.
Spark-ignition HDE	spark-ignition heavy-duty engine (see § 1036.140).
SI	spark-ignition.
UL	useful life.
U.S.	United States.
U.S.C.	United States Code.

(f) *Constants.* This part uses the following constants:

TABLE 6 TO PARAGRAPH (f) OF § 1036.805—CONSTANTS

Symbol	Quantity	Value
<i>g</i>	gravitational constant	9.80665 m·s ⁻²
<i>R</i>	molar gas constant	8.314472 J/(mol·K) (m ² ·kg·s ⁻² ·mol ⁻¹ ·K ⁻¹)

(g) *Prefixes*. This part uses the following prefixes to define a quantity:

TABLE 7 TO PARAGRAPH (g) OF § 1036.805—PREFIXES

Symbol	Quantity	Value
μ	micro	10 ⁻⁶
m	milli	10 ⁻³
c	centi	10 ⁻²
k	kilo	10 ³
M	mega	10 ⁶

§ 1036.810 Incorporation by reference.

Certain material is incorporated by reference into this part with the approval of the Director of the Federal Register under 5 U.S.C. 552(a) and 1 CFR part 51. To enforce any edition other than that specified in this section, EPA must publish a document in the Federal Register and the material must be available to the public. All approved incorporation by reference (IBR) material is available for inspection at EPA and at the National Archives and Records Administration (NARA). Contact EPA at: U.S. EPA, Air and Radiation Docket Center, WJC West Building, Room 3334, 1301 Constitution Ave. NW, Washington, DC 20004; www.epa.gov/dockets; (202) 202-1744. For information on inspecting this material at NARA, visit www.archives.gov/federal-register/cfr/ibr-locations.html or email fr.inspection@nara.gov. The material may be obtained from the following sources:

(a) ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA, 19428-2959; (877) 909-2786; www.astm.org.

(1) ASTM D975-22, Standard Specification for Diesel Fuel, approved October 1, 2022 (“ASTM D975”); IBR approved for § 1036.415(c).

(2) ASTM D3588-98 (Reapproved 2017)e1, Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels, approved April 1, 2017 (“ASTM D3588”); IBR approved for § 1036.550(b).

(3) ASTM D4809-18, Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method), approved July 1, 2018 (“ASTM D4809”); IBR approved for § 1036.550(b).

(4) ASTM D4814-21c, Standard Specification for Automotive Spark-Ignition Engine Fuel, approved December 15, 2021 (“ASTM D4814”); IBR approved for § 1036.415(c).

(5) ASTM D7467-20a, Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20), approved June 1, 2020 (“ASTM D7467”); IBR approved for § 1036.415(c).

(b) National Institute of Standards and Technology (NIST), 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070; (301) 975-6478; www.nist.gov.

(1) NIST Special Publication 811, 2008 Edition, Guide for the Use of the International System of Units (SI), Physics Laboratory, March 2008; IBR approved for § 1036.805.

(2) [Reserved]

(c) SAE International, 400 Commonwealth Dr., Warrendale, PA 15096-0001; (877) 606-7323 (U.S. and Canada) or (724) 776-4970 (outside the U.S. and Canada); www.sae.org:

(1) SAE J1979-2 APR2021, E/E Diagnostic Test Modes: OBDOnUDS, Issued April 2021, (“SAE J1979-2”); IBR approved for § 1036.150(v).

(2) [Reserved]

(d) State of California, Office of Administrative Law, 300 Capitol Mall, Suite 1250, Sacramento, CA 95814-4339; 916-323-6815; staff@oal.ca.gov; www.oal.ca.gov/publications/ccr.

(1) 2019 13 CCR 1968.2, Title 13. Motor Vehicles, Division 3. Air Resources Board, Chapter 1. Motor Vehicle Pollution Control Devices, Article 2. Approval of Motor Vehicle Pollution Control Devices (New Vehicles), § 1968.2. Malfunction and Diagnostic System Requirements—2004 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines, operative October 3, 2019 “13 CCR 1968.2”; into §§ 1036.110(b); 1036.111(a).

(2) 2019 13 CCR 1968.5, Title 13. Motor Vehicles, Division 3. Air Resources Board, Chapter 1. Motor Vehicle Pollution Control Devices, Article 2. Approval of Motor Vehicle Pollution Control Devices (New Vehicles), § 1968.5. Enforcement of Malfunction and Diagnostic System Requirements for 2004 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines, operative July 25, 2016 “13 CCR 1968.5”; into § 1036.110(b).

(3) 2019 13 CCR 1971.1, Title 13. Motor Vehicles, Division 3. Air Resources Board, Chapter 1. Motor Vehicle Pollution Control Devices, Article 2. Approval of Motor Vehicle Pollution Control Devices (New Vehicles), § 1971.1. On-Board Diagnostic System Requirements—2010 and Subsequent Model-Year Heavy-Duty Engines, operative October 3, 2019 “13 CCR 1971.1”; into §§ 1036.110(b); 1036.111(a); 1036.150(v).

(4) 13 CA ADC 1971.5: 2019 CA REG TEXT 504962 (NS), 13 CA ADC 1971.5. Enforcement of Malfunction and Diagnostic System Requirements for 2010 and Subsequent Model-Year Heavy-Duty Engines, operative October 3, 2019 “13 CCR 1971.5”; into § 1036.110(b).

(e) U.S. EPA, Office of Air and Radiation, 2565 Plymouth Road, Ann Arbor, MI 48105; www.epa.gov; complianceinfo@epa.gov.

(1) Greenhouse gas Emissions Model (GEM) Phase 2, Version 4.0, April 2022 (“GEM Phase 2, Version 4.0”); IBR approved for § 1036.545(a).

(2) [Reserved]

§ 1036.815 Confidential information.

(a) The provisions of 40 CFR 1068.10 and 1068.11 apply for information you submit under this part.

(b) Emission data or information that is publicly available cannot be treated as confidential business information as described in 40 CFR 1068.11. Data that vehicle manufacturers need for demonstrating compliance with greenhouse gas emission standards, including fuel-consumption data as described in §§ 1036.535 and ~~§ 1036.54540 CFR 1037.550~~, also qualify as emission data for purposes of confidentiality determinations.

§ 1036.820 Requesting a hearing.

(a) You may request a hearing under certain circumstances, as described elsewhere in this part. To do this, you must file a written request, including a description of your objection and any supporting data, within 30 days after we make a decision.

(b) For a hearing you request under the provisions of this part, we will approve your request if we find that your request raises a substantial factual issue.

(c) If we agree to hold a hearing, we will use the procedures specified in 40 CFR part 1068, subpart G.

§ 1036.825 Reporting and recordkeeping requirements.

(a) This part includes various requirements to submit and record data or other information. Unless we specify otherwise, store required records in any format and on any media and keep them readily available for eight years after you send an associated application for certification, or eight years after you generate the data if they do not support an application for certification. We may review these records at any time. You must promptly give us organized, written records in English if we ask for them. We may require you to submit written records in an electronic format.

(b) The regulations in § 1036.255 and 40 CFR 1068.25 and 1068.101 describe your obligation to report truthful and complete information. This includes information not related to certification. Failing to properly report information and keep the records we specify violates 40 CFR 1068.101(a)(2), which may involve civil or criminal penalties.

(c) Send all reports and requests for approval to the Designated Compliance Officer (see § 1036.801).

(d) Any written information we require you to send to or receive from another company is deemed to be a required record under this section. Such records are also deemed to be submissions to EPA. Keep these records for eight years unless the regulations specify a different period. We may require you to send us these records whether or not you are a certificate holder.

(e) Under the Paperwork Reduction Act (44 U.S.C. 3501 et seq.), the Office of Management and Budget approves the reporting and recordkeeping specified in the applicable regulations. The following items illustrate the kind of reporting and recordkeeping we require for engines and vehicles regulated under this part:

(1) We specify the following requirements related to engine certification in this part:

(i) In § 1036.135 we require engine manufacturers to keep certain records related to duplicate labels sent to vehicle manufacturers.

(ii) In § 1036.150 we include various reporting and recordkeeping requirements related to interim provisions.

(iii) In subpart C of this part we identify a wide range of information required to certify engines.

(iv) In §§ 1036.430 and 1036.435 we identify reporting and recordkeeping requirements related to field testing in-use engines.

(v) In subpart G of this part we identify several reporting and recordkeeping items for making demonstrations and getting approval related to various special compliance provisions.

(vi) In §§ 1036.725, 1036.730, and 1036.735 we specify certain records related to averaging, banking, and trading.

(2) We specify the following requirements related to testing in 40 CFR part 1065:

(i) In 40 CFR 1065.2 we give an overview of principles for reporting information.

(ii) In 40 CFR 1065.10 and 1065.12 we specify information needs for establishing various changes to published procedures.

(iii) In 40 CFR 1065.25 we establish basic guidelines for storing information.

(iv) In 40 CFR 1065.695 we identify the specific information and data items to record when measuring emissions.

(3) We specify the following requirements related to the general compliance provisions in 40 CFR part 1068:

- (i) In 40 CFR 1068.5 we establish a process for evaluating good engineering judgment related to testing and certification.
- (ii) In 40 CFR 1068.25 we describe general provisions related to sending and keeping information
- (iii) In 40 CFR 1068.27 we require manufacturers to make engines available for our testing or inspection if we make such a request.
- (iv) In 40 CFR 1068.105 we require vehicle manufacturers to keep certain records related to duplicate labels from engine manufacturers.
- (v) In 40 CFR 1068.120 we specify recordkeeping related to rebuilding engines.
- (vi) In 40 CFR part 1068, subpart C, we identify several reporting and recordkeeping items for making demonstrations and getting approval related to various exemptions.
- (vii) In 40 CFR part 1068, subpart D, we identify several reporting and recordkeeping items for making demonstrations and getting approval related to importing engines.
- (viii) In 40 CFR 1068.450 and 1068.455 we specify certain records related to testing production-line engines in a selective enforcement audit.
- (ix) In 40 CFR 1068.501 we specify certain records related to investigating and reporting emission-related defects.
- (x) In 40 CFR 1068.525 and 1068.530 we specify certain records related to recalling nonconforming engines.
- (xi) In 40 CFR part 1068, subpart G, we specify certain records for requesting a hearing.

Appendix A of Part 1036—Summary of Previous Emission Standards

Appendix B of Part 1036—Transient Duty Cycles

Appendix C of Part 1036—Default Engine Fuel Maps for § 1036.540

PART 1037— CONTROL OF EMISSIONS FROM NEW HEAVY-DUTY MOTOR VEHICLES

Authority: 42 U.S.C. 7401 - 7671q.

Subpart A—Overview and Applicability

§ 1037.1 Applicability.

- (a) The regulations in this part 1037 apply for all new heavy-duty vehicles, except as provided in §§ 1037.5 ~~and 1037.104~~. This includes battery electric vehicles, fuel cell electric vehicles, and vehicles fueled by conventional and alternative fuels. ~~This also includes certain trailers as described in §§ 1037.5, 1037.150, and 1037.801.~~
- (b) The provisions of this part apply for alternative fuel conversions as specified in 40 CFR part 85, subpart F.

§ 1037.2 Who is responsible for compliance?

The regulations in this part 1037 contain provisions that affect both vehicle manufacturers and others. However, the requirements of this part are generally addressed to the vehicle manufacturer(s). The term "you" generally means the vehicle manufacturer(s), especially for issues related to certification. See § 1037.801 for the definition of "manufacturer" and § 1037.620 for provisions related to compliance when there are multiple entities meeting the definition of "manufacturer." Additional requirements and prohibitions apply to other persons as specified in subpart G of this part and 40 CFR part 1068.

§ 1037.5 Excluded vehicles.

Except for the definitions specified in § 1037.801, this part does not apply to the following vehicles:

- (a) Vehicles not meeting the definition of "motor vehicle" in § 1037.801.
- (b) Vehicles excluded from the definition of "heavy-duty vehicle" in § 1037.801 because of vehicle weight, weight rating, and frontal area (such as light-duty vehicles and light-duty trucks).
- (c) Vehicles produced in model years before 2014, unless they were certified under § 1037.150.
- (d) Medium-duty passenger vehicles and other vehicles subject to the light-duty greenhouse gas standards of 40 CFR part 86. See 40 CFR 86.1818 for greenhouse gas standards that apply for these vehicles. An example of such a vehicle would be a vehicle meeting the definition of "heavy-duty vehicle" in § 1037.801 and 40 CFR 86.1803, but also meeting the definition of "light truck" in 40 CFR 86.1818-12(b)(2).
- (e) Vehicles subject to the heavy-duty emission standards of 40 CFR part 86. See 40 CFR ~~86.1816 and 86.1819 for~~ part 86, subpart S, for emission standards that apply for these vehicles. ~~This exclusion generally applies for complete heavy-duty vehicles at or below 14,000 pounds GVWR.~~
- (f) Aircraft meeting the definition of "motor vehicle". For example, this would include certain convertible aircraft that can be adjusted to operate on public roads. Standards apply separately to certain aircraft engines, as described in 40 CFR part 87.
- (g) ~~Non-box trailers other than flatbed trailers, tank trailers, and container chassis.~~
- (h) ~~Trailers meeting one or more of the following characteristics:~~

- ~~(1) Trailers with four or more axles and trailers less than 35 feet long with three axles (i.e., trailers intended for hauling very heavy loads).~~
- ~~(2) Trailers intended for temporary or permanent residence, office space, or other work space, such as campers, mobile homes, and carnival trailers.~~
- ~~(3) Trailers with a gap of at least 120 inches between adjacent axle centerlines. In the case of adjustable axle spacing, this refers to the closest possible axle positioning.~~
- ~~(4) Trailers built before January 1, 2018.~~
- ~~(5) Note that the definition of “trailer” in § 1037.801 excludes equipment that serves similar purposes but are not intended to be pulled by a tractor. This exclusion applies to such equipment whether or not they are known commercially as trailers. For example, any equipment pulled by a heavy-duty vehicle with a pintle hook or hitch instead of a fifth wheel does not qualify as a trailer under this part.~~
- (+) Where it is unclear, you may ask us to make a determination regarding the exclusions identified in this section. We recommend that you make your request before you produce the vehicle.

§ 1037.10 How is this part organized?

This part 1037 is divided into the following subparts:

- (a) Subpart A of this part defines the applicability of part 1037 and gives an overview of regulatory requirements.
- (b) Subpart B of this part describes the emission standards and other requirements that must be met to certify vehicles under this part. Note that § 1037.150 discusses certain interim requirements and compliance provisions that apply only for a limited time.
- (c) Subpart C of this part describes how to apply for a certificate of conformity.
- (d) Subpart D of this part addresses testing of production vehicles.
- (e) Subpart E of this part addresses testing of in-use vehicles.
- (f) Subpart F of this part describes how to test your vehicles and perform emission modeling (including references to other parts of the Code of Federal Regulations) for vehicles subject to the standards of § 1037.105 or § 1037.106.
- (g) Subpart G of this part and 40 CFR part 1068 describe requirements, prohibitions, and other provisions that apply to manufacturers, owners, operators, rebuilders, and all others. Section 1037.601 describes how 40 CFR part 1068 applies for heavy-duty vehicles.
- (h) Subpart H of this part describes how you may generate and use emission credits to certify vehicles.
- (i) Subpart I of this part contains definitions and other reference information.

§ 1037.15 Do any other regulation parts apply to me?

- (a) Parts 1065 and 1066 of this chapter describe procedures and equipment specifications for testing engines and vehicles to measure exhaust emissions. Subpart F of this part 1037 describes how to apply the provisions of part 1065 and part 1066 of this chapter to determine whether vehicles meet the exhaust emission standards in this part.
- (b) As described in § 1037.601, certain requirements and prohibitions of part 1068 of this chapter apply to everyone, including anyone who manufactures, imports, installs, owns, operates, or rebuilds any of the vehicles subject to this part 1037. Part 1068 of this chapter describes general provisions that apply broadly, but do not necessarily apply for all vehicles or all persons. The issues addressed by these provisions include these seven areas:
 - (1) Prohibited acts and penalties for manufacturers and others.

- (2) Rebuilding and other aftermarket changes.
- (3) Exclusions and exemptions for certain vehicles.
- (4) Importing vehicles.
- (5) Selective enforcement audits of your production.
- (6) Recall.
- (7) Procedures for hearings.
- (c) [Reserved]
- (d) Other parts of this chapter apply if referenced in this part.

§ 1037.30 Submission of information.

Unless we specify otherwise, send all reports and requests for approval to the Designated Compliance Officer (see § 1037.801). See § 1037.825 for additional reporting and recordkeeping provisions.

Subpart B—Emission Standards and Related Requirements

§ 1037.101 Overview of emission standards.

~~This part specifies emission standards for certain vehicles and for certain pollutants. This part contains standards and other regulations applicable to the emission of the air pollutant defined the aggregate group of six greenhouse gases: carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.~~

- (a) You must show that vehicles meet the following emission standards:
 - (1) *Exhaust emissions of criteria pollutants.* Criteria pollutant standards for NO_x, HC, PM, and CO apply as described in § 1037.102. These pollutants are sometimes described collectively as “criteria pollutants” because they are either criteria pollutants under the Clean Air Act or precursors to the criteria pollutants ozone and PM.
 - (2) *Exhaust emissions of greenhouse gases.* This part contains standards and other regulations applicable to the emission of the air pollutant defined as the aggregate group of six greenhouse gases: carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. ~~These pollutants are described collectively in this part as “greenhouse gas pollutants” because they are regulated primarily based on their impact on the climate.~~ Emission standards apply as follows for greenhouse gas (GHG) emissions:
 - (i) CO₂, ~~CH₄, and N₂O~~ emission standards apply as described in §§ 1037.105 ~~through 1037.107 and 1037.106.~~ No CH₄ or N₂O standards apply under this part. See 40 CFR part 1036 for CH₄ or N₂O standards that apply to engines used in these vehicles.
 - (ii) Hydrofluorocarbon standards apply as described in § 1037.115(e). These pollutants are also “greenhouse gas pollutants” but are treated separately from exhaust greenhouse gas pollutants listed in paragraph ~~(a)~~(2)(i) of this section.
 - (3) *Fuel evaporative and refueling emissions.* Requirements related to fuel evaporative and refueling emissions are described in § 1037.103.
- (b) The regulated heavy-duty vehicles are addressed in different groups as follows:
 - (1) For criteria pollutants, ~~vocational~~ vehicles ~~and tractors~~ are regulated based on gross vehicle weight rating (GVWR), whether they are considered “spark-ignition” or “compression-ignition,” and whether they are first sold as complete or incomplete vehicles.
 - (2) For greenhouse gas pollutants, vehicles are regulated in the following groups:
 - ~~(i) Tractors above 26,000 pounds GVWR.~~

~~(ii) Trailers.~~

~~(iii) Vocational vehicles.~~

~~(3) Greenhouse gas standards apply differently for vocational vehicles and tractors.~~ ~~G~~The greenhouse gas ~~emission~~ standards also apply differently depending on the vehicle service class as described in § 1037.140. In addition, standards apply differently for vehicles with spark-ignition and compression-ignition engines. References in this part 1037 to “spark-ignition” or “compression-ignition” generally relate to the application of standards under 40 CFR 1036.140. For example, a vehicle with an engine certified to spark-ignition standards under 40 CFR part 1036 is generally subject to requirements under this part 1037 that apply for spark-ignition vehicles. However, note that emission standards for Heavy HDE are considered to be compression-ignition standards for purposes of applying vehicle emission standards under this part. Also, for spark-ignition engines voluntarily certified as compression-ignition engines under 40 CFR part 1036, you must choose at certification whether your vehicles are subject to spark-ignition standards or compression-ignition standards. Heavy-duty vehicles with no installed propulsion engine, such as battery electric vehicles, are subject to compression-ignition emission standards under §§ 1037.105 and 1037.106 for the purpose of calculating emission credits.

~~(34)~~ For evaporative and refueling emissions, vehicles are regulated based on the type of fuel they use. Vehicles fueled with volatile liquid fuels or gaseous fuels are subject to evaporative and refueling emission standards.

§ 1037.102 ~~Criteria e~~Exhaust emission standards ~~—~~for NO_x, HC, PM, and CO.

(a) Engines installed in heavy-duty vehicles are subject to criteria pollutant standards for NO_x, HC, PM, and CO under 40 CFR part 86 through model year 2026 and 40 CFR part 1036 for model years 2027 and later.

(b) Heavy-duty vehicles with no installed propulsion engine, such as battery electric vehicles, are subject to criteria pollutant standards under this part. The emission standards that apply are the same as the standards that apply for compression-ignition engines under 40 CFR 86.007-11 and 1036.104 for a given model year.

(1) You may state in the application for certification that vehicles with no installed propulsion engine comply with all the requirements of this part related to criteria emission standards instead of submitting test data. Tailpipe emissions of criteria pollutants from vehicles with no installed propulsion engine are deemed to be zero.

(2) Vehicles with no installed propulsion engines may not generate NO_x credits.

§ 1037.103 Evaporative and refueling emission standards.

(a) *Applicability.* Evaporative and refueling emission standards apply to heavy-duty vehicles as follows:

(1) Complete and incomplete heavy-duty vehicles at or below 14,000 pounds GVWR must meet evaporative and refueling emission standards as specified in 40 CFR part 86, subpart S, instead of the requirements specified in this section.

(2) Heavy-duty vehicles above 14,000 pounds GVWR that run on volatile liquid fuel (such as gasoline or ethanol) or gaseous fuel (such as natural gas or LPG) must meet evaporative and refueling emission standards as specified in this section.

(b) *Emission standards.* The evaporative and refueling emission standards and measurement procedures specified in 40 CFR 86.1813 apply for vehicles above 14,000 pounds GVWR, except as described in this section. The evaporative emission standards phase in over model years 2018

through 2022, with provisions allowing for voluntary compliance with the standards as early as model year 2015. Count vehicles subject to standards under this section the same as heavy-duty vehicles at or below 14,000 pounds GVWR to comply with the phase-in requirements specified in 40 CFR 86.1813. These vehicles may generate and use emission credits as described in 40 CFR part 86, subpart S, but only for vehicles that are tested for certification instead of relying on the provisions of paragraph (c) of this section. The following provisions apply instead of what is specified in 40 CFR 86.1813:

(1) The refueling standards in 40 CFR 86.1813-17(b) and the related provisions in 40 CFR part 86, subpart S, apply to complete vehicles starting in model year 2022. Those standards and related provisions apply for incomplete vehicles starting in model year 2027, or as described in the alternate phase-in schedule described in 40 CFR 86.1813-17(b). If you do not certify all your incomplete heavy-duty vehicles above 14,000 pounds GVWR to the refueling standards in model year 2027, you must use the alternate phase-in schedule described in 40 CFR 86.1813-17(b).

(2) The leak standard in 40 CFR 86.1813-17(a)(4) does not apply.

(3) The FEL cap relative to the diurnal plus hot soak standard for low-altitude testing is 1.9 grams per test.

(4) The diurnal plus hot soak standard for high-altitude testing is 2.3 grams per test.

(5) Testing does not require measurement of exhaust emissions. Disregard references in subpart B of this part to procedures, equipment specifications, and recordkeeping related to measuring exhaust emissions. All references to the exhaust test under 40 CFR part 86, subpart B, are considered the “dynamometer run” as part of the evaporative testing sequence under this subpart.

(c) *Compliance demonstration.* You may provide a statement in the application for certification that vehicles above 14,000 pounds GVWR comply with evaporative and refueling emission standards in this section instead of submitting test data if you include an engineering analysis describing how vehicles include design parameters, equipment, operating controls, or other elements of design that adequately demonstrate that vehicles comply with the standards throughout the useful life. We would expect emission control components and systems to exhibit a comparable degree of control relative to vehicles that comply based on testing. For example, vehicles that comply under this paragraph (c) should rely on comparable material specifications to limit fuel permeation, and components should be sized and calibrated to correspond with the appropriate fuel capacities, fuel flow rates, purge strategies, and other vehicle operating characteristics. You may alternatively show that design parameters are comparable to those for vehicles at or below 14,000 pounds GVWR certified under 40 CFR part 86, subpart S.

(d) *CNG refueling requirement.* Compressed natural gas vehicles must meet the requirements for fueling connection devices as specified in 40 CFR 86.1813-17(f)(1). Vehicles meeting these requirements are deemed to comply with evaporative and refueling emission standards.

(e) *LNG refueling requirement.* Fuel tanks for liquefied natural gas vehicles must meet the hold-time requirements in Section 4.2 of SAE J2343 (incorporated by reference, [see-in](#) § 1037.810), as modified by this paragraph (e). All pressures noted are gauge pressure. Vehicles with tanks meeting these requirements are deemed to comply with evaporative and refueling emission standards. The provisions of this paragraph (e) are optional for vehicles produced before January 1, 2020. The hold-time requirements of SAE J2343 apply, with the following clarifications and additions:

(1) Hold time must be at least 120 hours. Use the following procedure to determine hold time for an LNG fuel tank that will be installed on a heavy-duty vehicle:

(i) Prepare the stored (offboard) fuel and the vehicle such that tank pressure after the refueling event stabilizes below 690 kPa.

- (ii) Fill the tank to the point of automatic shutoff using a conventional refueling system. This is intended to achieve a net full condition.
 - (iii) The hold time starts when tank pressure increases to 690 kPa, and ends when the tank first vents for pressure relief. Use good engineering judgment to document the point at which the pressure-relief valve opens.
 - (iv) Keep the tank at rest away from direct sun with ambient temperatures between (10 and 30) °C throughout the measurement procedure.
- (2) Following a complete refueling event as described in paragraph (e)(1) of this section and a short drive, installed tanks may not increase in pressure by more than 9 kPa per hour over a minimum 12 hour interval when parked away from direct sun with ambient temperatures at or below 30 °C. Calculate the allowable pressure gain by multiplying the park time in hours by 9 and rounding to the nearest whole number. Do not include the first hour after engine shutdown, and start the test only when tank pressure is between 345 and 900 kPa.
- (3) The standards described in this paragraph (e) apply over the vehicle's useful life as specified in paragraph (f) of this section. The warranty requirements of § 1037.120 also apply for these standards.
- (4) You may specify any amount of inspection and maintenance, consistent with good engineering judgment, to ensure that tanks meet the standards in this paragraph (e) during and after the useful life.
- (f) *Useful life.* The evaporative and refueling emission standards of this section apply for the full useful life, expressed in service miles or calendar years, whichever comes first. The useful life values for the standards of this section are the same as the values described for evaporative emission standards in 40 CFR 86.1805.
- (g) *Auxiliary engines and separate fuel systems.* The provisions of this paragraph (g) apply for vehicles with auxiliary engines. This includes any engines installed in the final vehicle configuration that contribute no motive power through the vehicle's transmission.
- (1) Auxiliary engines and associated fuel-system components must be installed when testing fully assembled vehicles. If the auxiliary engine draws fuel from a separate fuel tank, you must fill the extra fuel tank before the start of diurnal testing as described for the vehicle's main fuel tank. Use good engineering judgment to ensure that any nonmetal portions of the fuel system related to the auxiliary engine have reached stabilized levels of permeation emissions. The auxiliary engine must not operate during the running loss test or any other portion of testing under this section.
 - (2) For testing with partially assembled vehicles, you may omit installation of auxiliary engines and associated fuel-system components as long as those components installed in the final configuration are certified to meet the applicable emission standards for Small SI equipment described in 40 CFR 1054.112 or for Large SI engines in 40 CFR 1048.105. For any fuel-system components that you do not install, your installation instructions must describe this certification requirement.

~~§ 1037.104 Exhaust emission standards for chassis-certified heavy-duty vehicles at or below~~

~~14,000 pounds GVWR.~~

~~Heavy-duty vehicles at or below 14,000 pounds GVWR are not subject to the provisions of this part 1037 if they are subject to 40 CFR part 86, subpart S, including all vehicles certified under 40 CFR part 86, subpart S. See especially 40 CFR 86.1819 and 86.1865 for emission standards and compliance provisions that apply for these vehicles.~~

§ 1037.105 CO₂ emission standards for vocational vehicles.

(a) The standards of this section apply for the following vehicles:

- (1) Heavy-duty vehicles at or below 14,000 pounds GVWR that are not subject to excluded from the standards in 40 CFR 86.1819 greenhouse gas standards in 40 CFR part 86, subpart S. or that use engines certified under § 1037.150(m).
- (2) Vehicles above 14,000 pounds GVWR and at or below 26,000 pounds GVWR, but not certified to the vehicle standards in 40 CFR 86.1819 greenhouse gas standards in 40 CFR part 86, subpart S.
- (3) Vehicles above 26,000 pounds GVWR that are not tractors.
- (4) Vocational tractors.

(b) CO₂ standards in this paragraph (b) apply based on modeling and testing as specified in subpart F of this part. The provisions of § 1037.241 specify how to comply with these standards. Standards differ based on engine cycle, vehicle size, and intended vehicle duty cycle. See § 1037.510(c) to determine which duty cycle applies. Note that § 1037.230 describes how to divide vehicles into subcategories.

(1) Except as specified in paragraph (b)(2) of this section, mModel year 2027 and later vehicles are subject to Phase 3 CO₂ standards corresponding to the selected subcategories as shown in the following table:

TABLE 1 OF PARAGRAPH (b)(1) OF § 1037.105—PHASE 3 CO₂ STANDARDS FOR MODEL YEAR 2027 AND LATER VOCATIONAL VEHICLES (g/ton-mile)

<u>Model Year</u>	<u>Subcategory</u>	<u>CO₂ standard by vehicle service class (g/ton-mile)</u>				
		<u>CI Light Heavy</u>	<u>CI Medium Heavy</u>	<u>CI Heavy Heavy</u>	<u>SI Light Heavy</u>	<u>SI Medium Heavy</u>
<u>2027</u>	<u>Urban</u>	305	224	269	351	263
	<u>Multi-Purpose</u>	274	204	230	316	237
	<u>Regional</u>	242	190	189	270	219
<u>2028</u>	<u>Urban</u>	286	217	269	332	256
	<u>Multi-Purpose</u>	257	197	230	299	230
	<u>Regional</u>	227	183	189	255	212
<u>2029</u>	<u>Urban</u>	268	209	234	314	248
	<u>Multi-Purpose</u>	241	190	200	283	223
	<u>Regional</u>	212	177	164	240	206
<u>2030</u>	<u>Urban</u>	250	201	229	296	240
	<u>Multi-Purpose</u>	224	183	196	266	216
	<u>Regional</u>	198	170	161	226	199
<u>2031</u>	<u>Urban</u>	198	178	207	244	217
	<u>Multi-Purpose</u>	178	162	177	220	195
	<u>Regional</u>	157	150	146	185	179
<u>2032 and later</u>	<u>Urban</u>	147	155	188	193	194
	<u>Multi-Purpose</u>	132	141	161	174	174
	<u>Regional</u>	116	131	132	144	160

TABLE 1 OF § 1037.105—PHASE 2 CO₂ STANDARDS FOR MODEL YEAR 2027 AND LATER VOCATIONAL VEHICLES (G/TON MILE)

<u>Engine cycle</u>	<u>Vehicle size</u>	<u>Multi-purpose</u>	<u>Regional</u>	<u>Urban</u>
<u>Compression-ignition</u>	<u>Light HDV</u>	<u>330</u>	<u>291</u>	<u>367</u>
<u>Compression-ignition</u>	<u>Medium HDV</u>	<u>235</u>	<u>218</u>	<u>258</u>
<u>Compression-ignition</u>	<u>Heavy HDV</u>	<u>230</u>	<u>189</u>	<u>269</u>
<u>Spark-ignition</u>	<u>Light HDV</u>	<u>372</u>	<u>319</u>	<u>413</u>

Spark-ignition	Medium HDV	268	247	297
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(2) Qualifying small manufacturers of model year 2027 and later vehicles may continue to meet Phase 2 CO₂ standards in this paragraph (b)(2) instead of the standards specified in paragraph (b)(1) of this section. If you certify to these Phase 2 CO₂ standards, you may use the averaging provisions of subpart H to demonstrate compliance. You may use other credit provisions of this part only by certifying all vehicle families within a given averaging set to the Phase 3 standards that apply in that model year.

TABLE 2 OF PARAGRAPH (b)(2) OF § 1037.105—SMALL MANUFACTURER PHASE 2 CO₂ STANDARDS FOR MODEL YEAR 2027 AND LATER VOCATIONAL VEHICLES

<u>Engine cycle</u>	<u>Vehicle service class</u>	<u>CO₂ standard by regulatory subcategory (g/ton·mile)</u>		
		<u>Multi-purpose</u>	<u>Regional</u>	<u>Urban</u>
<u>Compression-ignition</u>	<u>Light HDV</u>	<u>330</u>	<u>291</u>	<u>367</u>
<u>Compression-ignition</u>	<u>Medium HDV</u>	<u>235</u>	<u>218</u>	<u>258</u>
<u>Compression-ignition</u>	<u>Heavy HDV</u>	<u>230</u>	<u>189</u>	<u>269</u>
<u>Spark-ignition</u>	<u>Light HDV</u>	<u>372</u>	<u>319</u>	<u>413</u>
<u>Spark-ignition</u>	<u>Medium HDV</u>	<u>268</u>	<u>247</u>	<u>297</u>

(32) Model year 2024 through 2026 vehicles are subject to Phase 2 CO₂ standards corresponding to the selected subcategories as shown in the following table:

TABLE 32 OF PARAGRAPH (b)(3) OF § 1037.105—PHASE 2 CO₂ STANDARDS FOR MODEL YEAR 2024 THROUGH 2026 VOCATIONAL VEHICLES (g/ton·mile)

<u>Engine cycle</u>	<u>Vehicle service classsize</u>	<u>CO₂ standard by regulatory subcategory (g/ton·mile)</u>		
		<u>Multi-purpose</u>	<u>Regional</u>	<u>Urban</u>
<u>Compression-ignition</u>	<u>Light HDV</u>	<u>344</u>	<u>296</u>	<u>385</u>
<u>Compression-ignition</u>	<u>Medium HDV</u>	<u>246</u>	<u>221</u>	<u>271</u>
<u>Compression-ignition</u>	<u>Heavy HDV</u>	<u>242</u>	<u>194</u>	<u>283</u>
<u>Spark-ignition</u>	<u>Light HDV</u>	<u>385</u>	<u>324</u>	<u>432</u>
<u>Spark-ignition</u>	<u>Medium HDV</u>	<u>279</u>	<u>251</u>	<u>310</u>

(43) Model year 2021 through 2023 vehicles are subject to Phase 2 CO₂ standards corresponding to the selected subcategories as shown in the following table:

TABLE 43 OF PARAGRAPH (b)(4) OF § 1037.105—PHASE 2 CO₂ STANDARDS FOR MODEL YEAR 2021 THROUGH 2023 VOCATIONAL VEHICLES (g/ton·mile)

<u>Engine cycle</u>	<u>Vehicle service classsize</u>	<u>CO₂ standard by regulatory subcategory (g/ton·mile)</u>		
		<u>Multi-purpose</u>	<u>Regional</u>	<u>Urban</u>
<u>Compression-ignition</u>	<u>Light HDV</u>	<u>373</u>	<u>311</u>	<u>424</u>
<u>Compression-ignition</u>	<u>Medium HDV</u>	<u>265</u>	<u>234</u>	<u>296</u>
<u>Compression-ignition</u>	<u>Heavy HDV</u>	<u>261</u>	<u>205</u>	<u>308</u>
<u>Spark-ignition</u>	<u>Light HDV</u>	<u>407</u>	<u>335</u>	<u>461</u>
<u>Spark-ignition</u>	<u>Medium HDV</u>	<u>293</u>	<u>261</u>	<u>328</u>

(54) Model year 2014 through 2020 vehicles are subject to Phase 1 CO₂ standards as shown in the following table:

TABLE 54 OF PARAGRAPH (b)(54) OF § 1037.105—PHASE 1 CO₂ STANDARDS FOR MODEL YEAR 2014 THROUGH 2020 VOCATIONAL VEHICLES (g/ton-mile)

Vehicle size	CO ₂ standard for model years 2014-2016	CO ₂ standard for model year 2017- and later-2020
Light HDV	388	373
Medium HDV	234	225
Heavy HDV	226	222

(c) ~~No CH₄ or N₂O standards apply under this section. See 40 CFR part 1036 for CH₄ or N₂O standards that apply to engines used in these vehicles.~~ [Reserved]

(d) You may generate or use emission credits for averaging, banking, and trading to demonstrate compliance with the standards in paragraph (b) of this section as described in subpart H of this part. This requires that you specify a Family Emission Limit (FEL) for CO₂ for each vehicle subfamily. The FEL may not be less than the result of emission modeling from § 1037.520. These FELs serve as the emission standards for the vehicle subfamily instead of the standards specified in paragraph (b) of this section.

(e) The exhaust emission standards of this section apply for the full useful life, expressed in service miles or calendar years, whichever comes first. The following useful life values apply for the standards of this section:

- (1) 150,000 miles or 15 years, whichever comes first, for Light HDV.
- (2) 185,000 miles or 10 years, whichever comes first, for Medium HDV.
- (3) 435,000 miles or 10 years, whichever comes first, for Heavy HDV.

(f) See § 1037.631 for provisions that exempt certain vehicles used in off-road operation from the standards of this section.

(g) You may optionally certify a vocational vehicle to the standards and useful life applicable to a heavier vehicle service class (such as Medium HDV instead of Light HDV). Provisions related to generating emission credits apply as follows:

- (1) If you certify all your vehicles from a given vehicle service class in a given model year to the standards and useful life that applies for a heavier vehicle service class, you may generate credits as appropriate for the heavier service class.
- (2) Class 8 hybrid vehicles with Light HDE or Medium HDE may be certified to compression-ignition standards for the Heavy HDV service class. You may generate and use credits as allowed for the Heavy HDV service class.
- (3) Except as specified in paragraphs (g)(1) and (2) of this section, you may not generate credits with the vehicle. If you include lighter vehicles in a subfamily of heavier vehicles with an FEL below the standard, exclude the production volume of lighter vehicles from the credit calculation. Conversely, if you include lighter vehicles in a subfamily with an FEL above the standard, you must include the production volume of lighter vehicles in the credit calculation.

(h) You may optionally certify certain vocational vehicles to alternative Phase 2 standards as specified in this paragraph (h) instead of the standards specified in paragraph (b) of this section. You may apply these provisions to any qualifying vehicles even though these standards were established for custom--chassis vehicles. For example, large, diversified vehicle manufacturers may certify vehicles to the refuse hauler standards of this section as long as the manufacturer ensures that those vehicles qualify as refuse haulers when placed into service. GEM simulates vehicle operation for each type of vehicle based on an assigned vehicle service class, independent of the vehicle's actual characteristics, as specified in § 1037.140(g)(7); however, standards apply for the vehicle's useful life based on its actual characteristics as specified in paragraph (e) of this section. Vehicles certified to these standards must include the following

statement on the emission control label: “THIS VEHICLE WAS CERTIFIED AS A [identify vehicle type as identified in [Table 5 of this section](#)] UNDER 40 CFR 1037.105(h).” These custom-chassis [standards-provisions](#) apply as follows:

(1) The following alternative emission standards apply by vehicle type and model year as follows:

[TABLE 5 OF PARAGRAPH \(h\)\(1\) OF § 1037.105—OPTIONAL PHASE 3 CO₂ STANDARDS FOR MODEL YEAR 2027 AND LATER CUSTOM CHASSIS VOCATIONAL VEHICLES \(g/ton-mile\)](#)

Optional custom-chassis vehicle type	Model year 2027	Model year 2028	Model year 2029	Model year 2030	Model year 2031	Model year 2032 and later
School Bus	190	182	176	168	163	149
Other Bus	286	269	255	237	220	189
Coach Bus	205	205	205	185	164	154
Refuse Hauler	253	241	232	221	212	191
Concrete Mixer	259	250	240	231	224	205
Motor home	226	226	226	226	226	226
Mixed-use vehicle	316	316	316	316	316	316
Emergency vehicle	319	319	319	319	319	319

[TABLE 65 OF PARAGRAPH \(h\)\(1\) OF § 1037.105—PHASE 2 CUSTOM CHASSIS STANDARDS FOR MODEL YEARS 2021 THROUGH 2026 \(g/ton-mile\)](#)

Vehicle type^a	Assigned vehicle service class	MY 2021-2026
School bus	Medium HDV	291
Motor home	Medium HDV	228
Coach bus	Heavy HDV	210
Other bus	Heavy HDV	300
Refuse hauler	Heavy HDV	313
Concrete mixer	Heavy HDV	319
Mixed-use vehicle	Heavy HDV	319
Emergency vehicle	Heavy HDV	324

^aVehicle types are generally defined in § 1037.801. “Other bus” includes any bus that is not a school bus or a coach bus. A “mixed-use vehicle” is one that meets at least one of the criteria specified in § 1037.631(a)(1) or (2).

(i) Except as specified in paragraph (h)(1)(ii) of this section, CO₂ standards apply for model year 2021 and later custom-chassis vehicles as shown in the following tables:

TABLE 6 OF PARAGRAPH (h)(1)(i) OF § 1037.105—CUSTOM-CHASSIS STANDARDS SCHOOL BUSES, OTHER BUSES, AND REFUSE HAULERS

<u>Phase</u>	<u>Model year</u>	<u>CO₂ standard by custom-chassis vehicle type (g/ton-mile)</u>		
		<u>School bus</u>	<u>Other bus</u>	<u>Refuse hauler</u>
<u>2</u>	<u>2021-2026</u>	<u>291</u>	<u>300</u>	<u>313</u>
<u>3</u>	<u>2027</u>	<u>236</u>	<u>286</u>	<u>298</u>
	<u>2028</u>	<u>228</u>	<u>286</u>	<u>283</u>
	<u>2029</u>	<u>220</u>	<u>249</u>	<u>268</u>
	<u>2030</u>	<u>211</u>	<u>243</u>	<u>253</u>
	<u>2031</u>	<u>187</u>	<u>220</u>	<u>250</u>
	<u>2032 and later</u>	<u>163</u>	<u>200</u>	<u>250</u>

TABLE 7 OF PARAGRAPH (h)(1)(i) OF § 1037.105—CUSTOM-CHASSIS STANDARDS FOR MOTOR HOMES, COACH BUSES, CONCRETE MIXERS, MIXED-USE VEHICLES, AND EMERGENCY VEHICLES

<u>Phase</u>	<u>Model year</u>	<u>CO₂ standard by custom-chassis vehicle type (g/ton-mile)</u>				
		<u>Motor home</u>	<u>Coach bus</u>	<u>Concrete mixer</u>	<u>Mixed-use vehicle</u>	<u>Emergency vehicle</u>
<u>2</u>	<u>2021-2026</u>	<u>228</u>	<u>210</u>	<u>319</u>	<u>319</u>	<u>324</u>
<u>3</u>	<u>2027 and later</u>	<u>226</u>	<u>205</u>	<u>316</u>	<u>316</u>	<u>319</u>

(ii) For qualifying small manufacturers, Phase 2 CO₂ standards apply for model year 2027 and later custom-chassis vehicles instead of the standards specified in paragraph (h)(1)(i) of this section.

TABLE 8 OF PARAGRAPH (h)(1)(ii) OF § 1037.105— SMALL MANUFACTURER PHASE 2 CO₂ STANDARDS FOR MODEL YEAR 2027 AND LATER CUSTOM-CHASSIS VOCATIONAL VEHICLES (g/ton-mile)

<u>Vehicle type</u>	<u>CO₂ standard</u>
<u>School bus</u>	<u>271</u>
<u>Motor home</u>	<u>226</u>
<u>Coach bus</u>	<u>205</u>
<u>Other bus</u>	<u>286</u>
<u>Refuse hauler</u>	<u>298</u>
<u>Concrete mixer</u>	<u>316</u>
<u>Mixed-use vehicle</u>	<u>316</u>
<u>Emergency vehicle</u>	<u>319</u>

(iii) Vehicle types identified in this paragraph (h)(1) are generally defined in § 1037.801. “Other bus” includes any bus that is not a school bus or a coach bus. A “mixed-use vehicle” is one that meets at least one of the criteria specified in § 1037.631(a)(1) or (2).

(2) You may generate or use emission credits for averaging to demonstrate compliance with the alternative standards as described in subpart H of this part. This requires that you specify a Family Emission Limit (FEL) for CO₂ for each vehicle subfamily. The FEL may not be less than the result of emission modeling as described in § 1037.520. These FELs serve as the emission standards for the vehicle subfamily instead of the standards specified in this paragraph (h). Calculate credits using the equation in § 1037.705(b) with the standard payload for the assigned vehicle service class and the useful life identified in paragraph (e) of this section. Each separate vehicle type identified in paragraph (h)(1) of this section Table 5 of this section (or group of vehicle types identified in a single row) represents a separate averaging set. You may not use averaging for vehicles meeting standards under paragraph

(h)(5) through (7) of this section, and you may not bank or trade emission credits from any vehicles certified under this paragraph (h).

(3) [Reserved]

(4) For purposes of emission modeling under § 1037.520, consider motor homes and coach buses to be subject to the Regional duty cycle, and consider all other vehicles to be subject to the Urban duty cycle.

(5) Emergency vehicles are deemed to comply with the standards of this paragraph (h) if they use tires with TRRL at or below 8.4 N/kN (8.7 N/kN for model years 2021 through 2026).

(6) Concrete mixers and mixed-use vehicles are deemed to comply with the standards of this paragraph (h) if they use tires with TRRL at or below 7.1 N/kN (7.6 N/kN for model years 2021 through 2026).

(7) Motor homes are deemed to comply with the standards of this paragraph (h) if they have tires with TRRL at or below 6.0 N/kN (6.7 N/kN for model years 2021 through 2026) and automatic tire inflation systems or tire pressure monitoring systems with wheels on all axles.

(8) Vehicles certified to standards under this paragraph (h) must use engines certified under 40 CFR part 1036 for the appropriate model year, except that motor homes and emergency vehicles may use engines certified with the loose-engine provisions of § 1037.150(m). This also applies for vehicles meeting standards under paragraphs (h)(5) through (7) of this section.

§ 1037.106 **CO₂ Exhaust** emission standards for tractors above 26,000 pounds GVWR.

(a) The CO₂ standards of this section apply for tractors above 26,000 pounds GVWR. Note that the standards of this section do not apply for vehicles classified as “vocational tractors” under § 1037.630.

(b) ~~The~~ CO₂ standards in this paragraph (b) for tractors above 26,000 pounds GVWR in Table 1 of this section apply based on modeling and testing as described in subpart F of this part. The provisions of § 1037.241 specify how to comply with these standards ~~in this paragraph (b)~~. Note that § 1037.230 describes how to divide vehicles into subcategories.

-(1) Except as specified in paragraph (b)(2) of this section, ~~m~~Model year 2027 and later tractors are subject to Phase 3 CO₂ standards corresponding to the selected subcategories as shown in the following tables:

TABLE 1 OF PARAGRAPH (b)(1) OF § 1037.106— PHASE 3 CO₂ EMISSION STANDARDS FOR MODEL YEAR 2027 AND LATER TRACTORS (g/ton-mile)

<u>Model Year</u>	<u>Roof Height</u>	<u>CO₂ standard by regulatory subcategory (g/ton-mile)</u>			
		<u>Class 7 all cab styles</u>	<u>Class 8 day cab</u>	<u>Class 8 sleeper cab</u>	<u>Heavy-haul</u>
<u>2027</u>	<u>Low Roof</u>	96.2	73.4	64.1	48.3
	<u>Mid Roof</u>	103.4	78.0	69.6	
	<u>High Roof</u>	100.0	75.7	64.3	
<u>2028</u>	<u>Low Roof</u>	88.5	67.5	64.1	48.3
	<u>Mid Roof</u>	95.1	71.8	69.6	
	<u>High Roof</u>	92.0	69.6	64.3	
<u>2029</u>	<u>Low Roof</u>	84.7	64.6	64.1	47.8
	<u>Mid Roof</u>	91.0	68.6	69.6	
	<u>High Roof</u>	88.0	66.6	64.3	
<u>2030</u>	<u>Low Roof</u>	80.8	61.7	60.3	47.8
	<u>Mid Roof</u>	86.9	65.5	65.4	
	<u>High Roof</u>	84.0	63.6	60.4	
<u>2031</u>	<u>Low Roof</u>	69.3	52.8	56.4	46.9
	<u>Mid Roof</u>	74.4	56.2	61.2	
	<u>High Roof</u>	72.0	54.5	56.6	
<u>2032 and Later</u>	<u>Low Roof</u>	57.7	44.0	48.1	45.9
	<u>Mid Roof</u>	62.0	46.8	52.2	
	<u>High Roof</u>	60.0	45.4	48.2	

<u>Model Year</u>	<u>Roof Height</u>	<u>Class 7 All-Cab Styles</u>	<u>Class 8 Day-Cab</u>	<u>Class 8 Sleeper-Cab</u>	<u>Heavy-Haul</u>
<u>2027</u>	<u>Low</u>	86.6	66.1	64.1	48.3
	<u>Mid</u>	93.1	70.2	69.6	
	<u>High</u>	90.0	68.1	64.3	
<u>2028</u>	<u>Low</u>	84.7	64.6	64.1	48.3
	<u>Mid</u>	91.0	68.6	69.6	
	<u>High</u>	88.0	66.6	64.3	
<u>2029</u>	<u>Low</u>	81.8	62.4	64.1	48.3
	<u>Mid</u>	87.9	66.3	69.6	
	<u>High</u>	85.0	64.3	64.3	
<u>2030</u>	<u>Low</u>	77.0	58.7	57.7	43.0
	<u>Mid</u>	82.7	62.4	62.6	
	<u>High</u>	80.0	60.6	57.9	
<u>2031</u>	<u>Low</u>	67.3	51.4	51.3	42.5
	<u>Mid</u>	72.4	54.6	55.7	
	<u>High</u>	70.0	53.0	51.4	
<u>2032 and later</u>	<u>Low</u>	63.5	48.4	48.1	41.1
	<u>Mid</u>	68.2	51.5	52.2	
	<u>High</u>	66.0	50.0	48.2	

(2) Qualifying small manufacturers of model year 2027 and later vehicles may continue to meet Phase 2 CO₂ standards in this paragraph (b)(2) instead of the standards specified in paragraph (b)(1) of this section. If you certify to these Phase 2 CO₂ standards, you may use the averaging provisions of subpart H to demonstrate compliance. You may use other credit provisions of this part only by certifying all vehicle families within a given averaging set to the Phase 3 standards that apply in that model year.

TABLE 2 OF PARAGRAPH (b)(2) OF § 1037.106— SMALL MANUFACTURER CO₂ STANDARDS FOR MODEL YEAR 2027 AND LATER TRACTORS

<u>Subcategory</u>	<u>Phase 2 CO₂ standards (g/ton-mile)</u>
<u>Class 7 Low-Roof (all cab styles)</u>	<u>96.2</u>
<u>Class 7 Mid-Roof (all cab styles)</u>	<u>103.4</u>
<u>Class 7 High-Roof (all cab styles)</u>	<u>100.0</u>
<u>Class 8 Low-Roof Day Cab</u>	<u>73.4</u>
<u>Class 8 Low-Roof Sleeper Cab</u>	<u>64.1</u>
<u>Class 8 Mid-Roof Day Cab</u>	<u>78.0</u>
<u>Class 8 Mid-Roof Sleeper Cab</u>	<u>69.6</u>
<u>Class 8 High-Roof Day Cab</u>	<u>75.7</u>
<u>Class 8 High-Roof Sleeper Cab</u>	<u>64.3</u>
<u>Heavy-Haul Tractors</u>	<u>48.3</u>

(32) Model year 2026 and earlier tractors are subject to CO₂ standards corresponding to the selected subcategory as shown in the following table:

TABLE 324 OF PARAGRAPH (b)(23) OF § 1037.106—CO₂ STANDARDS FOR MODEL YEAR 2026 AND EARLIER CLASS 7 AND CLASS 8 TRACTORS BY MODEL YEAR (g/ton-mile)

Subcategory*	Phase 1 standards for model years 2014-2016	Phase 1 standards for model years 2017-2020	Phase 2 standards for model years 2021-2023	Phase 2 standards for model years 2024-2026
Class 7 Low-Roof (all cab styles)	107	104	105.5	99.8
Class 7 Mid-Roof (all cab styles)	119	115	113.2	107.1
Class 7 High-Roof (all cab styles)	124	120	113.5	106.6
Class 8 Low-Roof Day Cab	81	80	80.5	76.2
Class 8 Low-Roof Sleeper Cab	68	66	72.3	68.0
Class 8 Mid-Roof Day Cab	88	86	85.4	80.9
Class 8 Mid-Roof Sleeper Cab	76	73	78.0	73.5
Class 8 High-Roof Day Cab	92	89	85.6	80.4
Class 8 High-Roof Sleeper Cab	75	72	75.7	70.7
Heavy-Haul Tractors	—	—	52.4	50.2

~~(c) No CH₄ or N₂O standards apply under this section. See 40 CFR part 1036 for CH₄ or N₂O standards that apply to engines used in these vehicles.~~ [Reserved]

(d) You may generate or use emission credits for averaging, banking, and trading as described in subpart H of this part. This requires that you calculate a credit quantity if you specify a Family Emission Limit (FEL) that is different than the standard specified in this section for a given pollutant. The FEL may not be less than the result of emission modeling from § 1037.520. These FELs serve as the emission standards for the specific vehicle subfamily instead of the standards specified in paragraph (a) of this section.

(e) The exhaust emission standards of this section apply for the full useful life, expressed in service miles or calendar years, whichever comes first. The following useful life values apply for the standards of this section:

- (1) 185,000 miles or 10 years, whichever comes first, for vehicles at or below 33,000 pounds GVWR.

(2) 435,000 miles or 10 years, whichever comes first, for vehicles above 33,000 pounds GVWR.

(f) You may optionally certify Class 7 tractors to Class 8 standards as follows:

(1) You may optionally certify 4×2 tractors with Heavy HDE to the standards and useful life for Class 8 tractors, with no restriction on generating or using emission credits within the Class 8 averaging set.

(2) You may optionally certify Class 7 tractors not covered by paragraph (f)(1) of this section to the standards and useful life for Class 8 tractors. This paragraph (f)(2) applies equally for hybrid vehicles, battery electric vehicles, and fuel cell electric vehicles. Credit provisions apply as follows:

(i) If you certify all your Class 7 tractors to Class 8 standards, you may use these Heavy HDV credits without restriction. ~~This paragraph (f)(2)(i) applies equally for hybrid and electric vehicles.~~

(ii) This paragraph (f)(2)(ii) applies if you certify some Class 7 tractors to Class 8 standards under this paragraph (f)(2) but not all of them. If you include Class 7 tractors in a subfamily of Class 8 tractors with an FEL below the standard, exclude the production volume of Class 7 tractors from the credit calculation. Conversely, if you include Class 7 tractors in a subfamily of Class 8 tractors with an FEL above the standard, you must include the production volume of Class 7 tractors in the credit calculation.

(g) Diesel auxiliary power units installed on tractors subject to standards under this section must meet PM standards as follows:

(1) For model years 2021 through 2023, the APU engine must be certified under 40 CFR part 1039 with a deteriorated emission level for PM at or below 0.15 g/kW-hr.

(2) Starting in model year 2024, auxiliary power units installed on tractors subject to standards under this section must be certified to the PM emission standard specified in 40 CFR 1039.699. Selling, offering for sale, or introducing or delivering into commerce in the United States or importing into the United States a new tractor subject to this standard is a violation of 40 CFR 1068.101(a)(1) unless the auxiliary power unit has a valid certificate of conformity and the required label showing that it meets the PM standard of this paragraph (g)(2).

(3) See § 1037.660(e) for requirements that apply for diesel APUs in model year 2020 and earlier tractors.

	Short	Long	Short	Long
2018-2020	125.4	81.3	129.1	83.0
2021-2023	123.7	78.9	127.5	80.6
2024-2026	120.9	77.2	124.7	78.9
2027+	118.8	75.7	122.7	77.4

~~—(3) CO₂ standards apply for partial-aero box vans as specified in the following table:~~

~~Table 2 of § 1037.107—Phase 2 CO₂ Standards for Partial-Aero-Box Vans (g/ton-mile)~~

Model year	Dry van		Refrigerated van	
	Short	Long	Short	Long
2018-2020	125.4	81.3	129.1	83.0
2021+	123.7	80.6	127.5	82.3

~~(4) Non-box trailers and non-aero box vans must meet standards as follows:~~

~~(i) Trailers must use automatic tire inflation systems or tire pressure monitoring systems with wheels on all axles.~~

~~(ii) Non-box trailers must use tires with a TRRL at or below 5.1 kg/tonne. Through model year 2020, non-box trailers may instead use tires with a TRRL at or below 6.0 kg/tonne.~~

~~(iii) Non-aero box vans must use tires with a TRRL at or below 4.7 kg/tonne. Through model year 2020, non-aero box vans may instead use tires with a TRRL at or below 5.1 kg/tonne.~~

~~(5) Starting in model year 2027, you may generate or use emission credits for averaging to demonstrate compliance with the standards specified in paragraph (a)(2) of this section as described in subpart H of this part. This requires that you specify a Family Emission Limit (FEL) for CO₂ for each vehicle subfamily. The FEL may not be less than the result of the emission calculation in § 1037.515. The FEL may not be greater than the appropriate standard for model year 2018 trailers. These FELs serve as the emission standards for the specific vehicle subfamily instead of the standards specified in paragraph (a) of this section. You may not use averaging for non-box trailers, partial-aero box vans, or non-aero box vans that meet standards under paragraph (a)(3) or (a)(4) of this section, and you may~~

~~not use emission credits for banking or trading for any trailers.~~

~~(6) The provisions of § 1037.241 specify how to comply with the standards of this section~~

~~(b) No CH₄, N₂O, or HFC standards apply under this section~~

~~(e) The emission standards of this section apply for a useful life of 10 years.~~

§ 1037.115 Other requirements.

Vehicles required to meet the emission standards of this part must meet the following additional requirements, except as noted elsewhere in this part:

(a) *Adjustable parameters.* Vehicles that have adjustable parameters must meet all the requirements of this part for any adjustment in the practically adjustable range. We may require that you set adjustable parameters to any specification within the practically adjustable range during any testing. See 40 CFR 1068.50 for general provisions related to adjustable parameters. You must ensure safe vehicle operation throughout the practically adjustable range of each adjustable parameter, including consideration of production tolerances. Note that adjustable roof fairings ~~and trailer rear fairings~~ are deemed not to be adjustable parameters.

(b) *Prohibited controls.* You may not design your vehicles with emission control devices, systems, or elements of design that cause or contribute to an unreasonable risk to public health, welfare, or safety while operating. For example, this would apply if the vehicle emits a noxious or toxic substance it would otherwise not emit that contributes to such an unreasonable risk.

(c) [Reserved]

(d) *Defeat devices.* 40 CFR 1068.101 prohibits the use of defeat devices.

(e) *Air conditioning leakage.* Loss of refrigerant from your air conditioning systems may not exceed a total leakage rate of 11.0 grams per year or a percent leakage rate of 1.50 percent per year, whichever is greater. Calculate the total leakage rate in g/year as specified in 40 CFR 86.1867-12(a). Calculate the percent leakage rate as: $[\text{total leakage rate (g/yr)}] \div [\text{total refrigerant capacity (g)}] \times 100$. Round your percent leakage rate to the nearest one-hundredth of a percent. This paragraph (e) applies for all refrigerants.

(1) This paragraph (e) is intended to address air conditioning systems for which the primary purpose is to cool the driver compartment. This would generally include all cab-complete pickups and vans. ~~This paragraph (e) does not apply for refrigeration units on trailers.~~ Similarly, it does not apply for self-contained air conditioning used to cool passengers or refrigeration units used to cool cargo on vocational vehicles. ~~Air conditioning and refrigeration units may be considered self-contained whether or not they draw electrical power from engines used to propel the vehicles.~~ For purposes of this paragraph (e), a self-contained system is an enclosed unit with its own evaporator and condenser even if it draws power from the engine.

(2) For purposes of this paragraph (e), “refrigerant capacity” is the total mass of refrigerant recommended by the vehicle manufacturer as representing a full charge. Where full charge is specified as a pressure, use good engineering judgment to convert the pressure and system volume to a mass.

(3) If air conditioning systems are designed such that a compliance demonstration under 40 CFR 86.1867-12(a) is impossible or impractical, you may ask to use alternative means to demonstrate that your air conditioning system achieves an equivalent level of control.

(f) Battery durability monitor. Model year 2030 and later battery electric vehicles and plug-in hybrid electric vehicles must meet the following monitoring requirements to estimate and monitor usable battery energy for related to batteries serving as a Rechargeable Energy Storage Systems from GTR No. 22 (incorporated by reference, see § 1037.810) as described in §1037.115(f). The requirements of this section apply starting in model year 2030. The following clarifications and adjustments to GTR No. 22 apply for vehicles subject to this section monitor must meet the following requirements:

(1) Create ~~install~~ a customer-accessible system that monitors and displays ~~display that monitors, estimates, and communicates~~ the vehicle's State of Certified Energy (SOCE) with an accuracy of ±5 %. Display the SOCE from paragraph (f)(3) of this section as a percentage expressed to the nearest whole number. Update the display as needed to reflect the current value of SOCE.

~~include information in the application for certification as described in §1037.205. Monitoring requirements related to State of Certified Range (SOCR) do not apply.~~

(2) Accuracy requirements for SOCE monitor must have an accuracy of 5% in GTR No. 22 do not apply. The onboard SOCE shall have a resolution of 1 part in 100 and be reported as the nearest whole number from 0 to 100. The onboard SOCE shall be update with sufficient frequency as to maintain the necessary degree of accuracy during all normal vehicle operation. Minimum Performance Requirements for battery durability also do not apply.

(3) Determine SOCE using the following equation:

~~1037.115~~

$$SOCE = \frac{UBE_{aged}}{UBE_{certified}} = \frac{\left(\int_0^{end} V(t)I(t)dt \right)_{aged}}{\left(\int_0^{end} V(t)I(t)dt \right)_{certified}}$$

Eq. 1037.115-1

Where:

UBE = usable battery energy as determined in paragraphs (f)(3) or (4) of this section, where certified refers to the value established for certification and aged refers to the current value as the battery ages.

V = battery voltage.

t = the time for the test, running from time zero to the end point when the battery is not able to maintain the target power.

I = battery current.

(34) For battery electric vehicles, ask us to approve a procedure you develop to determine UBE that meets the following requirements:

(i) Measure UBE by discharging the battery at a constant power that is representative of the vehicle cruising on the highway. For many HDV, the power to cruise on the highway would result in a C-rate between 1/6 C and 1/2 C. Where C-rate is a measure of the rate at which a battery is discharged or charged relative to its maximum capacity and has units of inverse hours. For example, at a 2 C discharge rate, it would take 0.5 hours to fully discharge a battery. For test procedures that involve driving a vehicle, you may discharge the battery at variable rates until the last portion of the test, consistent with good engineering judgment.

(ii) The test is complete when the battery is not able to maintain the target power.

(iii) Use the same procedure for measuring certified and aged UBE.

(iv) The measurements for the determination of power must meet the requirements given in 40 CFR 1036.545(a)(10). ~~use good engineering judgment to develop a test procedure for determining useable battery energy (UBE).~~

(45) For plug-hybrid electric vehicles, determine UBE as described in 40 CFR 1036.545(p). Alternatively, you may use a procedure that meets the requirements of paragraph (f)(3) of this section.

§ 1037.120 Emission-related warranty requirements.

(a) *General requirements.* You must warrant to the ultimate purchaser and each subsequent purchaser that the new vehicle, including all parts of its emission control system, meets two conditions:

(1) It is designed, built, and equipped so it conforms at the time of sale to the ultimate purchaser with the requirements of this part.

(2) It is free from defects in materials and workmanship that cause the vehicle to fail to conform to the requirements of this part during the applicable warranty period.

(b) *Warranty period.* (1) Your emission-related warranty must be valid for at least:

(i) 5 years or 50,000 miles for Light HDV (except tires).

(ii) 5 years or 100,000 miles for Medium HDV and Heavy HDV (except tires).

(iii) ~~5 years for trailers (except tires).~~

~~(iv) 1 year for tires installed on trailers, and 2 years or 24,000 miles for all other tires.~~

(2) You may offer an emission-related warranty more generous than we require. The emission-related warranty for the vehicle may not be shorter than any basic mechanical warranty you provide to that owner without charge for the vehicle. Similarly, the emission-related warranty for any component may not be shorter than any warranty you provide to that owner without charge for that component. This means that your warranty for a given vehicle may not treat emission-related and nonemission-related defects differently for any component. The warranty period begins when the vehicle is placed into service.

(c) *Components covered.* The emission-related warranty covers tires, automatic tire inflation systems, tire pressure monitoring systems, vehicle speed limiters, idle-reduction systems, ~~hybrid system components, and~~ devices added to the vehicle to improve aerodynamic performance (not including standard components such as hoods or mirrors even if they have been optimized for aerodynamics), ~~fuel cell stacks, and RESS and other components used with hybrid systems, battery electric vehicles, and fuel cell electric vehicles~~ to the extent such emission-related components are included in your application for certification. The emission-related warranty similarly covers fuel cell stacks, RESS, and other components used with hybrid systems, battery electric vehicles, and fuel cell electric vehicles. The emission-related warranty also covers other added emission-related components to the extent they are included in your application for certification, ~~and any other components whose failure would increase a vehicle's CO₂ emissions.~~ The emission-related warranty covers all components whose failure would increase a vehicle's emissions of air conditioning refrigerants (for vehicles subject to air conditioning leakage standards), and it covers all components whose failure would increase a vehicle's evaporative and refueling emissions (for vehicles subject to evaporative and refueling emission standards). The emission-related warranty covers components that are part of your certified configuration even if another company produces the component. ~~Your emission-related warranty does not need to cover components whose failure would not increase a vehicle's emissions of any regulated pollutant.~~

(d) *Limited applicability*. You may deny warranty claims under this section if the operator caused the problem through improper maintenance or use, as described in 40 CFR 1068.115. For example, it may be appropriate to require the seals on automatic tire inflation systems to be replaced during the warranty period.

(e) *Owners manual*. Describe in the owners manual the emission-related warranty provisions from this section that apply to the vehicle.

§ 1037.125 Maintenance instructions and allowable maintenance.

Give the ultimate purchaser of each new vehicle written instructions for properly maintaining and using the vehicle, including the emission control system. The maintenance instructions also apply to service accumulation on any of your emission-data vehicles. See paragraph (i) of this section for requirements related to tire replacement.

(a) *Critical emission-related maintenance*. Critical emission-related maintenance includes any adjustment, cleaning, repair, or replacement of critical emission-related components. Critical emission-related maintenance may also include additional emission-related maintenance that you determine is critical if we approve it in advance. You may schedule critical emission-related maintenance on these components if you demonstrate that the maintenance is reasonably likely to be done at the recommended intervals on in-use vehicles. We will accept scheduled maintenance as reasonably likely to occur if you satisfy any of the following conditions:

(1) You present data showing that, if a lack of maintenance increases emissions, it also unacceptably degrades the vehicle's performance.

(2) You present survey data showing that at least 80 percent of vehicles in the field get the maintenance you specify at the recommended intervals.

(3) You provide the maintenance free of charge and clearly say so in your maintenance instructions.

(4) You otherwise show us that the maintenance is reasonably likely to be done at the recommended intervals.

(b) *Recommended additional maintenance*. You may recommend any additional amount of maintenance on the components listed in paragraph (a) of this section, as long as you state clearly that these maintenance steps are not necessary to keep the emission-related warranty valid. If operators do the maintenance specified in paragraph (a) of this section, but not the recommended additional maintenance, this does not allow you to disqualify those vehicles from in-use testing or deny a warranty claim. Do not take these maintenance steps during service accumulation on your emission-data vehicles.

(c) *Special maintenance*. You may specify more frequent maintenance to address problems related to special situations, such as atypical vehicle operation. You must clearly state that this additional maintenance is associated with the special situation you are addressing. We may disapprove your maintenance instructions if we determine that you have specified special maintenance steps to address vehicle operation that is not atypical, or that the maintenance is unlikely to occur in use. If we determine that certain maintenance items do not qualify as special maintenance under this paragraph (c), you may identify this as recommended additional maintenance under paragraph (b) of this section.

(d) *Noncritical emission-related maintenance*. Subject to the provisions of this paragraph (d), you may schedule any amount of emission-related inspection or maintenance that is not covered by paragraph (a) of this section (that is, maintenance that is neither explicitly identified as critical emission-related maintenance, nor that we approve as critical emission-related maintenance). Noncritical emission-related maintenance generally includes maintenance on the components we specify in 40 CFR part 1068, appendix A, that is not covered in paragraph (a) of this section.

You must state in the owners manual that these steps are not necessary to keep the emission-related warranty valid. If operators fail to do this maintenance, this does not allow you to disqualify those vehicles from in-use testing or deny a warranty claim. Do not take these inspection or maintenance steps during service accumulation on your emission-data vehicles.

(e) *Maintenance that is not emission-related.* For maintenance unrelated to emission controls, you may schedule any amount of inspection or maintenance. You may also take these inspection or maintenance steps during service accumulation on your emission-data vehicles, as long as they are reasonable and technologically necessary. You may perform this nonemission-related maintenance on emission-data vehicles at the least frequent intervals that you recommend to the ultimate purchaser (but not the intervals recommended for severe service).

(f) *Source of parts and repairs.* State clearly in your written maintenance instructions that a repair shop or person of the owner's choosing may maintain, replace, or repair emission control devices and systems. Your instructions may not require components or service identified by brand, trade, or corporate name. Also, do not directly or indirectly condition your warranty on a requirement that the vehicle be serviced by your franchised dealers or any other service establishments with which you have a commercial relationship. You may disregard the requirements in this paragraph (f) if you do one of two things:

(1) Provide a component or service without charge under the purchase agreement.

(2) Get us to waive this prohibition in the public's interest by convincing us the vehicle will work properly only with the identified component or service.

(g) [Reserved]

(h) *Owners manual.* Explain the owner's responsibility for proper maintenance in the owners manual.

(i) *Tire maintenance and replacement.* Include instructions that will enable the owner to replace tires so that the vehicle conforms to the original certified vehicle configuration.

§ 1037.130 Assembly instructions for secondary vehicle manufacturers.

(a) If you sell a certified incomplete vehicle to a secondary vehicle manufacturer, give the secondary vehicle manufacturer instructions for completing vehicle assembly consistent with the requirements of this part. Include all information necessary to ensure that the final vehicle assembly (including the engine ~~for vehicles other than trailers~~) will be in its certified configuration.

(b) Make sure these instructions have the following information:

(1) Include the heading: "Emission-related installation instructions".

(2) State: "Failing to follow these instructions when completing assembly of a heavy-duty motor vehicle violates federal law, subject to fines or other penalties as described in the Clean Air Act."

(3) Describe the necessary steps for installing emission-related diagnostic systems.

(4) Describe how your certification is limited for any type of application, as illustrated in the following examples:

(i) If the incomplete vehicle is at or below 8,500 pounds GVWR, state that the vehicle's certification is valid under this part 1037 only if the final configuration has a vehicle curb weight above 6,000 pounds or basic vehicle frontal area above 45 square feet.

(ii) If your engine will be installed in a vehicle that you certify to meet diurnal emission standards using an evaporative canister, but you do not install the fuel tank, identify the maximum permissible fuel tank capacity.

(5) Describe any other instructions to make sure the vehicle will operate according to design specifications in your application for certification.

(c) Provide instructions in writing or in an equivalent format. You may include this information with the incomplete vehicle document required by DOT. If you do not provide the instructions in writing, explain in your application for certification how you will ensure that each installer is informed of the installation requirements.

§ 1037.135 Labeling.

(a) Assign each vehicle a unique identification number and permanently affix, engrave, or stamp it on the vehicle in a legible way. The vehicle identification number (VIN) serves this purpose.

(b) At the time of manufacture, affix a permanent and legible label identifying each vehicle. The label must meet the requirements of 40 CFR 1068.45.

(c) The label must—

(1) Include the heading "VEHICLE EMISSION CONTROL INFORMATION".

(2) Include your full corporate name and trademark. You may identify another company and use its trademark instead of yours if you comply with the branding provisions of 40 CFR 1068.45.

(3) Include EPA's standardized designation for the vehicle family.

(4) [Reserved].

(5) State the date of manufacture [DAY (optional), MONTH, and YEAR]. You may omit this from the label if you stamp, engrave, or otherwise permanently identify it elsewhere on the vehicle, in which case you must also describe in your application for certification where you will identify the date on the vehicle.

(6) [For Phase 1 vehicles, identify the emission control system. Use terms and abbreviations as described in appendix C to this part or other applicable conventions.](#) ~~Phase 2 tractors and Phase 2 vocational vehicles may omit this information.~~

(7) Identify any requirements for fuel and lubricants that do not involve fuel-sulfur levels.

(8) State: "THIS VEHICLE COMPLIES WITH U.S. EPA REGULATIONS FOR [MODEL YEAR] HEAVY-DUTY VEHICLES."

(9) If you rely on another company to design and install fuel tanks in incomplete vehicles that use an evaporative canister for controlling diurnal emissions, include the following statement: "THIS VEHICLE IS DESIGNED TO COMPLY WITH EVAPORATIVE EMISSION STANDARDS WITH UP TO x GALLONS OF FUEL TANK CAPACITY." Complete this statement by identifying the maximum specified fuel tank capacity associated with your certification.

(d) You may add information to the emission control information label as follows:

(1) You may identify other emission standards that the vehicle meets or does not meet (such as European standards).

(2) You may add other information to ensure that the vehicle will be properly maintained and used.

(3) You may add appropriate features to prevent counterfeit labels. For example, you may include the vehicle's unique identification number on the label.

(e) You may ask us to approve modified labeling requirements in this part 1037 if you show that it is necessary or appropriate. We will approve your request if your alternate label is consistent with the requirements of this part.

§ 1037.140 Classifying vehicles and determining vehicle parameters.

- (a) Where applicable, a vehicle's roof height and a trailer's length are determined from nominal design specifications, as provided in this section. Specify design values for roof height and trailer length to the nearest inch.
- (b) Base roof height on fully inflated tires having a static loaded radius equal to the arithmetic mean of the largest and smallest static loaded radius of tires you offer or a standard tire we approve.
- (c) Base [a standard](#) trailer's length on the outer dimensions of the load-carrying structure. Do not include aerodynamic devices or HVAC units.
- (d) The nominal design specifications must be within the range of the actual values from production vehicles considering normal production variability. In the case of roof height, use the mean tire radius specified in paragraph (b) of this section. If after production begins it is determined that your nominal design specifications do not represent production vehicles, we may require you to amend your application for certification under § 1037.225.
- (e) If your vehicle is equipped with an adjustable roof fairing, measure the roof height with the fairing in its lowest setting.
- (f) For any provisions in this part that depend on the number of axles on a vehicle, include lift axles or any other installed axles that can be used to carry the vehicle's weight while in motion.
- (g) The standards and other provisions of this part apply to specific vehicle service classes ~~for tractors and vocational vehicles~~ as follows:
 - (1) ~~Phase 1 and Phase 2~~ Tractors are divided based on GVWR into Class 7 tractors and Class 8 tractors. Where provisions of this part apply to both tractors and vocational vehicles, Class 7 tractors are considered "Medium HDV" and Class 8 tractors are considered "Heavy HDV". This paragraph (g)(1) applies for hybrid and non-hybrid vehicles.
 - (2) Phase 1 vocational vehicles are divided based on GVWR. "Light HDV" includes Class 2b through Class 5 vehicles; "Medium HDV" includes Class 6 and Class 7 vehicles; and "Heavy HDV" includes Class 8 vehicles.
 - (3) Phase 2 [and later](#) vocational vehicles propelled by engines subject to the spark-ignition standards of 40 CFR part 1036 are divided as follows:
 - (i) Class 2b through Class 5 vehicles are considered "Light HDV".
 - (ii) Class 6 through Class 8 vehicles are considered "Medium HDV".
 - (4) Phase 2 [and later](#) vocational vehicles propelled by engines subject to the compression-ignition standards in 40 CFR part 1036 are divided as follows:
 - (i) Class 2b through Class 5 vehicles are considered "Light HDV".
 - (ii) Class 6 through 8 vehicles are considered "Heavy HDV" if the installed engine's primary intended service class is Heavy HDE (see 40 CFR 1036.140), except that Class 8 hybrid vehicles are considered "Heavy HDV" regardless of the engine's primary intended service class.
 - (iii) All other Class 6 through Class 8 vehicles are considered "Medium HDV".
 - (5) Heavy-duty vehicles with no installed propulsion engine, such as [battery](#) electric vehicles, are divided as follows:
 - (i) Class 2b through Class 5 vehicles are considered "Light HDV".
 - (ii) Class 6 and 7 vehicles are considered "Medium HDV".
 - (iii) Class 8 vehicles are considered "Heavy HDV".
 - (6) In certain circumstances, you may certify vehicles to standards that apply for a different vehicle service class. For example, see §§ 1037.105(g) and 1037.106(f). If you optionally certify vehicles to different standards, those vehicles are subject to all the regulatory requirements as if the standards were mandatory.

(7) Vehicles meeting the custom-chassis standards of § 1037.105(h)(1) are subject to the following vehicle service classes instead of the other provisions in this section:

(i) School buses and motor homes are considered “Medium HDV”.

(ii) All other custom-chassis are considered “Heavy HDV”.

(h) Use good engineering judgment to identify the intended regulatory subcategory (Urban, Multi-Purpose, or Regional) for each of your vocational vehicle configurations based on the expected use of the vehicles.

§ 1037.150 Interim provisions.

The provisions in this section apply instead of other provisions in this part.

(a) *Incentives for early introduction.* The provisions of this paragraph (a) apply with respect to ~~tractors and vocational~~ vehicles produced in model years before 2014. Manufacturers may voluntarily certify in model year 2013 (or earlier model years for electric vehicles) to the greenhouse gas standards of this part.

(1) This paragraph (a)(1) applies for regulatory subcategories subject to the standards of § 1037.105 or § 1037.106. Except as specified in paragraph (a)(3) of this section, to generate early credits under this paragraph (a)(1) for any vehicles other than electric vehicles, you must certify your entire U.S.-directed production volume within the regulatory subcategory to these standards. Except as specified in paragraph (a)(4) of this section, if some vehicle families within a regulatory subcategory are certified after the start of the model year, you may generate credits only for production that occurs after all families are certified. For example, if you produce three vehicle families in an averaging set and you receive your certificates for those families on January 4, 2013, March 15, 2013, and April 24, 2013, you may not generate credits for model year 2013 production in any of the families that occurs before April 24, 2013. Calculate credits relative to the standard that would apply in model year 2014 using the equations in subpart H of this part. You may bank credits equal to the surplus credits you generate under this paragraph (a) multiplied by 1.50. For example, if you have 1.0 Mg of surplus credits for model year 2013, you may bank 1.5 Mg of credits. Credit deficits for an averaging set prior to model year 2014 do not carry over to model year 2014. These credits may be used to show compliance with the standards of this part for 2014 and later model years. We recommend that you notify EPA of your intent to use this provision before submitting your applications.

(2) [Reserved]

(3) You may generate emission credits for the number of additional SmartWay designated tractors (relative to your 2012 production), provided you do not generate credits for those vehicles under paragraph (a)(1) of this section. Calculate credits for each regulatory subcategory relative to the standard that would apply in model year 2014 using the equations in subpart H of this part. Use a production volume equal to the number of designated model year 2013 SmartWay tractors minus the number of designated model year 2012 SmartWay tractors. You may bank credits equal to the surplus credits you generate under this paragraph (a)(3) multiplied by 1.50. Your 2012 and 2013 model years must be equivalent in length.

(4) This paragraph (a)(4) applies where you do not receive your final certificate in a regulatory subcategory within 30 days of submitting your final application for that subcategory. Calculate your credits for all production that occurs 30 days or more after you submit your final application for the subcategory.

(b) Phase 1 coastdown procedures. For tractors subject to Phase 1 standards under § 1037.106, the default method for measuring drag area (C_dA) is the coastdown procedure specified in 40 CFR part 1066, subpart D. This includes preparing the tractor and the standard trailer with

wheels meeting specifications of § 1037.528(b) and submitting information related to your coastdown testing under § 1037.528(h).

(c) *Small manufacturers.* The following provisions apply for qualifying small manufacturers:

(1) ~~Small manufacturers are not subject to the greenhouse gas standards of § 1037.107 for trailers with a date of manufacture before January 1, 2019. The following provisions apply through model year 2026:~~

~~(2)(i)~~ The greenhouse gas standards of §§ 1037.105 and 1037.106 are optional for small manufacturers producing vehicles with a date of manufacture before January 1, 2022. In addition, small manufacturers producing vehicles that run on any fuel other than gasoline, E85, or diesel fuel may delay complying with every later standard under this part by one model year.

~~(2)(i)~~ Qualifying manufacturers must notify the Designated Compliance Officer each model year before introducing excluded vehicles into U.S. commerce. This notification must include a description of the manufacturer’s qualification as a small business under 13 CFR 121.201. Manufacturers must label excluded vehicles with the following statement: “THIS VEHICLE IS EXCLUDED UNDER 40 CFR 1037.150(c).”

~~(3)(i)~~ Small manufacturers may meet Phase 1 standards instead of Phase 2 standards in the first year Phase 2 standards apply to them if they voluntarily comply with the Phase 1 standards for the full preceding year. Specifically, small manufacturers may certify their model year 2022 vehicles to the Phase 1 greenhouse gas standards of §§ 1037.105 and 1037.106 if they certify all the vehicles from their annual ~~U.S.-directed~~ production volume included in emission credit calculations for the Phase 1 standards starting on or before January 1, 2021.

(2) The following provisions apply for model year 2027 and later for qualifying small manufacturers:

(i) The following standards apply for vocational vehicles instead of the standards specified in § 1037.105:

TABLE 1 OF PARAGRAPH (c)(2)(i) OF § 1037.150 — SMALL MANUFACTURER CO₂ STANDARDS VOCATIONAL VEHICLES (g/ton-mile)

<u>Engine cycle</u>	<u>Vehicle size</u>	<u>Multi-purpose</u>	<u>Regional</u>	<u>Urban</u>
<u>Compression ignition</u>	<u>Light HDV</u>	<u>330</u>	<u>291</u>	<u>367</u>
<u>Compression ignition</u>	<u>Medium HDV</u>	<u>235</u>	<u>218</u>	<u>258</u>
<u>Compression ignition</u>	<u>Heavy HDV</u>	<u>230</u>	<u>189</u>	<u>269</u>
<u>Spark ignition</u>	<u>Light HDV</u>	<u>372</u>	<u>319</u>	<u>413</u>
<u>Spark ignition</u>	<u>Medium HDV</u>	<u>268</u>	<u>247</u>	<u>297</u>

TABLE 2 OF PARAGRAPH (c)(2)(i) OF § 1037.150 — SMALL MANUFACTURER CO₂ STANDARDS FOR CUSTOM CHASSIS VOCATIONAL VEHICLES (g/ton-mile)

<u>Vehicle type*</u>	<u>Assigned vehicle service class</u>	<u>MY 2027 and later</u>
<u>School bus</u>	<u>Medium HDV</u>	<u>271</u>
<u>Motor home</u>	<u>Medium HDV</u>	<u>226</u>
<u>Coach bus</u>	<u>Heavy HDV</u>	<u>205</u>
<u>Other bus</u>	<u>Heavy HDV</u>	<u>286</u>
<u>Refuse hauler</u>	<u>Heavy HDV</u>	<u>298</u>
<u>Concrete mixer</u>	<u>Heavy HDV</u>	<u>316</u>
<u>Mixed-use vehicle</u>	<u>Heavy HDV</u>	<u>316</u>
<u>Emergency vehicle</u>	<u>Heavy HDV</u>	<u>319</u>

^aVehicle types are generally defined in § 1037.801. “Other bus” includes any bus that is not a school bus or a coach bus. A “mixed-use vehicle” is one that meets at least one of the criteria specified in § 1037.631(a)(1) or (2).

(ii) The following standards apply for tractors instead of the standards specified in § 1037.106:

TABLE 3 OF PARAGRAPH (c)(2)(ii) OF § 1037.150 — SMALL MANUFACTURER CO₂ STANDARDS FOR CLASS 7 AND CLASS 8 TRACTORS BY SUBCATEGORY (g/ton-mile)

<u>Subcategory^a</u>	<u>Phase 2 standards for model year 2027 and later</u>
<u>Class 7 Low Roof (all cab styles)</u>	<u>96.2</u>
<u>Class 7 Mid Roof (all cab styles)</u>	<u>103.4</u>
<u>Class 7 High Roof (all cab styles)</u>	<u>100.0</u>
<u>Class 8 Low Roof Day Cab</u>	<u>73.4</u>
<u>Class 8 Low Roof Sleeper Cab</u>	<u>64.1</u>
<u>Class 8 Mid Roof Day Cab</u>	<u>78.0</u>
<u>Class 8 Mid Roof Sleeper Cab</u>	<u>69.6</u>
<u>Class 8 High Roof Day Cab</u>	<u>75.7</u>
<u>Class 8 High Roof Sleeper Cab</u>	<u>64.3</u>
<u>Heavy Haul Tractors</u>	<u>48.3</u>

^aSubcategory terms are defined in § 1037.801.

(iii) Small manufacturers producing vehicles that run on any fuel other than gasoline, E85, or diesel fuel may delay complying with the model year 2027 standards under this paragraph (c) by one model year.

(iv) Label qualifying vehicles with the following statement: “THIS VEHICLE MEETS PHASE 2 STANDARDS AS ALLOWED UNDER 40 CFR 1037.150(e).”

(v) Small manufacturers may bank emission credits only by certifying all their vehicle families within a given averaging set to the Phase 3 standards that apply for the current model year.

(vi) The battery durability monitor requirements of § 1037.115(f) apply for vehicles subject to standards under this paragraph (c).

(435) See paragraphs (r), (t), and (yu), and (aaw) of this section for additional allowances for small manufacturers.

(d) *Air conditioning leakage for vocational vehicles.* The air conditioning leakage standard of § 1037.115 does not apply for model year 2020 and earlier vocational vehicles.

(e) *Delegated assembly.* The delegated-assembly provisions of § 1037.621 do not apply before January 1, 2018.

~~(f) *Testing exemption for qualifying vehicles.* Tailpipe CO₂ emissions from battery electric vehicles, fuel cell electric vehicles, and vehicles with engines fueled with neat hydrogen are deemed to be zero. No CO₂-related testing is required under this part for these vehicles. *Electric and hydrogen fuel cell vehicles.* Tailpipe emissions of regulated GHG pollutants from electric vehicles and hydrogen fuel cell vehicles are deemed to be zero. No CO₂-related emission testing is required for electric vehicles or hydrogen fuel cell vehicles. Use good engineering judgment to apply other requirements of this part to electric vehicles.~~

(g) *Compliance date.* Compliance with the standards of this part was optional prior to January 1, 2014. This means that if your 2014 model year begins before January 1, 2014, you may certify

for a partial model year that begins on January 1, 2014 and ends on the day your model year would normally end. You must label model year 2014 vehicles excluded under this paragraph (g) with the following statement: “THIS VEHICLE IS EXCLUDED UNDER 40 CFR 1037.150(g).”

(h) *Off-road vehicle exemption.* (1) Vocational vehicles with a date of manufacture before January 1, 2021 automatically qualify for an exemption under § 1037.631 if the tires installed on the vehicle have a maximum speed rating at or below 55 miles per hour.

(2) In unusual circumstances, vehicle manufacturers may ask us to exempt vehicles under § 1037.631 based on other criteria that are equivalent to those specified in § 1037.631(a); however, we will normally not grant relief in cases where the vehicle manufacturer has credits or can otherwise comply with applicable standards. Request approval for an exemption under this paragraph (h) before you produce the subject vehicles. Send your request with supporting information to the Designated Compliance Officer; we will coordinate with NHTSA in making a determination under § 1037.210. If you introduce into U.S. commerce vehicles that depend on our approval under this paragraph (h) before we inform you of our approval, those vehicles violate 40 CFR 1068.101(a)(1).

(i) *Limited carryover from Phase 1 to Phase 2.* The provisions for carryover data in § 1037.235(d) do not allow you to use aerodynamic test results from Phase 1 to support a compliance demonstration for Phase 2 certification.

(j) *Limited prohibition related to early model year engines.* The provisions of this paragraph (j) apply only for vehicles that have a date of manufacture before January 1, 2018. See § 1037.635 for related provisions that apply in later model years. The prohibition in § 1037.601 against introducing into U.S. commerce a vehicle containing an engine not certified to the standards applicable for the calendar year of installation does not apply for vehicles using model year 2014 or 2015 spark-ignition engines, or any model year 2013 or earlier engines.

(k) *Verifying drag areas from in-use tractors.* This paragraph (k) applies for tractors instead of § 1037.401(b) through model year 2020. We may measure the drag area of your vehicles after they have been placed into service. To account for measurement variability, your vehicle is deemed to conform to the regulations of this part with respect to aerodynamic performance if we measure its drag area to be at or below the maximum drag area allowed for the bin above the bin to which you certified (for example, Bin II if you certified the vehicle to Bin III), unless we determine that you knowingly produced the vehicle to have a higher drag area than is allowed for the bin to which it was certified.

(l) *Optional sister-vehicle certification under 40 CFR part 86.* You may certify certain complete or cab-complete vehicles to the GHG standards of 40 CFR 86.1819 instead of the standards of § 1037.105 as specified in 40 CFR 86.1819-14(j).

(m) *Loose engine sales.* Manufacturers may certify certain spark-ignition engines along with chassis-certified heavy-duty vehicles where they are identical to engines used in those vehicles as described in 40 CFR 86.1819-14(k)(8). Vehicles in which those engines are installed are subject to standards under this part as specified in § 1037.105.

(n) *Transition to engine-based model years.* The following provisions apply for production and ABT reports during the transition to engine-based model year determinations for ~~tractors and vocational~~ vehicles in 2020 and 2021:

(1) If you install model year 2020 or earlier engines in your vehicles in calendar year 2020, include all those Phase 1 vehicles in your production and ABT reports related to model year 2020 compliance, although we may require you identify these separately from vehicles produced in calendar year 2019.

(2) If you install model year 2020 engines in your vehicles in calendar year 2021, submit production and ABT reports for those Phase 1 vehicles separate from the reports you submit for Phase 2 vehicles with model year 2021 engines.

(o) *Interim useful life for light heavy-duty vocational vehicles.* Class 2b through Class 5 vocational vehicles certified to Phase 1 standards are subject to a useful life of 110,000 miles or 10 years, whichever comes first, instead of the useful life specified in § 1037.105. For emission credits generated from these Phase 1 vehicles, multiply any banked credits that you carry forward to demonstrate compliance with Phase 2 standards by 1.36.

(p) *Credit multiplier for advanced technology.* The following provisions describe how you may generate and use credits from vehicles certified with advanced technology:

~~(1) You may calculate credits you generate from vehicles certified with advanced technology as follows: If you generate credits from Phase 1 vehicles certified with advanced technology, you may~~

~~(i1) For Phase 1 vehicles, multiply the credits by 1.50, except that you may not apply this multiplier in addition to the early-credit multiplier of paragraph (a) of this section.~~

~~(ii2) For model year 2026 and earlier Phase 2 vehicles, apply multipliers of 3.5 for plug-in hybrid electric vehicles, 4.5 for battery electric vehicles, and 5.5 for fuel cell electric vehicles. Calculate credits relative to the Phase 2 standard. In model year 2027, the advanced technology multiplier applies only for fuel cell electric vehicles, with credits multiplied relative to the Phase 3 standard.~~

~~(iii) For Phase 3 vehicles, the advanced-technology multipliers described in paragraph (p)(2)(ii) of this section apply only in model year 2027. Calculate credits relative to the Phase 3 standard.~~

(2) You may use credit quantities described in paragraphs (p)(1)(i) and (ii) of this section through model year 2026. The following provisions apply for advanced technology credits starting in model year 2027:

(i) Quantify accumulated credit balances in each model year that result from multiplier credit values. For example, if BEV earns 100 Mg of CO₂ credits that become 450 Mg of credits when multiplied, the base credit value is 100 Mg and the multiplier credit value is 350 Mg. Provide a detailed accounting of base and multiplier credits in your annual ABT reports for the relevant model years.

(ii) For each vehicle family, calculate a credit quantity with no consideration of credit multipliers. Sum these credit quantities for every family within a given averaging set.

(iii) Apply available credits in the following priority order as long as the summed credit quantity from paragraph (p)(2)(ii) of this section is negative.

(A) Base credits banked or traded within the same averaging set.

(B) Base credits earned in the same model year from other averaging sets as specified in 1037.150(z).

(C) Base credits from other averaging sets as specified in § 1037.150(z) that are banked or traded.

(D) Multiplier credits within the same averaging set for the same model year.

(E) Multiplier credits banked or traded within the same averaging set.

(F) Multiplier credits earned in the same model year from other averaging sets as specified in 1037.150(z).

(G) Multiplier credits from other averaging sets as specified in § 1037.150(z) that are banked or traded.

(iv) You may no longer use multiplier credits for certifying model year 2030 and later vehicles.

(v) Credit provisions not addressed in this paragraph (p)(2), such as limitations on credit life and credit trading, continue to apply as specified. Note the following:

(A) Unlike multiplier credits, the life of base credits is not limited under this paragraph (p)(2).

[\(B\) You may apply multiplier credits without the restrictions described in this paragraph \(p\)\(2\) to resolve a deficit that remains from complying with Phase 2 standards in model years 2026 and earlier.](#)

(q) *Vehicle families for advanced and off-cycle technologies.* Apply the following provisions for grouping vehicles into families if you use off-cycle technologies under § 1037.610 or advanced technologies under § 1037.615:

(1) For [Phase 1 vocational vehicles and tractors subject to Phase 1 standards](#), create separate vehicle families for vehicles that contain advanced or off-cycle technologies; group those vehicles together in a vehicle family if they use the same advanced or off-cycle technologies.

(2) For [Phase 2 and Phase 3 vocational vehicles and tractors subject to Phase 2 standards](#), create separate vehicle subfamilies [for vehicles that contain if there is a credit multiplier for advanced or off-cycle technology](#); group those vehicles together in a vehicle subfamily if they use the same [advanced or off-cycle technologies multiplier](#).

(r) *Conversion to mid- roof and high-roof configurations.* Secondary vehicle manufacturers that qualify as small manufacturers may convert low- and mid-roof tractors to mid- and high-roof configurations without recertification for the purpose of building a custom sleeper tractor or converting it to run on natural gas, as follows:

(1) The original low- or mid-roof tractor must be covered by a valid certificate of conformity.

(2) The modifications may not increase the frontal area of the tractor beyond the frontal area of the equivalent mid- or high-roof tractor with the corresponding standard trailer. Note that these dimensions have a tolerance of ± 2 inches. Use good engineering judgment to achieve aerodynamic performance similar to or better than the certifying manufacturer's corresponding mid- or high-roof tractor.

(3) Add a permanent supplemental label to the vehicle near the original manufacturer's emission control information label. On the label identify your full corporate name and include the following statement: "THIS VEHICLE WAS MODIFIED AS ALLOWED UNDER 40 CFR 1037.150."

(4) We may require that you submit annual production reports as described in § 1037.250.

(5) Modifications made under this paragraph (r) do not violate 40 CFR 1068.101(b)(1).

(s) *Confirmatory testing for $F_{alt-aero}$.* If we conduct coastdown testing to verify your $F_{alt-aero}$ value for Phase 2 [and later](#) tractors, we will make our determination using the principles of SEA testing in § 1037.305. We will not replace your $F_{alt-aero}$ value if the tractor passes. If your tractor fails, we will generate a replacement value of $F_{alt-aero}$ based on at least one C_dA value and corresponding effective yaw angle, ψ_{eff} , from a minimum of 100 valid runs using the procedures of § 1037.528(h). Note that we intend to minimize the differences between our test conditions and those of the manufacturer by testing at similar times of the year where possible and the same location where possible and when appropriate.

(t) *Glider kits and glider vehicles.* (1) Glider vehicles conforming to the requirements in this paragraph (t)(1) are exempt from the Phase 1 emission standards of this part 1037 prior to January 1, 2021. Engines in such vehicles (including vehicles produced after January 1, 2021) remain subject to the requirements of 40 CFR part 86 applicable for the engines' original model year, but not subject to the Phase 1 or Phase 2 standards of 40 CFR part 1036 unless they were originally manufactured in model year 2014 or later.

(i) You are eligible for this exemption if you are a small manufacturer and you sold one or more glider vehicles in 2014 under the provisions of § 1037.150(c). You do not qualify if you only produced glider vehicles for your own use. You must notify us of your plans to use this exemption before you introduce exempt vehicles into U.S. commerce. In your notification, you must identify your annual U.S.-directed production volume (and sales, if

different) of such vehicles for calendar years 2010 through 2014. Vehicles you produce before notifying us are not exempt under this section.

(ii) In a given calendar year, you may produce up to 300 exempt vehicles under this section, or up to the highest annual production volume you identify in paragraph (t)(1) of this section, whichever is less.

(iii) Identify the number of exempt vehicles you produced under this exemption for the preceding calendar year in your annual report under § 1037.250.

(iv) Include the appropriate statement on the label required under § 1037.135, as follows:

(A) For Phase 1 vehicles, “THIS VEHICLE AND ITS ENGINE ARE EXEMPT UNDER 40 CFR 1037.150(t)(1).”

(B) For Phase 2 vehicles, “THE ENGINE IN THIS VEHICLE IS EXEMPT UNDER 40 CFR 1037.150(t)(1).”

(v) If you produce your glider vehicle by installing remanufactured or previously used components in a glider kit produced by another manufacturer, you must provide the following to the glider kit manufacturer prior to obtaining the glider kit:

(A) Your name, the name of your company, and contact information.

(B) A signed statement that you are a qualifying small manufacturer and that your production will not exceed the production limits of this paragraph (t)(1). This statement is deemed to be a submission to EPA, and we may require the glider kit manufacturer to provide a copy to us at any time.

(vi) This exemption is valid for a given vehicle and engine only if you meet all the requirements and conditions of this paragraph (t)(1) that apply with respect to that vehicle and engine. Introducing such a vehicle into U.S. commerce without meeting all applicable requirements and conditions violates 40 CFR 1068.101(a)(1).

(vii) Companies that are not small manufacturers may sell uncertified incomplete vehicles without engines to small manufacturers for the purpose of producing exempt vehicles under this paragraph (t)(1), subject to the provisions of § 1037.622. However, such companies must take reasonable steps to ensure that their incomplete vehicles will be used in conformance with the requirements of this part 1037.

(2) Glider vehicles produced using engines certified to model year 2010 or later standards for all pollutants are subject to the same provisions that apply to vehicles using engines within their useful life in § 1037.635.

(3) For calendar year 2017, you may produce a limited number of glider kits and/or glider vehicles subject to the requirements applicable to model year 2016 glider vehicles, instead of the requirements of § 1037.635. The limit applies to your combined 2017 production of glider kits and glider vehicles and is equal to your highest annual production of glider kits and glider vehicles for any year from 2010 to 2014. Any glider kits or glider vehicles produced beyond this cap are subject to the provisions of § 1037.635. Count any glider kits and glider vehicles you produce under paragraph (t)(1) of this section as part of your production with respect to this paragraph (t)(3).

~~(u) Streamlined preliminary approval for trailer devices. Before January 1, 2018, manufacturers of aerodynamic devices for trailers may ask for preliminary EPA approval of compliance data for their devices based on qualifying for designation under the SmartWay program based on measured C_dA values, whether or not that involves testing or other methods specified in § 1037.526. Trailer manufacturers may certify based on AC_dA values established under this paragraph (u) through model year 2020. Manufacturers must perform testing as specified in subpart F of this part for any vehicles or aerodynamic devices not qualifying for approval under this paragraph (u).~~

~~(v) Transitional allowances for trailers. Through model year 2026, trailer manufacturers may calculate a number of trailers that are exempt from the standards and certification requirements of this part. Calculate the number of exempt box vans in a given model year by multiplying your total U.S. directed production volume of certified box vans by 0.20 and rounding to the nearest whole number; however, in no case may the number of exempted box vans be greater than 350 units in any given model year. Repeat this calculation to determine the number of non-box trailers, up to 250 annual units, that are exempt from standards and certification requirements. Perform the calculation based on your projected production volumes in the first year that standards apply; in later years, use actual production volumes from the preceding model year. Include these calculated values and your production volumes of exempt trailers in your annual production report under § 1037.250. You must apply a label meeting the requirements of 40 CFR 1068.45(a) that identifies your corporate name and states that the trailer is exempt under the provisions of § 1037.150. Unlabeled trailers will be considered in violation of 40 CFR 1068.101(a)(1).~~

~~(w) Roll up doors for non-aero box vans. Through model year 2023, box vans may qualify for non-aero or partial-aero standards under § 1037.107 by treating roll-up rear doors as being equivalent to rear lift gates.~~

~~(x) Aerodynamic testing for trailers. Section 1037.526 generally requires you to adjust AC_{dA} values from alternate test methods to be equivalent to measurements with the primary test method. This paragraph (x) describes approximations that we believe are consistent with good engineering judgment; however, you may not use these approximations where we determine that clear and convincing evidence shows that they would significantly overestimate actual improvements in aerodynamic performance.~~

~~(1) You may presume that CFD measurements at a yaw angle of 4.5° are equal to measurements made using the primary method, and you may use them without adjustment.~~

~~(2) You may presume that coastdown measurements at yaw angles smaller than $\pm 4.5^\circ$ are equal to measurements made using the primary method, and you may use them without adjustment. This applies equally for device manufacturers, but it does not apply for EPA testing.~~

~~(3) You may use testing or analytical methods to adjust coastdown measurements to account for aerodynamic effects at a yaw angle of $\pm 4.5^\circ$. This applies for rear fairings and other devices whose performance is affected by yaw angle.~~

(y) Transition to Phase 2 standards. The following provisions allow for enhanced generation and use of emission credits from Phase 1 ~~tractors and vocational~~ vehicles for meeting the Phase 2 standards:

(1) For vocational Light HDV and vocational Medium HDV, emission credits you generate in model years 2018 through 2021 may be used through model year 2027, instead of being limited to a five-year credit life as specified in § 1037.740(c). For Class 8 vocational vehicles with Medium HDE, we will approve your request to generate these credits in and use these credits for the Medium HDV averaging set if you show that these vehicles would qualify as Medium HDV under the Phase 2 program as described in § 1037.140(g)(4).

(2) You may use the off-cycle provisions of § 1037.610 to apply technologies to Phase 1 vehicles as follows:

(i) You may apply an improvement factor of 0.988 for ~~tractors and vocational~~ vehicles with automatic tire inflation systems on all axles.

(ii) For vocational vehicles with automatic engine shutdown systems that conform with § 1037.660, you may apply an improvement factor of 0.95.

(iii) For vocational vehicles with stop-start systems that conform with § 1037.660, you may apply an improvement factor of 0.92.

(iv) For vocational vehicles with neutral-idle systems conforming with § 1037.660, you may apply an improvement factor of 0.98. You may adjust this improvement factor if we approve a partial reduction under § 1037.660(a)(2); for example, if your design reduces fuel consumption by half as much as shifting to neutral, you may apply an improvement factor of 0.99.

(3) Small manufacturers may generate emission credits for natural gas-fueled vocational vehicles as follows:

(i) Small manufacturers may certify their vehicles instead of relying on the exemption of paragraph (c) of this section. The provisions of this part apply for such vehicles, except as specified in this paragraph (yu)(3).

(ii) Use GEM version 2.0.1 to determine a CO₂ emission level for your vehicle, then multiply this value by the engine's [Family Certification Level FCL](#) for CO₂ and divide by the engine's applicable CO₂ emission standard.

(4) Phase 1 vocational vehicle credits that small manufacturers generate may be used through model year 2027.

~~(zv)~~ *Constraints for vocational regulatory subcategories.* The following provisions apply to determinations of vocational regulatory subcategories as described in § 1037.140:

~~(1) Select the Regional regulatory subcategory if you certify the engine based on testing only with the Supplemental Emission Test.~~

~~(2) Select the Regional regulatory subcategory for coach buses and motor homes you certify under § 1037.105(b).~~

~~(3) You may not select the Urban regulatory subcategory for any vehicle with a manual or single-clutch automated manual transmission.~~

~~(4) Starting in model year 2024, you must select the Regional regulatory subcategory for any vehicle with a manual transmission.~~

~~(5) You may select the Multi-purpose regulatory subcategory for any vocational vehicle, except as specified in paragraph (v)(1) paragraphs (z)(1) through (3) of this section.~~

~~(6) You may not select the Urban regulatory subcategory for any vehicle with a manual or single-clutch automated manual transmission.~~

~~(7) You may select the Urban regulatory subcategory for a hybrid vehicle equipped with regenerative braking, unless it is equipped with a manual transmission.~~

~~(8) You may select the Urban regulatory subcategory for any vehicle with a hydrokinetic torque converter paired with an automatic transmission, or a continuously variable automatic transmission, or a dual-clutch transmission with no more than two consecutive forward gears between which it is normal for both clutches to be momentarily disengaged.~~

~~(aw)~~ *Custom-chassis standards for small manufacturers.* The following provisions apply uniquely to [qualifying](#) small manufacturers under the custom-chassis standards of § 1037.105(h):

(1) You may use emission credits generated under § 1037.105(d), including banked or traded credits from any averaging set. Such credits remain subject to other limitations that apply under subpart H of this part.

(2) You may produce up to 200 drayage tractors in a given model year to the standards described in § 1037.105(h) for "other buses". The limit in this paragraph (aa)(2) applies with respect to vehicles produced by you and your affiliated companies. Treat these drayage tractors as being in their own averaging set.

~~(bx)~~ *Transition to updated GEM.* (1) Vehicle manufacturers may demonstrate compliance with Phase 2 [GHG-greenhouse gas](#) standards in model years 2021 through 2023 using GEM Phase 2, Version 3.0, Version 3.5.1, or Version 4.0 (~~all~~ incorporated by reference, ~~see~~ § 1037.810). Manufacturers may change to a different version of GEM for model years 2022 and 2023 for a given vehicle family after initially submitting an application for certification; such a change must

be documented as an amendment under § 1037.225. Manufacturers may submit an end-of-year report for model year 2021 using any of the three regulatory versions of GEM, but only for demonstrating compliance with the custom-chassis standards in § 1037.105(h); such a change must be documented in the report submitted under § 1037.730. Once a manufacturer certifies a vehicle family based on GEM Version 4.0, it may not revert back to using GEM Phase 2, Version 3.0 or Version 3.5.1 for that vehicle family in any model year.

(2) Vehicle manufacturers may certify for model years 2021 through 2023 based on fuel maps from engines or powertrains that were created using GEM Phase 2, Version 3.0, Version 3.5.1, or Version 4.0 (all incorporated by reference, ~~see~~ § 1037.810). Vehicle manufacturers may alternatively certify in those years based on fuel maps from powertrains that were created using GEM Phase 2, Version 3.0, GEM HIL model 3.8, or GEM Phase 2, Version 4.0 (all incorporated by reference, ~~see~~ § 1037.810). Vehicle manufacturers may continue to certify vehicles in later model years using fuel maps generated with earlier versions of GEM for model year 2024 and later vehicle families that qualify for using carryover provisions in § 1037.235(d).

(y) Correcting credit calculations. If you notify us by October 1, 2024 that errors mistakenly decreased your balance of emission credits for 2020 or any earlier model years, you may correct the errors and recalculate the balance of emission credits after applying a 10 percent discount to the credit correction.

(z) Credit exchanges across averaging sets for certain vehicles. The provisions of this paragraph (z) apply for credits generated from model year 2026 and earlier vehicles certified with advanced technology under this part 1037. The provisions of this paragraph (z) also apply for credits generated from model year 2027 through 2032 vehicles, as follows:

(1) Credits generated under this part may be used through model year 2032 for any of the averaging sets identified in § 1037.740(a).

(2) Credits generated from vehicles certified to the standards in 40 CFR 86.1819-14 may be used through model year 2032 to demonstrate compliance with the CO₂ emission standards for Light HDV or Medium HDV in this part.

(3) The following provisions apply for redesignating credits for use in different averaging sets:

(i) The restrictions that apply for trading credits under § 1037.720 also apply for redesignating credits.

(ii) Send us a report by June 30 after model year to describe how you are redesignating credits. Identify the averaging set and number of credits generated from each vehicle family. Also identify the number of redesignated emission credits you intend to apply for each averaging set.

(4) You may trade redesignated credits as allowed under the standard setting part. Credit provisions not addressed in this paragraph (z), such as limitations on credit life and credit multipliers for advanced technology, continue to apply as specified.

(aa) Warranty for advanced technologies. The emission-related warranty requirements in § 1037.120 are optional for fuel cell stacks, RESS, and other components used with battery electric vehicles and fuel cell electric vehicles before model year 2027.

Subpart C—Certifying Vehicle Families

§ 1037.201 General requirements for obtaining a certificate of conformity.

(a) You must send us a separate application for a certificate of conformity for each vehicle family. A certificate of conformity is valid from the indicated effective date until the end of the

model year for which it is issued. You must renew your certification annually for any vehicles you continue to produce.

(b) The application must contain all the information required by this part and must not include false or incomplete statements or information (see § 1037.255).

(c) We may ask you to include less information than we specify in this subpart, as long as you maintain all the information required by § 1037.250.

(d) You must use good engineering judgment for all decisions related to your application (see 40 CFR 1068.5).

(e) An authorized representative of your company must approve and sign the application.

(f) See § 1037.255 for provisions describing how we will process your application.

(g) We may perform confirmatory testing on your vehicles or components; for example, we may test vehicles to verify drag areas or other GEM inputs. This includes tractors used to determine $F_{alt-aero}$ under § 1037.525. We may require you to deliver your test vehicles or components to a facility we designate for our testing. Alternatively, you may choose to deliver another vehicle or component that is identical in all material respects to the test vehicle or component, or a different vehicle or component that we determine can appropriately serve as an emission-data vehicle for the family. We may perform confirmatory testing on engines under 40 CFR part 1036 and may require you to apply modified fuel maps from that testing for certification under this part.

(h) The certification and testing provisions of 40 CFR part 86, subpart S, apply instead of the provisions of this subpart relative to the evaporative and refueling emission standards specified in § 1037.103, except that § 1037.243 describes how to demonstrate compliance with evaporative and refueling emission standards. For vehicles that do not use an evaporative canister for controlling diurnal emissions, you may certify with respect to exhaust emissions and use the provisions of § 1037.622 to let a different company certify with respect to evaporative emissions.

(i) Vehicles and installed engines must meet exhaust, evaporative, and refueling emission standards and certification requirements in 40 CFR part 86 or 40 CFR part 1036, as applicable. Include the information described in 40 CFR part 86, subpart S, or 40 CFR 1036.205 in your application for certification in addition to what we specify in § 1037.205 so we can issue a single certificate of conformity for all the requirements that apply for your vehicle and the installed engine.

§ 1037.205 What must I include in my application?

This section specifies the information that must be in your application, unless we ask you to include less information under § 1037.201(c). We may require you to provide additional information to evaluate your application. References to testing and emission-data vehicles refer to testing vehicles or components to measure any quantity that serves as an input value for modeling emission rates under § ~~1037.515~~ or 1037.520.

(a) Describe the vehicle family's specifications and other basic parameters of the vehicle's design and emission controls. List the fuel type on which your ~~vocational~~ vehicles ~~and tractors~~ are designed to operate (for example, ultra-low-sulfur diesel fuel).

(b) Explain how the emission control system operates. As applicable, describe in detail all system components for controlling greenhouse gas emissions, including all auxiliary emission control devices (AECs) and all fuel-system components you will install on any production vehicle. For any vehicle using RESS (such as hybrid vehicles, fuel cell electric vehicles, and battery electric vehicles), describe in detail all components needed to charge the system, store energy, and transmit power to move the vehicle. Identify the part number of each component you describe. For this paragraph (b), treat as separate AECs any devices that modulate or activate

differently from each other. Also describe your modeling inputs as described in §§ ~~1037.515 and 1037.520~~, with the following additional information if it applies for your vehicles:

- (1) Describe your design for vehicle speed limiters, consistent with § 1037.640.
 - (2) Describe your design for predictive cruise control.
 - (3) Describe your design for automatic engine shutdown systems, consistent with § 1037.660.
 - (4) Describe your engineering analysis demonstrating that your air conditioning compressor qualifies as a high-efficiency model as described in 40 CFR 86.1868-12(h)(5).
 - (5) Describe your design for idle-reduction technology, including the logic for engine shutdown and the maximum duration of engine operation after the onset of any vehicle conditions described in § 1037.660.
 - (6) If you perform powertrain testing under ~~§ 40 CFR 10367.5450~~, report both CO₂ and NO_x emission levels corresponding to each test run.
 - (7) Describe the configuration and basic design of hybrid systems. Include measurements for vehicles with hybrid power take-off systems.
 - (8) If you install auxiliary power units in tractors under § 1037.106(g), identify the family name associated with the engine's certification under 40 CFR part 1039. Starting in model year 2024, also identify the family name associated with the auxiliary power unit's certification to the standards of 40 CFR 1039.699.
 - (9) Describe how you meet any applicable criteria in § 1037.631(a)(1) and (2).
- (c) For vehicles subject to air conditioning standards, include:
- (1) The refrigerant leakage rates (leak scores).
 - (2) The type of refrigerant and the refrigerant capacity of the air conditioning systems.
 - (3) The corporate name of the final installer of the air conditioning system.
- (d) Describe any vehicles or components you selected for testing and the reasons for selecting them.
- (e) Describe any test equipment and procedures that you used, including any special or alternate test procedures you used (see § 1037.501). Include information describing the procedures you used to determine C_{dA} values as specified in §§ 1037.525 ~~through and~~ 1037.527. Describe which type of data you are using for engine fuel maps (see 40 CFR 1036.505). ~~If your trailer certification relies on approved data from device manufacturers, identify the device and device manufacturer.~~
- (f) Describe how you operated any emission-data vehicle before testing, including the duty cycle and the number of vehicle operating miles used to stabilize emission-related performance. Explain why you selected the method of service accumulation. Describe any scheduled maintenance you did, and any practices or specifications that should apply for our testing.
- (g) Where applicable, list the specifications of any test fuel to show that it falls within the required ranges we specify in 40 CFR part 1065.
- (h) Identify the vehicle family's useful life.
- (i) Include the maintenance instructions and warranty statement you will give to the ultimate purchaser of each new vehicle (see §§ 1037.120 and 1037.125).
- (j) Describe your emission control information label (see § 1037.135).
- (k) Identify the emission standards or FELs to which you are certifying vehicles in the vehicle family. For families containing multiple subfamilies, this means that you must identify the highest and lowest FELs to which any of your subfamilies will be certified.
- (l) Where applicable, identify the vehicle family's deterioration factors and describe how you developed them. Present any emission test data you used for this (see § 1037.241(c)).

- (m) Where applicable, state that you operated your emission-data vehicles as described in the application (including the test procedures, test parameters, and test fuels) to show you meet the requirements of this part.
- (n) [Reserved]
- (o) Report calculated and modeled emission results ~~as follows:~~
- ~~(1) For vocational vehicles and tractors, report modeling results~~ for ten configurations. Include modeling inputs and detailed descriptions of how they were derived. Unless we specify otherwise, include the configuration with the highest modeling result, the lowest modeling result, and the configurations with the highest projected sales.
- ~~(2) For trailers that demonstrate compliance with g/ton-mile emission standards as described in § 1037.515, report the CO₂ emission result for the configuration with the highest calculated value. If your trailer family generates or uses emission credits, also report the CO₂ emission results for the configuration with the lowest calculated value, and for the configuration with the highest projected sales.~~
- (p) Where applicable, describe all adjustable operating parameters (see § 1037.115), including production tolerances. For any operating parameters that do not qualify as adjustable parameters, include a description supporting your conclusion (see 40 CFR 1068.50(c)). Include the following in your description of each adjustable parameter:
- (1) The nominal or recommended setting.
 - (2) The intended practically adjustable range.
 - (3) The limits or stops used to establish adjustable ranges.
 - (4) Information showing why the limits, stops, or other means of inhibiting adjustment are effective in preventing adjustment of parameters on in-use engines to settings outside your intended practically adjustable ranges.
- (q) For battery electric vehicles and plug-in hybrid electric vehicles, describe the recharging procedures and methods for determining battery performance, such as state of charge and charging capacity. Also include the certified usable battery energy for each battery durability subfamily. Include the following information for electric vehicles and fuel cell vehicles to show they meet the standards of this part:
- ~~(1) You may attest that vehicles comply with the standards of § 1037.102 instead of submitting test data.~~
- ~~(2) For vehicles generating credits under § 1037.616, you may attest that the vehicle meets the durability requirements described in § 1037.102(b)(3) based on an engineering analysis of measured values and other information, consistent with good engineering judgment, instead of testing at the end of the useful life. Send us your test results for work produced over the FTP and initial useable battery energy or initial fuel cell voltage. Also send us your engineering analysis describing how you meet the durability requirements if we ask for it.~~
- (r) Unconditionally certify that all the vehicles in the vehicle family comply with the requirements of this part, other referenced parts of the CFR, and the Clean Air Act.
- (s) Include good-faith estimates of U.S.-directed production volumes by subfamily. We may require you to describe the basis of your estimates.
- (t) Include the information required by other subparts of this part. For example, include the information required by § 1037.725 if you plan to generate or use emission credits.
- (u) Include other applicable information, such as information specified in this part or 40 CFR part 1068 related to requests for exemptions.
- (v) Name an agent for service located in the United States. Service on this agent constitutes service on you or any of your officers or employees for any action by EPA or otherwise by the United States related to the requirements of this part.

§ 1037.210 Preliminary approval before certification.

If you send us information before you finish the application, we may review it and make any appropriate determinations. Decisions made under this section are considered to be preliminary approval, subject to final review and approval. We will generally not reverse a decision where we have given you preliminary approval, unless we find new information supporting a different decision. If you request preliminary approval related to the upcoming model year or the model year after that, we will make best-efforts to make the appropriate determinations as soon as practicable. We will generally not provide preliminary approval related to a future model year more than two years ahead of time.

~~§ 1037.211 Preliminary approval for manufacturers of aerodynamic devices.~~

~~(a) If you design or manufacture aerodynamic devices for trailers, you may ask us to provide preliminary approval for the measured performance of your devices. While decisions made under this section are considered to be preliminary approval, we will not reverse a decision where we have given you preliminary approval, unless we find new information supporting a different decision. For example, where we measure the performance of your device after giving you preliminary approval and its measured performance is less than your data indicated, we may rescind the preliminary approval of your test results.~~

~~(b) To request this, you must provide test data for AC_{dA} values as specified in § 1037.150(u) or § 1037.526. Trailer manufacturers may use approved AC_{dA} values as inputs under § 1037.515 to support their application for certification.~~

§ 1037.220 Amending maintenance instructions.

You may amend your emission-related maintenance instructions after you submit your application for certification as long as the amended instructions remain consistent with the provisions of § 1037.125. You must send the Designated Compliance Officer a written request to amend your application for certification for a vehicle family if you want to change the emission-related maintenance instructions in a way that could affect emissions. In your request, describe the proposed changes to the maintenance instructions. If operators follow the original maintenance instructions rather than the newly specified maintenance, this does not allow you to disqualify those vehicles from in-use testing or deny a warranty claim.

(a) If you are decreasing or eliminating any specified maintenance, you may distribute the new maintenance instructions to your customers 30 days after we receive your request, unless we disapprove your request. This would generally include replacing one maintenance step with another. We may approve a shorter time or waive this requirement.

(b) If your requested change would not decrease the specified maintenance, you may distribute the new maintenance instructions any time after you send your request. For example, this paragraph (b) would cover adding instructions to increase the frequency of filter changes for vehicles in severe-duty applications.

(c) You need not request approval if you are making only minor corrections (such as correcting typographical mistakes), clarifying your maintenance instructions, or changing instructions for maintenance unrelated to emission control. We may ask you to send us copies of maintenance instructions revised under this paragraph (c).

§ 1037.225 Amending applications for certification.

Before we issue you a certificate of conformity, you may amend your application to include new or modified vehicle configurations, subject to the provisions of this section. After we have issued your certificate of conformity, you may send us an amended application any time before the end of the model year requesting that we include new or modified vehicle configurations within the scope of the certificate, subject to the provisions of this section. You must amend your application if any changes occur with respect to any information that is included or should be included in your application.

(a) You must amend your application before you take any of the following actions:

(1) Add any vehicle configurations to a vehicle family that are not already covered by your application. For example, if your application identifies three possible engine models, and you plan to produce vehicles using an additional engine model, then you must amend your application before producing vehicles with the fourth engine model. The added vehicle configurations must be consistent with other vehicle configurations in the vehicle family with respect to the criteria listed in § 1037.230.

(2) Change a vehicle configuration already included in a vehicle family in a way that may change any of the components you described in your application for certification, or make any other changes that would make the emissions inconsistent with the information in your application. This includes production and design changes that may affect emissions any time during the vehicle's lifetime.

(3) Modify an FEL for a vehicle family as described in paragraph (f) of this section.

(b) To amend your application for certification, send the relevant information to the Designated Compliance Officer.

(1) Describe in detail the addition or change in the vehicle model or configuration you intend to make.

(2) Include engineering evaluations or data showing that the amended vehicle family complies with all applicable requirements. You may do this by showing that the original emission-data vehicle is still appropriate for showing that the amended family complies with all applicable requirements.

(3) If the original emission-data vehicle or emission modeling for the vehicle family is not appropriate to show compliance for the new or modified vehicle configuration, include new test data or emission modeling showing that the new or modified vehicle configuration meets the requirements of this part.

(4) Include any other information needed to make your application correct and complete.

(c) We may ask for more test data or engineering evaluations. You must give us these within 30 days after we request them.

(d) For vehicle families already covered by a certificate of conformity, we will determine whether the existing certificate of conformity covers your newly added or modified vehicle. You may ask for a hearing if we deny your request (see § 1037.820).

(e) The amended application applies starting with the date you submit the amended application, as follows:

(1) For vehicle families already covered by a certificate of conformity, you may start producing a new or modified vehicle configuration any time after you send us your amended application and before we make a decision under paragraph (d) of this section. However, if we determine that the affected vehicles do not meet applicable requirements in this part, we will notify you to cease production of the vehicles and may require you to recall the vehicles at no expense to the owner. Choosing to produce vehicles under this paragraph (e) is deemed to be consent to recall all vehicles that we determine do not meet applicable emission

standards or other requirements in this part and to remedy the nonconformity at no expense to the owner. If you do not provide information required under paragraph (c) of this section within 30 days after we request it, you must stop producing the new or modified vehicles.

(2) [Reserved]

(f) You may ask us to approve a change to your FEL in certain cases after the start of production. The changed FEL may not apply to vehicles you have already introduced into U.S. commerce, except as described in this paragraph (f). You may ask us to approve a change to your FEL in the following cases:

(1) You may ask to raise your FEL for your vehicle subfamily at any time. In your request, you must show that you will still be able to meet the emission standards as specified in subparts B and H of this part. Use the appropriate FELs with corresponding production volumes to calculate emission credits for the model year, as described in subpart H of this part.

(2) Where testing applies, you may ask to lower the FEL for your vehicle subfamily only if you have test data from production vehicles showing that emissions are below the proposed lower FEL. Otherwise, you may ask to lower your FEL for your vehicle subfamily at any time. The lower FEL applies only to vehicles you produce after we approve the new FEL. Use the appropriate FELs with corresponding production volumes to calculate emission credits for the model year, as described in subpart H of this part.

(3) You may ask to add an FEL for your vehicle family at any time.

(g) You may produce vehicles or modify in-use vehicles as described in your amended application for certification and consider those vehicles to be in a certified configuration. Modifying a new or in-use vehicle to be in a certified configuration does not violate the tampering prohibition of 40 CFR 1068.101(b)(1), as long as this does not involve changing to a certified configuration with a higher family emission limit. See § 1037.621(g) for special provisions that apply for changing to a different certified configuration in certain circumstances.

§ 1037.230 Vehicle families, sub-families, and configurations.

(a) For purposes of certifying your vehicles to greenhouse gas standards, divide your product line into families of vehicles based on regulatory subcategories as specified in this section. Subcategories are specified using terms defined in § 1037.801. Your vehicle family is limited to a single model year.

(1) Apply subcategories for vocational vehicles and vocational tractors as shown in [Table 1](#) of this section. This involves 15 separate subcategories for Phase 2 [and later](#) vehicles to account for engine characteristics, GVWR, and the selection of duty cycle for vocational vehicles as specified in § 1037.510; vehicles may additionally fall into one of the subcategories defined by the custom-chassis standards in § 1037.105(h). Divide Phase 1 vehicles into three GVWR-based vehicle service classes as shown in [Table 1](#) of this section, disregarding additional specified characteristics. Table 1 follows:

TABLE 1 OF § 1037.230—VOCATIONAL VEHICLE SUBCATEGORIES

Engine cycle	Light HDV	Medium HDV	Heavy HDV
Compression-ignition	Urban	Urban	Urban
	Multi-Purpose	Multi-Purpose	Multi-Purpose
	Regional	Regional	Regional
Spark-ignition	Urban	Urban	—
	Multi-Purpose	Multi-Purpose	—
	Regional	Regional	—

(2) Apply subcategories for tractors (other than vocational tractors) as shown in Table 2 of this section.

- (i) For vehicles certified to the optional tractor standards in § 1037.670, assign the subcategories as described in § 1037.670.
- (ii) For vehicles intended for export to Canada, you may assign the subcategories as specified in the Canadian regulations.
- (iii) Table 2 follows:

TABLE 2 OF § 1037.230—TRACTOR SUBCATEGORIES

Class 7	Class 8	
Low-roof tractors	Low-roof day cabs	Low-roof sleeper cabs
Mid-roof tractors	Mid-roof day cabs	Mid-roof sleeper cabs
High-roof tractors	High-roof day cabs	High-roof sleeper cabs
—	Heavy-haul tractors (starting with Phase 2)	

~~—(3) Apply subcategories for trailers as shown in the following table:~~

~~Table 3 of § 1037.230—Trailer Subcategories~~

Full-aero trailers	Partial-aero trailers	Other trailers
Long-dry box vans	Long-dry box vans	Non-aero trailers
Short-dry box vans	Short-dry box vans	Non-box trailers
Long-refrigerated box vans	Long-refrigerated box vans	
Short-refrigerated box vans	Short-refrigerated box vans	

(b) If the vehicles in your family are being certified to more than one FEL, subdivide your greenhouse gas vehicle families into subfamilies that include vehicles with identical FELs. Note that you may add subfamilies at any time during the model year.

(c) Group vehicles into configurations consistent with the definition of “vehicle configuration” in § 1037.801. Note that vehicles with hardware or software differences that are related to measured or modeled emissions are considered to be different vehicle configurations even if they have the same modeling inputs and FEL. Note also, that you are not required to separately identify all configurations for certification. Note that you are not required to identify all possible configurations for certification; also, you are required to include in your final ABT report only those configurations you produced.

(d) You may combine dissimilar vehicles into a single vehicle family in special circumstances as follows:

(1) For a Phase 1 vehicle model that straddles a roof-height, cab type, or GVWR division, you may include all the vehicles in the same vehicle family if you certify the vehicle family to the more stringent standard. For roof height, this means you must certify to the taller roof standards. For cab-type and GVWR, this means you must certify to the numerically lower standards.

(2) For a Phase 2 [or later](#) vehicle model that includes a range of GVWR values that straddle weight classes, you may include all the vehicles in the same vehicle family if you certify the vehicle family to the numerically lower CO₂ emission standard from the affected service classes. Vehicles that are optionally certified to a more stringent standard under this paragraph (d)(2) are subject to useful-life and all other provisions corresponding to the weight class with the numerically lower CO₂ emission standard. For a Phase 2 [or later](#) tractor model that includes a range of roof heights that straddle subcategories, you may include all

the vehicles in the same vehicle family if you certify the vehicle family to the appropriate subcategory as follows:

(i) You may certify mid-roof tractors as high-roof tractors, but you may not certify high-roof tractors as mid-roof tractors.

(ii) For tractor families straddling the low-roof/mid-roof division, you may certify the family based on the primary roof-height as long as no more than 10 percent of the tractors are certified to the otherwise inapplicable subcategory. For example, if 95 percent of the tractors in the family are less than 120 inches tall, and the other 5 percent are 122 inches tall, you may certify the tractors as a single family in the low-roof subcategory.

(iii) Determine the appropriate aerodynamic bin number based on the actual roof height if you measure a C_dA value. However, use the GEM input for the bin based on the standards to which you certify. For example, if you certify as mid-roof tractors some low-roof tractors with a measured C_dA value of 4.2 m², they qualify as Bin IV; and you must input into GEM the mid-roof Bin IV value of 5.85 m².

~~(3) You may include refrigerated box vans in a vehicle family with dry box vans by treating them all as dry box vans for demonstrating compliance with emission standards. You may include certain other types of trailers in a vehicle family with a different type of trailer, such that the combined set of trailers are all subject to the more stringent standards, as follows:~~

~~(i) Standards for long trailers are more stringent than standards for short trailers.~~

~~(ii) Standards for long dry box vans are more stringent than standards for short refrigerated box vans.~~

~~(iii) Standards for non-aero box vans are more stringent than standards for non-box trailers.~~

(e) You may divide your families into more families than specified in this section.

(f) You may ask us to allow you to group into the same configuration vehicles that have very small body hardware differences that do not significantly affect drag areas.

§ 1037.231 Powertrain families.

(a) If you choose to perform powertrain testing as specified in ~~§ 40 CFR 10367.5450~~, use good engineering judgment to divide your product line into powertrain families that are expected to have similar fuel consumptions and CO₂ emission characteristics throughout the useful life. Your powertrain family is limited to a single model year.

(b) Except as specified in paragraph (c) of this section, group powertrains in the same powertrain family if they share all the following attributes:

(1) Engine family as specified in 40 CFR 1036.230.

(2) Shared vehicle service class grouping, as follows:

(i) Light HDV or Medium HDV.

(ii) Heavy HDV other than heavy-haul tractors.

(iii) Heavy-haul tractors.

(3) Number of clutches.

(4) Type of clutch (e.g., wet or dry).

(5) Presence and location of a fluid coupling such as a torque converter.

(6) Gear configuration, as follows:

(i) Planetary (e.g., simple, compound, meshed-planet, stepped-planet, multi-stage).

(ii) Countershaft (e.g., single, double, triple).

(iii) Continuously variable (e.g., pulley, magnetic, toroidal).

- (7) Number of available forward gears, and transmission gear ratio for each available forward gear, if applicable. Count forward gears as being available only if the vehicle has the hardware and software to allow operation in those gears.
- (8) Transmission oil sump configuration (e.g., conventional or dry).
- (9) The power transfer configuration of any hybrid technology (e.g., series or parallel).
- (10) The energy storage device and capacity of any hybrid technology (e.g., 10 MJ hydraulic accumulator, 10 kW·hr Lithium-ion battery pack, 10 MJ ultracapacitor bank).
- (11) The rated output of any hybrid mechanical power technology (e.g., 50 kW electric motor).

- (c) For powertrains that share all the attributes described in paragraph (b) of this section, divide them further into separate powertrain families based on common calibration attributes. Group powertrains in the same powertrain family to the extent that powertrain test results and corresponding emission levels are expected to be similar throughout the useful life.
- (d) You may subdivide a group of powertrains with shared attributes under paragraph (b) of this section into different powertrain families.
- (e) In unusual circumstances, you may group powertrains into the same powertrain family even if they do not have shared attributes under in paragraph (b) of this section if you show that their emission characteristics throughout the useful life will be similar.
- (f) If you include the axle when performing powertrain testing for the family, you must limit the family to include only those axles represented by the test results. You may include multiple axle ratios in the family if you test with the axle expected to produce the highest emission results.

§ 1037.232 Axle and transmission families.

- (a) If you choose to perform axle testing as specified in § 1037.560 or transmission testing as specified in § 1037.565, use good engineering judgment to divide your product line into axle or transmission families that are expected to have similar hardware, noting that efficiencies can differ across the members of a family. Note that, while there is no certification for axle and transmission families under this part, vehicle manufacturers may rely on axle and transmission test data to certify their vehicles.
- (b) Except as specified in paragraph (d) of this section, group axles in the same axle family if they have the same number of drive axles and the same load rating.
- (c) Except as specified in paragraph (d) of this section, group transmissions in the same transmission family if they share all the following attributes:
 - (1) Number and type of clutches (wet or dry).
 - (2) Presence and location of a fluid coupling such as a torque converter.
 - (3) Gear configuration, as follows:
 - (i) Planetary (e.g., simple, compound, meshed-planet, stepped-planet, multi-stage).
 - (ii) Countershaft (e.g., single, double, triple).
 - (iii) Continuously variable (e.g., pulley, magnetic, toroidal). Note that GEM does not accommodate efficiency testing for continuously variable transmissions.
 - (4) Transmission oil sump configuration (conventional or dry).
- (d) You may subdivide a group of axles or powertrains with shared attributes under paragraph (b) or (c) of this section into different families.

§ 1037.235 Testing requirements for certification.

This section describes the emission testing you must perform to show compliance with respect to the greenhouse gas ~~emission~~ standards in subpart B of this part, and to determine any input values from ~~§§ 1037.515 and~~ 1037.520 that involve measured quantities.

(a) Select emission-data vehicles that represent production vehicles and components for the vehicle family consistent with the specifications in §§ 1037.205(o), ~~1037.515~~, and 1037.520. Where the test results will represent multiple vehicles or components with different emission performance, use good engineering judgment to select worst-case emission data vehicles or components. In the case of powertrain testing under ~~§ 40 CFR 10367.5450~~, select a test engine, test hybrid components, test axle and test transmission as applicable, by considering the whole range of vehicle models covered by the powertrain family and the mix of duty cycles specified in § 1037.510. If the powertrain has more than one transmission calibration, for example economy vs. performance, you may weight the results from the powertrain testing in ~~40 CFR§ 10367.5450~~ by the percentage of vehicles in the family by prior model year for each configuration. This can be done, for example, through the use of survey data or based on the previous model year's sales volume. Weight the results of $M_{\text{fuel}[\text{cycle}]}$, $\frac{f_{\text{powertrain}}}{v_{\text{powertrain}}}$, and $W_{[\text{cycle}]}$ from ~~t~~Table 52 of ~~40 CFR§ 10367.5450~~ according to the percentage of vehicles in the family that use each transmission calibration.

(b) Test your emission-data vehicles (including emission-data components) using the procedures and equipment specified in subpart F of this part. Measure emissions (or other parameters, as applicable) using the specified procedures.

(c) We may perform confirmatory testing by measuring emissions (or other parameters, as applicable) from any of your emission-data vehicles.

(1) We may decide to do the testing at your plant or any other facility. If we do this, you must deliver the vehicle or component to a test facility we designate. The vehicle or component you provide must be in a configuration that is suitable for testing. For example, vehicles must have the tires you used for testing, and tractors must be set up with the trailer you used for testing. If we do the testing at your plant, you must schedule it as soon as possible and make available the instruments, personnel, and equipment we need (see paragraph (g) of this section for provisions that apply specifically for testing a tractor's aerodynamic performance).

(2) If we measure emissions (or other parameters, as applicable) from your vehicle or component, the results of that testing become the official emission results for the vehicle or component. Note that changing the official emission result does not necessarily require a change in the declared modeling input value. These results will only affect your vehicle FEL if the results of our confirmatory testing result in a GEM vehicle emission value that is higher than the vehicle FEL declared by the manufacturer. Unless we later invalidate these data, we may decide not to consider your data in determining if your vehicle family meets applicable requirements in this part.

(3) Before we test one of your vehicles or components, we may set its adjustable parameters to any point within the ~~physically-practically~~ adjustable ranges, if applicable.

(4) Before we test one of your vehicles or components, we may calibrate it within normal production tolerances for anything we do not consider an adjustable parameter. For example, this would apply for a vehicle parameter that is subject to production variability because it is adjustable during production, but is not considered an adjustable parameter (as defined in § 1037.801) because it is permanently sealed. For parameters that relate to a level of performance that is itself subject to a specified range (such as maximum power output), we

will generally perform any calibration under this paragraph (c)(4) in a way that keeps performance within the specified range. Note that this paragraph (c)(4) does not allow us to test your vehicles in a condition that would be unrepresentative of production vehicles.

(d) You may ask to use carryover data for a vehicle or component from a previous model year instead of doing new tests if the applicable emission-data vehicle from the previous model year remains the appropriate emission-data vehicle under paragraph (b) of this section.

(e) We may require you to test a second vehicle or component of the same configuration in addition to the vehicle or component tested under paragraph (a) of this section.

(f) If you use an alternate test procedure under 40 CFR 1065.10 and later testing shows that such testing does not produce results that are equivalent to the procedures specified in subpart F of this part, we may reject data you generated using the alternate procedure.

(g) We may perform testing to verify your aerodynamic drag area values using any method specified in subpart F of this part. The following additional provisions apply:

(1) We intend to use the same aerodynamic test facility you used, and if you provide any instruments you used, we intend to use those instruments to perform our testing.

(2) We may perform coastdown testing to verify your tractor drag area for any certified configuration. If you use an alternate method for determining aerodynamic drag area for tractors, we may perform testing to verify $F_{\text{alt-aero}}$ as specified in subpart F of this part.

~~(3) We may test trailers (and devices receiving preliminary approval) using the wind tunnel method described in § 1037.530. We may also test using an alternate method; however, we will determine how to appropriately correct or correlate those results to testing with the wind tunnel method.~~

(h) You may ask us to use analytically derived GEM inputs for untested configurations (such as untested axle ratios within an axle family) as identified in subpart F of this part based on interpolation of all relevant measured values for related configurations, consistent with good engineering judgment. We may establish specific approval criteria based on prevailing industry practice. If we allow this, we may test any configuration. We may also require you to test any configuration as part of a selective enforcement audit.

§ 1037.241 Demonstrating compliance with exhaust emission standards for greenhouse gas pollutants.

(a) Compliance determinations for purposes of certification depend on whether or not you participate in the ABT program in subpart H of this part.

(1) If none of your vehicle families generate or use emission credits in a given model year, each of your vehicle families is considered in compliance with the CO₂ emission standards in §§ 1037.105 ~~through 1037.107 and 1037.106~~ if all vehicle configurations in the family have ~~calculated or~~ modeled CO₂ emission rates from ~~§ 1037.515 or~~ § 1037.520 that are at or below the applicable standards. A vehicle family is deemed not to comply if any vehicle configuration in the family has a ~~calculated or~~ modeled CO₂ emission rate that is above the applicable standard.

(2) If you generate or use emission credits with one or more vehicle families in a given model year, your vehicle families within an averaging set are considered in compliance with the CO₂ emission standards in §§ 1037.105 ~~through 1037.107 and 1037.106~~ if the sum of positive and negative credits for all vehicle configurations in those vehicle families lead to a zero balance or a positive balance of credits, except as allowed by § 1037.745. Note that the FEL is considered to be the applicable emission standard for an individual configuration.

~~(b) For non-box trailers and non-aero box vans, your vehicle family is considered in compliance with the emission standards if all vehicle configurations in that family meet specified design standards and have TRRL values at or below the specified standard. Your family is deemed not to comply for certification if any trailer does not meet specified design standards or if any vehicle configuration in that family has a measured TRRL value above the specified standard.~~

~~(e)~~ We may require you to provide an engineering analysis showing that the performance of your emission controls will not deteriorate during the useful life with proper maintenance. If we determine that your emission controls are likely to deteriorate during the useful life, we may require you to develop and apply deterioration factors consistent with good engineering judgment. For example, you may need to apply a deterioration factor to address deterioration of battery performance for a hybrid ~~electric~~ vehicle. Where the highest useful life emissions occur between the end of useful life and at the low-hour test point, base deterioration factors for the vehicles on the difference between (or ratio of) the point at which the highest emissions occur and the low-hour test point.

§ 1037.243 Demonstrating compliance with evaporative and refueling emission standards.

(a) For purposes of certification, your vehicle family is considered in compliance with the evaporative and refueling emission standards in subpart B of this part if you prepare an engineering analysis showing that your vehicles in the family will comply with applicable standards throughout the useful life, and there are no test results from an emission-data vehicle representing the family that exceed an emission standard.

(b) Your evaporative/refueling emission family is deemed not to comply if your engineering analysis is not adequate to show that all the vehicles in the family will comply with applicable emission standards throughout the useful life, or if a test result from an emission-data vehicle representing the family exceeds an emission standard.

(c) Apply deterioration factors to measured emission levels for comparing to the emission standard in subpart B of this part. Establish an additive deterioration factor based on an engineering analysis that takes into account the expected aging from in-use vehicles.

(d) Apply the deterioration factor to the official emission result, as described in paragraph (c) of this section, then round the adjusted figure to the same number of decimal places as the emission standard. Compare the rounded emission levels to the emission standard for each emission-data vehicle.

(e) Your analysis to demonstrate compliance with emission standards must take into account your design strategy for vehicles that require testing. Specifically, vehicles above 14,000 pounds GVWR are presumed to need the same technologies that are required for heavy-duty vehicles at or below 14,000 pounds GVWR. Similarly, your analysis to establish a deterioration factor must take into account your testing to establish deterioration factors for smaller vehicles.

§ 1037.250 Reporting and recordkeeping.

(a) By September 30 following the end of the model year, send the Designated Compliance Officer a report including the total U.S.-directed production volume of vehicles you produced in each vehicle family during the model year (based on information available at the time of the report). Report by vehicle identification number and vehicle configuration and identify the subfamily identifier. Report uncertified vehicles sold to secondary vehicle manufacturers. We may waive the reporting requirements of this paragraph (a) for small manufacturers.

(b) Organize and maintain the following records:

(1) A copy of all applications and any summary information you send us.

- (2) Any of the information we specify in § 1037.205 that you were not required to include in your application.
 - (3) A detailed history of each emission-data vehicle (including emission-related components), if applicable.
 - (4) Production figures for each vehicle family divided by assembly plant.
 - (5) Keep a list of vehicle identification numbers for all the vehicles you produce under each certificate of conformity. Also identify the technologies that make up the certified configuration for each vehicle you produce.
- (c) Keep required data from emission tests and all other information specified in this section for eight years after we issue your certificate. If you use the same emission data or other information for a later model year, the eight-year period restarts with each year that you continue to rely on the information.
- (d) Store these records in any format and on any media, as long as you can promptly send us organized, written records in English if we ask for them. You must keep these records readily available. We may review them at any time.
- (e) If you fail to properly keep records or to promptly send us information as required under this part, we may require that you submit the information specified in this section after each calendar quarter, and we may require that you routinely send us information that the regulation requires you to submit only if we request it. If we find that you are fraudulent or grossly negligent or otherwise act in bad faith regarding information reporting and recordkeeping, we may require that you send us a detailed description of the certified configuration for each vehicle before you produce it.

§ 1037.255 What decisions may EPA make regarding my certificate of conformity?

- (a) If we determine an application is complete and shows that the vehicle family meets all the requirements of this part and the Act, we will issue a certificate of conformity for the vehicle family for that model year. We may make the approval subject to additional conditions.
- (b) We may deny an application for certification if we determine that a vehicle family fails to comply with emission standards or other requirements of this part or the Clean Air Act. We will base our decision on all available information. If we deny an application, we will explain why in writing.
- (c) In addition, we may deny an application or suspend or revoke a certificate of conformity if you do any of the following:
- (1) Refuse to comply with any testing or reporting requirements in this part.
 - (2) Submit false or incomplete information. This includes doing anything after submitting an application that causes submitted information to be false or incomplete.
 - (3) Cause any test data to become inaccurate.
 - (4) Deny us from completing authorized activities (see 40 CFR 1068.20). This includes a failure to provide reasonable assistance.
 - (5) Produce vehicles for importation into the United States at a location where local law prohibits us from carrying out authorized activities.
 - (6) Fail to supply requested information or amend an application to include all vehicles being produced.
 - (7) Take any action that otherwise circumvents the intent of the Act or this part.
- (d) We may void a certificate of conformity if you fail to keep records, send reports, or give us information as required under this part or the Act. Note that these are also violations of 40 CFR 1068.101(a)(2).

- (e) We may void a certificate of conformity if we find that you intentionally submitted false or incomplete information. This includes doing anything after submitting an application that causes submitted information to be false or incomplete after submission.
- (f) If we deny an application or suspend, revoke, or void a certificate, you may ask for a hearing (see § 1037.820).

Subpart D— Testing Production Vehicles and Engines

§ 1037.301 Overview of measurements related to GEM inputs in a selective enforcement audit.

- (a) We may require you to perform selective enforcement audits under 40 CFR part 1068, subpart E, with respect to any GEM inputs in your application for certification. Sections 1037.305 through 1037.315 describe how this applies uniquely in certain circumstances.
- (b) A selective enforcement audit for this part consists of performing measurements with production vehicles relative to one or more declared values for GEM inputs, and using those measured values in place of your declared values to run GEM. Except as specified in this subpart, the vehicle is considered passing if the new modeled emission result is at or below the modeled emission result corresponding to the declared GEM inputs. If you report an FEL for the vehicle configuration before the audit, we will instead consider the vehicle passing if the new cycle-weighted emission result is at or below the FEL.
- (c) We may audit your production components and your records to confirm that physical parameters are correct, such as dimensional accuracy and material selection. We may also audit your records to confirm that you are properly documenting the certified configurations of production vehicles.
- (d) Selective enforcement audit provisions for fuel maps apply to engine manufacturers as specified in 40 CFR 1036.301. See § 1037.315 for selective enforcement audit provisions applicable to powertrain fuel maps.
- (e) We may suspend or revoke certificates based on the outcome of a selective enforcement audit for any appropriate configurations within one or more vehicle families.
- (f) We may apply selective enforcement audit provisions with respect to off-cycle technologies, with any necessary modifications, consistent with good engineering judgment.

§ 1037.305 Audit procedures for tractors— aerodynamic testing.

To perform a selective enforcement audit with respect to drag area for tractors, use the reference method specified in § 1037.525; we may instead require you to use the same method you used for certification. The following provisions apply instead of 40 CFR 1068.415 through 1068.425 for a selective enforcement audit with respect to drag area:

- (a) Determine whether a tractor meets standards as follows:
 - (1) We will select a vehicle configuration for testing. Perform a coastdown measurement according to § 1037.528 with the vehicle in its production configuration. If the production configuration cannot be connected to a standard trailer, you may ask us to approve trailer specifications different than § 1037.501(g)(1) based on good engineering judgment. Instead of the process described in § 1037.528(h)(12), determine your test result as described in this paragraph (a). You must have an equal number of runs in each direction.

- (2) Measure a yaw curve for your test vehicle using your alternate method according to § 1037.525(b)(3). You do not need to test at the coastdown effective yaw angle. You may use a previously established yaw curve from your certification testing if it is available.
- (3) Using the yaw curve, perform a regression using values of drag area, C_dA_{alt} , and yaw angle, ψ_{alt} , to determine the air-direction correction coefficients, a_0 , a_1 , a_2 , a_3 , and a_4 , for the following equation:

$$C_dA_{alt}(\psi) = a_0 + a_1 \cdot \psi_{alt} + a_2 \cdot \psi_{alt}^2 + a_3 \cdot \psi_{alt}^3 + a_4 \cdot \psi_{alt}^4$$

Eq. 1037.305-1

- (4) Adjust the drag area value from each coastdown run, C_dA_{run} , from the yaw angle of each run, ψ_{run} , to $\pm 4.5^\circ$ to represent a wind-averaged drag area value, C_dA_{wa} by applying Eq. 1037.305-1 as follows:

$$C_dA_{wa-run} = C_dA_{run} \cdot \left[\frac{C_dA_{alt,4.5^\circ} + C_dA_{alt,-4.5^\circ}}{C_dA_{alt,\psi_{run}} + C_dA_{alt,-\psi_{run}}} \right]$$

Eq. 1037.305-2

- (5) Perform additional coastdown measurements until you reach a pass or fail decision under this paragraph (a). The minimum number of runs to pass is 24. The minimum number of runs to fail is 100.

- (6) Calculate statistical values to characterize cumulative test results at least once per day based on an equal number of coastdown runs in each direction. Determine the wind-averaged drag area value for the test C_dA_{wa} by averaging all C_dA_{wa-run} values for all days of testing. Determine the upper and lower bounds of the drag area value, $C_dA_{wa-bounded}$, expressed to two decimal places, using a confidence interval as follows:

$$C_dA_{wa-bounded} = C_dA_{wa} \pm \left(\frac{1.5 \cdot \sigma}{\sqrt{n}} + 0.03 \right)$$

Eq. 1037.305-3

Where:

$C_dA_{wa-bounded}$ = the upper bound, $C_dA_{wa-upper}$, and lower bound, $C_dA_{wa-lower}$, of the drag area value, where $C_dA_{wa-upper}$ is the larger number.

C_dA_{wa} = the average of all C_dA_{wa-run} Values.

σ = the standard deviation of all C_dA_{run} values (see 40 CFR 1065.602(c)).

n = the total number of coastdown runs.

- (7) Determine compliance based on the values of $C_dA_{wa-upper}$ and $C_dA_{wa-lower}$ relative to the adjusted bin boundary. For purposes of this section, the upper limit of a bin is expressed as the specified value plus 0.05 to account for rounding. For example, for a bin including values of 5.5-5.9 m², being above the upper limit means exceeding 5.95 m². The vehicle passes or fails relative to the adjusted bin boundary based on one of the following criteria:

(i) The vehicle passes if $C_dA_{wa-upper}$ is less than or equal to the upper limit of the bin to which you certified the vehicle.

(ii) The vehicle fails if $C_dA_{wa-lower}$ is greater than the upper limit of the bin to which you certified the vehicle.

(iii) The vehicle passes if you perform 100 coastdown runs and $C_dA_{wa-upper}$ is greater than and $C_dA_{wa-lower}$ is lower than the upper limit of the bin to which you certified the vehicle.

(iv) The vehicle fails if you choose to stop testing before reaching a final determination under this paragraph (a)(7).

(v) You may continue testing beyond the stopping point specified in this paragraph (a)(7). We may consider the additional data in making pass/fail determinations.

(b) If you reach a pass decision on the first test vehicle, the emission family passes the SEA and you may stop testing. If you reach a fail decision on the first test vehicle, repeat the testing described in paragraph (a) of this section for two additional vehicles of the same configuration, or of a different configuration that we specify. Continue testing two additional vehicles for each failing vehicle until you reach a pass or fail decision for the family based on one of the following criteria:

(1) The emission family passes if at any point more than 50 percent of the vehicles have reached a pass decision.

(2) The emission family fails if six vehicles reach a fail decision.

(3) The emission family passes if you test 11 vehicles with five or fewer vehicles reaching a fail decision.

(4) The emission family fails if you choose to stop testing before reaching a final determination under this paragraph (b).

(c) We may suspend a certificate of conformity as described in 40 CFR 1068.430 if your emission family fails an SEA, subject to the following provisions:

(1) We may reinstate a suspended certificate if you revise $F_{\text{alt-aero}}$ or make other changes to your testing methodology to properly correlate your testing to the reference method specified in § 1037.525.

(2) We may require you to apply any adjustments and corrections determined under paragraph (c)(1) of this section to your other emission families in any future application for certification.

(d) If we test some of your vehicles in addition to your testing, we may decide not to include your test results as official data for those vehicles if there is substantial disagreement between your testing and our testing. We will reinstate your data as valid if you show us that we made an error and your data are correct. If we perform testing, we may choose to stop testing after any number of tests and not determine a failure.

(e) If we rely on our test data instead of yours, we will notify you in writing of our decision and the reasons we believe your facility is not appropriate for doing the tests we require under this paragraph (b). You may request in writing that we consider your test results from the same facility for future testing if you show us that you have made changes to resolve the problem.

(f) We may allow you to perform additional replicate tests with a given vehicle or to test additional vehicles, consistent with good engineering judgment.

(g) You must assign the appropriate CdA bin for your compliance demonstration at the end of the model year for every configuration you tested that failed under this section.

~~§ 1037.310 Audit procedures for trailers.~~

~~(a) We may audit trailer manufacturers to ensure that trailers are being produced to conform with the certificate of conformity. If this involves aerodynamic measurements, we will specify how to adapt the protocol described in § 1037.305 to appropriately evaluate trailer performance.~~

~~(b) We may require device manufacturers that obtain preliminary approval under § 1037.211 to perform aerodynamic testing of production samples of approved devices to ensure that the devices conform to the approved configuration.~~

§ 1037.315 Audit procedures related to powertrain testing.

(a) For vehicles certified based on powertrain testing as specified in ~~§ 40 CFR 10367.5450~~, we may apply the selective enforcement audit requirements to the powertrain. If engine manufacturers perform the powertrain testing and include those results in their certification under 40 CFR part 1036, they are responsible for selective enforcement audits related to those results. Otherwise, the certificate holder for the vehicle is responsible for the selective enforcement audit.

(b) The following provisions apply for a selective enforcement audit with respect to powertrain testing:

(1) A selective enforcement audit for powertrains would generally consist of performing a test with the complete powertrain (engine and transmission together). We may alternatively allow you to test the engine on a dynamometer with no installed transmission as described in § 1037.551.

(2) Recreate a set of test results for each of three separate powertrains. Generate GEM results for each of the configurations that are defined as the centers of each group of four points that define a boundary of cycle work and average powertrain speed divided by average vehicle speed, for each of the three selected powertrains. See 40 CFR 1036.301(b)(2) for an example on how these points are defined. Each unique map for a given configuration with a particular powertrain constitutes a separate test for purposes of evaluating whether the vehicle family meets the pass-fail criteria under 40 CFR 1068.420. The test result for a single test run in the audit is considered passing if it is at or below the value selected as an input for GEM. Perform testing with the same GEM configurations for additional powertrains as needed to reach a pass-fail decision under 40 CFR 1068.240.

§ 1037.320 Audit procedures for axles and transmissions.

Selective enforcement audit provisions apply for axles and transmissions relative to the efficiency demonstrations of §§ 1037.560 and 1037.565 as specified in this section. The following provisions apply instead of 40 CFR 1068.415 through 1068.445 for the selective enforcement audit.

(a) A selective enforcement audit for axles or transmissions would consist of performing measurements with a production axle or transmission to determine mean power loss values as declared for GEM simulations, and running GEM over one or more applicable duty cycles based on those measured values. The axle or transmission is considered passing for a given configuration if the new modeled emission result for every applicable duty cycle is at or below the modeled emission result corresponding to the declared GEM inputs.

(b) Run GEM with the define vehicles to determine whether the transmission or axle family passes the audit.

(1) For transmission audits, run GEM for each applicable vehicle configuration and GEM regulatory subcategory identified in 40 CFR 1036.540 and for each vehicle class as defined in § 1037.140(g) using the applicable default engine map in appendix C of 40 CFR part 1036, the cycle-average fuel map in Table 1 of this section, the torque curve in Table 2 of this section for both the engine full-load torque curve and parent engine full-load torque curve, the motoring torque curve in Table 3 of this section, the idle fuel map in Table 4 of this section. For transmission testing, use the test transmission's gear ratios in place of the gear ratios defined in 40 CFR 1036.540. Table 1 through Table 4 follow:

TABLE 1 TO PARAGRAPH (b)(1) OF § 1037.320—TRANSIENT CYCLE-AVERAGE FUEL MAP BY VEHICLE CLASS

Light HDV and Medium HDV— Spark-Ignition					Light HDV and Medium HDV— Compression-Ignition					Heavy HDV				
Engine Cycle Work (kW·hr)	N/V (r/min)	Fuel Mass (g)	Idle Speed (r/min)	Idle Torque (N·m)	Engine Cycle Work (kW·hr)	N/V (r/min)	Fuel Mass (g)	Idle Speed (r/min)	Idle Torque (N·m)	Engine Cycle Work (kW·hr)	N/V (r/min)	Fuel Mass (g)	Idle Speed (r/min)	Idle Torque (N·m)
3.5404	2.8739	1109.31	600.5	37.997	3.3057	2.3317	919.01	750.3	36.347	11.4255	2.3972	2579.58	600.7	89.658
3.6574	3.0198	1153.35	600.4	37.951	3.3822	2.5075	982.53	750.2	36.461	11.6112	2.2432	2591.08	601.2	90.428
3.8119	3.0370	1188.66	600.2	37.956	3.4917	2.5320	998.64	750.2	36.608	12.5052	2.1620	2763.28	602.4	92.014
4.0121	3.1983	1250.76	600.1	38.153	3.6087	2.6181	1036.34	750.2	36.734	17.7747	2.5195	3835.77	602.2	91.780
5.5567	3.1325	1585.32	604.6	56.535	5.2397	2.5050	1354.33	753.0	51.992	18.4901	2.4155	3994.29	603.5	93.724
5.6814	3.2956	1639.08	604.0	56.549	5.3153	2.7289	1417.20	751.9	51.488	20.1904	2.3800	4374.06	605.1	96.340
5.8720	3.3255	1686.14	602.5	56.234	5.4112	2.6689	1416.75	751.3	51.280					
6.1774	3.4848	1773.39	601.7	56.038	5.5590	2.7231	1450.67	751.0	51.254					

TABLE 2 TO PARAGRAPH (b)(1) OF § 1037.320—FULL-LOAD TORQUE CURVES BY VEHICLE CLASS

Light HDV and Medium HDV— Spark-Ignition		Light HDV and Medium HDV— Compression-Ignition		Heavy HDV	
Engine Speed (r/min)	Engine Torque (N·m)	Engine Speed (r/min)	Engine Torque (N·m)	Engine Speed (r/min)	Engine Torque (N·m)
600	433	750	470	600	1200
700	436	907	579	750	1320
800	445	1055	721	850	1490
900	473	1208	850	950	1700
1000	492	1358	876	1050	1950
1100	515	1507	866	1100	2090
1200	526	1660	870	1200	2100
1300	541	1809	868	1250	2100
1400	542	1954	869	1300	2093
1500	542	2105	878	1400	2092
1600	542	2258	850	1500	2085
1700	547	2405	800	1520	2075
1800	550	2556	734	1600	2010
1900	551	2600	0	1700	1910
2000	554			1800	1801
2100	553			1900	1640
2200	558			2000	1350
2300	558			2100	910
2400	566			2250	0
2500	571				
2600	572				
2700	581				
2800	586				
2900	587				
3000	590				
3100	591				
3200	589				
3300	585				
3400	584				
3500	582				
3600	573				
3700	562				
3800	555				
3900	544				
4000	534				
4100	517				
4200	473				
4291	442				
4500	150				

TABLE 3 TO PARAGRAPH (b)(1) OF § 1037.320—MOTORING TORQUE CURVES BY VEHICLE CLASS

Light HDV and Medium HDV—Spark-Ignition		Light HDV and Medium HDV—Compression-Ignition		Heavy HDV	
Engine Speed (r/min)	Engine Torque (N·m)	Engine Speed (r/min)	Engine Torque (N·m)	Engine Speed (r/min)	Engine Torque (N·m)
700	-41	750	-129	600	-98
800	-42	907	-129	750	-121
900	-43	1055	-130	850	-138
1000	-45	1208	-132	950	-155
1100	-48	1358	-135	1050	-174
1200	-49	1507	-138	1100	-184
1300	-50	1660	-143	1200	-204
1411	-51	1809	-148	1250	-214
1511	-52	1954	-155	1300	-225
1611	-53	2105	-162	1400	-247
1711	-56	2258	-170	1500	-270
1811	-56	2405	-179	1520	-275
1911	-57	2556	-189	1600	-294
2011	-57			1700	-319
2111	-58			1800	-345
2211	-60			1900	-372
2311	-65			2000	-400
2411	-81			2100	-429
2511	-85				
2611	-87				
2711	-88				
2811	-89				
2911	-91				
3011	-91				
3111	-96				
3211	-96				
3311	-97				
3411	-98				
3511	-99				
3611	-104				
3711	-105				
3811	-108				
3911	-108				
4011	-111				
4111	-111				
4211	-115				
4291	-112				

TABLE 4 TO PARAGRAPH (b)(1) OF § 1037.320—ENGINE IDLE FUEL MAPS BY VEHICLE CLASS

Light HDV and Medium HDV— Spark-Ignition			Light HDV and Medium HDV— Compression-Ignition			Heavy HDV		
Engine Speed (r/min)	Engine Torque (N·m)	Fuel Mass Rate (g/s)	Engine Speed (r/min)	Engine Torque (N·m)	Fuel Mass Rate (g/s)	Engine Speed (r/min)	Engine Torque (N·m)	Fuel Mass Rate (g/s)
600	0	0.4010	750	0	0.2595	600	0	0.3501
700	0	0.4725	850	0	0.2626	700	0	0.4745
600	100	0.6637	750	100	0.6931	600	100	0.6547
700	100	0.7524	850	100	0.7306	700	100	0.8304

(2) Follow the procedure in paragraph (b)(1) of this section for axle audits, but cover the range of tire sizes by using good engineering judgment to select three representative tire sizes for each axle ratio for each vehicle configuration instead of using the tire size determined in 40 CFR 1036.540.

(3) The GEM “Default FEL CO₂ Emissions” result for each vehicle configuration counts as a separate test for determining whether the family passes the audit. For vocational vehicles, use the GEM “Default FEL CO₂ Emissions” result for the Regional subcategory.

(c) If the initial axle or transmission passes, the family passes and no further testing is required. If the initial axle or transmission does not pass, select two additional production axles or transmissions, as applicable, to perform additional tests. Note that these could be different axle and transmission configurations within the family. These become official test results for the family. Use good engineering judgment to use the results of these tests to update the declared maps for the axle or transmission family. For example, if you fail the audit test for any of the axles or transmissions tested, the audit result becomes the declared map. This may also require revising any analytically derived maps.

Subpart E—In-Use Testing

§ 1037.401 General provisions.

(a) We may perform in-use testing of any vehicle subject to the standards of this part. For example, we may test vehicles to verify drag areas or other GEM inputs as specified in paragraph (b) of this section.

(b) We may measure the drag area of a vehicle you produced after it has been placed into service. We may use any of the procedures as specified in §§ 1037.525 ~~and through~~ 1037.527 for measuring drag area. Your vehicle conforms to the regulations of this part with respect to aerodynamic performance if we measure its drag area to be at or below the maximum drag area allowed for the bin to which that configuration was certified.

Subpart F—Test and Modeling Procedures

§ 1037.501 General testing and modeling provisions.

This subpart specifies how to perform emission testing and emission modeling required elsewhere in this part.

(a) Except as specified in subpart B of this part, you must demonstrate that you meet emission standards using emission modeling as described in §§ ~~1037.515 and~~ 1037.520. This modeling depends on several measured values as described in this subpart F. You may use fuel-mapping

information from the engine manufacturer as described in 40 CFR 1036.535 and 1036.540, or you may use powertrain testing as described in ~~40 CFR § 1037.1036.5450~~.

(b) Where exhaust emission testing is required, use equipment and procedures as described in 40 CFR part 1065 and part 1066. Measure emissions of all the exhaust constituents subject to emission standards as specified in 40 CFR part 1065 and part 1066. Use the applicable duty cycles specified in § 1037.510.

(c) See 40 CFR 86.101 and 86.1813 for measurement procedures that apply for evaporative and refueling emissions.

(d) Use the applicable fuels specified 40 CFR part 1065 to perform valid tests.

(1) For service accumulation, use the test fuel or any commercially available fuel that is representative of the fuel that in-use vehicles will use.

(2) For diesel-fueled vehicles, use the appropriate diesel fuel specified for emission testing.

Unless we specify otherwise, the appropriate diesel test fuel is ultra-low sulfur diesel fuel.

(3) For gasoline-fueled vehicles, use the gasoline for “general testing” as specified in 40 CFR 86.1305.

(e) You may use special or alternate procedures as specified in 40 CFR 1065.10.

(f) This subpart is addressed to you as a manufacturer, but it applies equally to anyone who does testing for you, and to us when we perform testing to determine if your vehicles meet emission standards.

(g) Apply this paragraph (g) whenever we specify the use of standard trailers. Unless otherwise specified, a tolerance of ± 2 inches applies for all nominal trailer dimensions.

(1) The standard trailer for high-roof tractors must meet the following criteria:

(i) It is an unloaded two-axle dry van 53.0 feet long, 102 inches wide, and 162 inches high (measured from the ground with the trailer level).

(ii) It has a king pin located with its center 36 ± 0.5 inches from the front of the trailer and a minimized trailer gap (no greater than 45 inches).

(iii) It has a simple orthogonal shape with smooth surfaces and nominally flush rivets. Except as specified in paragraph (g)(1)(v) of this section, the standard trailer does not include any aerodynamic features such as side fairings, rear fairings, or gap reducers. It may have a scuff band no more than 0.13 inches thick.

(iv) It includes dual 22.5 inch wheels, standard tandem axle, standard mudflaps, and standard landing gear. The centerline of the tandem axle assembly must be 145 ± 5 inches from the rear of the trailer. The landing gear must be installed in a conventional configuration.

(v) For the Phase 2 or later standards, include side skirts meeting the specifications of this paragraph (g)(1)(v). The side skirts must be mounted flush with both sides of the trailer. The skirts must be an isosceles trapezoidal shape. Each skirt must have a height of 36 ± 2 inches. The top edge of the skirt must be straight with a length of 341 ± 2 inches. The bottom edge of the skirt must be straight with a length of 268 ± 2 inches and have a ground clearance of 8 ± 2 inches through that full length. The sides of the skirts must be straight. The rearmost point of the skirts must be mounted 32 ± 2 inches in front of the centerline of the trailer tandem axle assembly. We may approve your request to use a skirt with different dimensions if these specified values are impractical or inappropriate for your test trailer, and you propose alternative dimensions that provide an equivalent or comparable degree of aerodynamic drag for your test configuration.

(2) The standard trailer for mid-roof tractors is an empty two-axle tank trailer 42 ± 1 feet long by 140 inches high and 102 inches wide.

- (i) It has a 40±1 feet long cylindrical tank with a 7000±7 gallon capacity, smooth surface, and rounded ends.
- (ii) The standard tank trailer does not include any aerodynamic features such as side fairings, but does include a centered 20 inch manhole, side-centered ladder, and lengthwise walkway. It includes dual 24.5 inch wheels.
- (3) The standard trailer for low-roof tractors is an unloaded two-axle flatbed trailer 53±1 feet long and 102 inches wide.
 - (i) The deck height is 60.0±0.5 inches in the front and 55.0±0.5 inches in the rear. The standard trailer does not include any aerodynamic features such as side fairings.
 - (ii) It includes an air suspension and dual 22.5 inch wheels on tandem axles.
- (h) ~~Use a standard tractor for measuring aerodynamic drag of trailers. Standard tractors must be certified at Bin III (or more aerodynamic if a Bin III tractor is unavailable) for Phase 1 or Phase 2 under § 1037.520(b)(1) or (3). The standard tractor for long trailers is a Class 8 high roof sleeper cab. The standard tractor for short trailers is a Class 7 or Class 8 high roof day cab with a 4×2 drive axle configuration.~~
- (i) Note that declared GEM inputs for fuel maps and aerodynamic drag area typically includes compliance margins to account for testing variability; for other measured GEM inputs, the declared values are typically the measured values without adjustment.

§ 1037.510 Duty-cycle exhaust testing.

This section applies for powertrain testing, cycle-average engine fuel mapping, certain off-cycle testing under § 1037.610, and the advanced-technology provisions of § 1037.615.

- (a) Measure emissions by testing ~~the vehicle on a chassis dynamometer or~~ the powertrain on a powertrain dynamometer with the applicable duty cycles. Each duty cycle consists of a series of speed commands over time—variable speeds for the transient test and constant speeds for the highway cruise tests. None of these cycles include vehicle starting or warmup.
 - (1) Perform testing for Phase 1 vehicles as follows to generate credits or adjustment factors for off-cycle or advanced technologies:
 - (i) *Transient cycle.* The transient cycle is specified in appendix A of this part. Warm up the vehicle. Start the duty cycle within 30 seconds after concluding the preconditioning procedure. Start sampling emissions at the start of the duty cycle.
 - (ii) *Cruise cycle.* For the 55 mi/hr and 65 mi/hr highway cruise cycles, warm up the vehicle at the test speed, then sample emissions for 300 seconds while maintaining vehicle speed within ±1.0 mi/hr of the speed setpoint; this speed tolerance applies instead of the approach specified in 40 CFR 1066.425(b)(1) and (2).
 - (2) Perform cycle-average engine fuel mapping [for Phase 2 and later vehicles](#) as described in 40 CFR 1036.540. For powertrain testing under ~~40 CFR § 1037.1036.545~~ or § 1037.555, perform testing as described in this paragraph (a)(2) to generate GEM inputs for each simulated vehicle configuration, and test runs representing different idle conditions. Perform testing as follows:
 - (i) *Transient cycle.* The transient cycle is specified in appendix A of this part.
 - (ii) *Highway cruise cycles.* The grade portion of the route corresponding to the 55 mi/hr and 65 mi/hr highway cruise cycles is specified in appendix D of this part. Maintain vehicle speed between -1.0 mi/hr and 3.0 mi/hr of the speed setpoint; this speed tolerance applies instead of the approach specified in 40 CFR 1066.425(b)(1) and (2).
 - (iii) *Drive idle.* Perform testing at a loaded idle condition for Phase 2 vocational vehicles. For engines with an adjustable warm idle speed setpoint, test at the minimum warm idle

speed and the maximum warm idle speed; otherwise simply test at the engine's warm idle speed. Warm up the powertrain as described in 40 CFR 1036.520(ed)(4). Within 60 seconds after concluding the warm-up, linearly ramp the powertrain down to zero vehicle speed over 20 seconds. Apply the brake and keep the transmission in drive (or clutch depressed for manual transmission). Stabilize the powertrain for (60 ±1) seconds and then sample emissions for (30±1) seconds.

(iv) *Parked idle*. Perform testing at a no-load idle condition for Phase 2 vocational vehicles. For engines with an adjustable warm idle speed setpoint, test at the minimum warm idle speed and the maximum warm idle speed; otherwise simply test at the engine's warm idle speed. Warm up the powertrain as described in 40 CFR 1036.520(de)(4). Within 60 seconds after concluding the warm-up, linearly ramp the powertrain down to zero vehicle speed in 20 seconds. Put the transmission in park (or neutral for manual transmissions and apply the parking brake if applicable). Stabilize the powertrain for (180 ±1) seconds and then sample emissions for (600 ±1) seconds.

(3) Where applicable, perform testing on a chassis dynamometer as follows:

(i) *Transient cycle*. The transient cycle is specified in appendix A of this part. Warm up the vehicle by operating over one transient cycle. Within 60 seconds after concluding the warm up cycle, start emission sampling and operate the vehicle over the duty cycle.

(ii) *Highway cruise cycle*. The grade portion of the route corresponding to the 55 mi/hr and 65 mi/hr highway cruise cycles is specified in appendix D of this part. Warm up the vehicle by operating it at the appropriate speed setpoint over the duty cycle. Within 60 seconds after concluding the preconditioning cycle, start emission sampling and operate the vehicle over the duty cycle, maintaining vehicle speed within ±1.0 mi/hr of the speed setpoint; this speed tolerance applies instead of the approach specified in 40 CFR 1066.425(b)(1) and (2).

(b) Calculate the official emission result from the following equation:

$$e_{\text{CO2comp}} = \frac{1}{PL \cdot \bar{v}_{\text{moving}} \cdot (1 - w_{\text{drive-idle}} - w_{\text{parked-idle}})} \cdot \left((1 - w_{\text{drive-idle}} - w_{\text{parked-idle}}) \cdot \left(\frac{w_{\text{transient}} \cdot m_{\text{transient}}}{D_{\text{transient}}} + \frac{w_{55} \cdot m_{55}}{D_{55}} + \frac{w_{65} \cdot m_{65}}{D_{65}} \right) \cdot \bar{v}_{\text{moving}} \right) + w_{\text{drive-idle}} \cdot \bar{m}_{\text{drive-idle}} + w_{\text{parked-idle}} \cdot \bar{m}_{\text{parked-idle}}$$

Eq. 1037.510-1

Where:

e_{CO2comp} = total composite mass of CO₂ emissions in g/ton-mile, rounded to the nearest whole number for vocational vehicles and to the first decimal place for tractors.

PL = the standard payload, in tons, as specified in § 1037.705.

\bar{v}_{moving} = mean composite weighted driven vehicle speed, excluding idle operation, as shown in table 1 ~~to~~ [paragraph \(c\)\(3\) of this section](#) for Phase 2 vocational vehicles. For other vehicles, let $\bar{v}_{\text{moving}} = 1$.

$w_{[\text{cycle}]}$ = weighting factor for the appropriate test cycle, as shown in table 1 ~~to~~ [paragraph \(c\)\(3\) of this section](#).

$m_{[\text{cycle}]}$ = CO₂ mass emissions over each test cycle (other than idle).

$D_{[\text{cycle}]}$ = the total driving distance for the indicated duty cycle. Use 2.842 miles for the transient cycle, and use 13.429 miles for both of the highway cruise cycles.

$\bar{m}_{[\text{cycle}]\text{-idle}} = \text{CO}_2 \text{ emission rate at idle.}$

Example:

Class 7 vocational vehicle meeting the Phase 2 standards based on the Regional duty cycle.

$PL = 5.6 \text{ tons}$

$\bar{v}_{\text{moving}} = 38.41 \text{ mi/hr}$

$w_{\text{transient}} = 20 \% = 0.20$

$w_{\text{drive-idle}} = 0 \% = 0$

$w_{\text{parked-idle}} = 25 \% = 0.25$

$w_{55} = 24 \% = 0.24$

$w_{65} = 56 \% = 0.56$

$m_{\text{transient}} = 4083 \text{ g}$

$m_{55} = 13834 \text{ g}$

$m_{65} = 17018 \text{ g}$

$D_{\text{transient}} = 2.8449 \text{ miles}$

$D_{55} = 13.429 \text{ miles}$

$D_{65} = 13.429 \text{ miles}$

$\bar{m}_{\text{drive-idle}} = 4188 \text{ g/hr}$

$\bar{m}_{\text{parked-idle}} = 3709 \text{ g/hr}$

$$e_{\text{CO}_2} = \frac{1}{5.6 \cdot 38.41 \cdot (1 - 0 - 0.25)} \cdot \left((1 - 0.0 - 0.25) \cdot \left(\frac{0.20 \cdot 4083}{2.8449} + \frac{0.24 \cdot 13834}{13.429} + \frac{0.56 \cdot 17018}{13.429} \right) \right)$$

$e_{\text{CO}_2} = 228 \text{ g/ton-mile}$

- (c) Weighting factors apply for each type of vehicle and for each duty cycle as follows:
- (1) GEM applies weighting factors for specific types of tractors as shown in Table 1 of this section.
 - (2) GEM applies weighting factors for vocational vehicles as shown in Table 1 of this section. Modeling for Phase 2 vocational vehicles depends on characterizing vehicles by duty cycle to apply proper weighting factors and average speed values. Select either Urban, Regional, or Multi-Purpose as the most appropriate duty cycle for modeling emission results with each vehicle configuration, as specified in §§ 1037.140 and 1037.150.
 - (3) Table 1 follows:

TABLE 1 ~~OF TO PARAGRAPH (C)(3) OF~~ § 1037.510—WEIGHTING FACTORS FOR DUTY CYCLES

	Distance-weighted			Time-weighted ^a			Average speed during non-idle cycles (mi/hr) ^b
	Transient	55 mi/hr cruise	65 mi/hr cruise	Drive idle	Parked idle	Non-idle	
Day Cabs	19 %	17 %	64 %	—	—	—	—
Sleeper Cabs	5 %	9 %	86 %	—	—	—	—
Heavy-haul Tractors	19 %	17 %	64 %	—	—	—	—
Vocational—Regional	20 %	24 %	56 %	0 %	25 %	75 %	38.41
Vocational—Multi-Purpose (2b-7)	54 %	29 %	17 %	17 %	25 %	58 %	23.18
Vocational—Multi-Purpose (8)	54 %	23 %	23 %	17 %	25 %	58 %	23.27
Vocational—Urban (2b-7)	92 %	8 %	0 %	15 %	25 %	60 %	16.25
Vocational—Urban (8)	90 %	10 %	0 %	15 %	25 %	60 %	16.51
Vocational with conventional powertrain (Phase 1 only)	42 %	21 %	37 %	—	—	—	—
Vocational Hybrid Vehicles (Phase 1 only)	75 %	9 %	16 %	—	—	—	—

^aNote that these drive idle and non-idle weighting factors do not reflect additional drive idle that occurs during the transient cycle. The transient cycle does not include any parked idle.

^bThese values apply even for vehicles not following the specified speed traces.

(d) For highway cruise and transient testing, compare actual second-by-second vehicle speed with the speed specified in the test cycle and ensure any differences are consistent with the criteria as specified in ~~40 CFR~~ § 1036.5450(g)(1). If the speeds do not conform to these criteria, the test is not valid and must be repeated.

(e) Run test cycles as specified in 40 CFR part 1066. For testing vehicles equipped with cruise control over the highway cruise cycles, you may use the vehicle’s cruise control to control the vehicle speed. For vehicles equipped with adjustable vehicle speed limiters, test the vehicle with the vehicle speed limiter at its highest setting.

(f) For Phase 1, test the vehicle using its adjusted loaded vehicle weight, unless we determine this would be unrepresentative of in-use operation as specified in 40 CFR 1065.10(c)(1).

(g) For hybrid vehicles, correct for the net energy change of the energy storage device as described in 40 CFR 1066.501(a)(3).

~~§ 1037.515 Determining CO₂ emissions to show compliance for trailers.~~

~~This section describes a compliance approach for trailers that is consistent with the modeling for vocational vehicles and tractors described in § 1037.520, but is simplified consistent with the smaller number of trailer parameters that affect CO₂ emissions. Note that the calculated CO₂ emission rate, eco_2 , is equivalent to the value that would result from running GEM with the same input values.~~

~~(a) Compliance equation. Calculate CO₂ emissions for demonstrating compliance with emission standards for each trailer configuration.~~

~~(1) Use the following equation:~~

$$e_{CO_2} = (C_1 + C_2 \cdot TRRL + C_3 \cdot \Delta C_d A + C_4 \cdot WR) \cdot C_5$$

Eq. 1037.515-1

Where:

C_i = constant values for calculating CO₂ emissions from this regression equation derived from GEM, as shown in Table 1 of this section. Let $C_5 = 0.988$ for trailers that have automatic tire inflation systems with all wheels, and let $C_5 = 0.990$ for trailers that have tire pressure monitoring systems with all wheels (or a mix of the two systems); otherwise, let $C_5 = 1$.

$TRRL$ = tire rolling resistance level as specified in paragraph (b) of this section.

$\Delta C_d A$ = the $\Delta C_d A$ value for the trailer as specified in paragraph (c) of this section.

WR = weight reduction as specified in paragraph (d) or (e) of this section.

TABLE 1 OF § 1037.515 — REGRESSION COEFFICIENTS FOR CALCULATING CO₂ EMISSIONS

Trailer Category	C_1	C_2	C_3	C_4
Long dry box van	76.1	1.67	-5.82	-0.00103
Long refrigerated box van	77.4	1.75	-5.78	-0.00103
Short dry box van	117.8	1.78	-9.48	-0.00258
Short refrigerated box van	121.1	1.88	-9.36	-0.00264

(2) The following is an example for calculating the mass of CO₂ emissions, e_{CO_2} , from a long dry box van that has a tire pressure monitoring system for all wheels, an aluminum suspension assembly, aluminum floor, and is designated as Bin IV:

$$C_1 = 76.1$$

$$C_2 = 1.67$$

$$TRRL = 4.6 \text{ kg/tonne}$$

$$C_3 = -5.82$$

$$\Delta C_d A = 0.7 \text{ m}^2$$

$$C_4 = -0.00103$$

$$WR = 655 \text{ lbs}$$

$$C_5 = 0.990$$

$$e_{CO_2} = (76.1 + 1.67 \cdot 4.6 + (-5.82 \cdot 0.7) + (-0.00103 \cdot 655)) \cdot 0.990$$

$$e_{CO_2} = 78.24 \text{ g/ton mile}$$

(b) *Tire rolling resistance.* Use the procedure specified in § 1037.520(c) to determine the tire rolling resistance level for your tires. Note that you may base tire rolling resistance levels on measurements performed by tire manufacturers, as long as those measurements meet this part's specifications.

(c) *Drag area.* You may use $\Delta C_d A$ values approved under § 1037.211 for device manufacturers if your trailers are properly equipped with those devices. Determine $\Delta C_d A$ values for other trailers based on testing. Measure $C_d A$ and determine $\Delta C_d A$ values as described in § 1037.526(a). You may use $\Delta C_d A$ values from one trailer configuration to represent any number of additional trailers based on worst-case testing. This means that you may apply $\Delta C_d A$ values from your measurements to any trailer models of the same category with drag area at or below that of the tested configuration. For trailers in the short dry box vans and short refrigerated box vans that are not 28 feet long, apply the $\Delta C_d A$ value established for a comparable 28-foot trailer model; you may use the same devices designed for 28-foot trailers or you may adapt those devices as appropriate for the different trailer length, consistent with good engineering judgment. For

example, 48-foot trailers may use longer side skirts than the skirts that were tested with a 28-foot trailer. Trailer and device manufacturers may seek preliminary approval for these adaptations. Determine bin levels based on AC_dA test results as described in the following table:

TABLE 2 OF § 1037.515 — BIN DETERMINATIONS FOR TRAILERS BASED ON AERODYNAMIC TEST RESULTS (AC_dA in m^2)

If a trailer's measured AC_dA is ...	designate the trailer as ...	and use the following value for AC_dA
≤ 0.09	Bin I	0.0
0.10—0.39	Bin II	0.1
0.40—0.69	Bin III	0.4
0.70—0.99	Bin IV	0.7
1.00—1.39	Bin V	1.0
1.40—1.79	Bin VI	1.4
≥ 1.80	Bin VII	1.8

(d) *Weight reduction.* Determine weight reduction for a trailer configuration by summing all applicable values, as follows:

- (1) Determine weight reduction for using lightweight materials for wheels as described in § 1037.520(e).
- (2) Apply weight reductions for other components made with light-weight materials as shown in the following table:

TABLE 3 OF § 1037.515 — WEIGHT REDUCTIONS FOR TRAILERS (POUNDS)

Component	Material	Weight reduction (pounds)
Structure for Suspension Assembly ^a	Aluminum	280
Hub and Drum (per axle)	Aluminum	80
Floor ^b	Aluminum	375
Floor ^b	Composite (wood and plastic)	245
Floor Crossmembers ^b	Aluminum	250
Landing Gear	Aluminum	50
Rear Door	Aluminum	187
Rear Door Surround	Aluminum	150
Roof Bows	Aluminum	100
Side Posts	Aluminum	300
Slider Box	Aluminum	150
Upper Coupler Assembly	Aluminum	430

^aFor tandem axle suspension sub-frames made of aluminum, apply a weight reduction of 280 pounds. Use good engineering judgment to estimate a weight reduction for using aluminum sub-frames with other axle configurations.

^bCalculate a smaller weight reduction for short trailers by multiplying the indicated values by 0.528 (28/53).

- ~~(e) Off cycle. You may apply the off cycle provisions of § 1037.610 to trailers as follows:~~
- ~~(1) You may account for weight reduction based on measured values instead of using paragraph (d) of this section. Quantify the weight reduction by measuring the weight of a trailer in a certified configuration and comparing it to the weight of an equivalent trailer without weight reduction technologies. This qualifies as A to B testing under § 1037.610. Use good engineering judgment to select an equivalent trailer representing a baseline configuration. Use the calculated weight reduction in Eq. 1037.515-1 to calculate the trailer's CO₂ emission rate.~~
 - ~~(2) If your off cycle technology reduces emissions in a way that is proportional to measured emissions as described in § 1037.610(b)(1), multiply the trailer's CO₂ emission rate by the appropriate improvement factor.~~
 - ~~(3) If your off cycle technology does not yield emission reductions that are proportional to measured emissions, as described in § 1037.610(b)(2), calculate an adjusted CO₂ emission rate for your trailers by subtracting the appropriate off cycle credit.~~
 - ~~(4) Note that these off cycle provisions do not apply for trailers subject to design standards.~~

§ 1037.520 Modeling CO₂ emissions to show that vehicles comply with standard compliance for vocational vehicles and tractors.

This section describes how to use the Greenhouse gas Emissions Model (GEM) ~~(incorporated by reference in § 1037.810)~~ to show compliance with the CO₂ standards of §§ 1037.105 and 1037.106 ~~for vocational vehicles and tractors.~~ Use GEM version 2.0.1 to demonstrate compliance with Phase 1 standards; use GEM Phase 2, Version 4.0 to demonstrate compliance with Phase 2 and Phase 3 standards ~~(both incorporated by reference, see § 1037.810)~~. Use good engineering judgment when demonstrating compliance using GEM. ~~See § 1037.515 for calculation procedures for demonstrating compliance with trailer standards.~~

(a) *General modeling provisions.* To run GEM, enter all applicable inputs as specified by the model.

- (1) GEM inputs apply for Phase 1 standards as follows:
 - (i) Model year and regulatory subcategory (see § 1037.230).
 - (ii) Coefficient of aerodynamic drag or drag area, as described in paragraph (b) of this section (tractors only).
 - (iii) Steer and drive tire rolling resistance, as described in paragraph (c) of this section.
 - (iv) Vehicle speed limit, as described in paragraph (d) of this section (tractors only).
 - (v) Vehicle weight reduction, as described in paragraph (e) of this section (tractors only for Phase 1).
 - (vi) Automatic engine shutdown systems, as described in § 1037.660 (only for Class 8 sleeper cabs). Enter a GEM input value of 5.0 g/ton-mile, or an adjusted value as specified in § 1037.660.
- (2) For Phase 2 and Phase 3 later vehicles, the GEM inputs described in paragraphs (a)(1)(i) through (v) of this section continue to apply. Note that the provisions in this part related to vehicle speed limiters and automatic engine shutdown systems are available for Phase 2 and later vocational vehicles ~~in Phase 2 and Phase 3~~. The rest of this section describes additional GEM inputs for demonstrating compliance with Phase 2 and Phase 3 later standards. Simplified versions of GEM apply for limited circumstances as follows:
 - (i) You may use default engine fuel maps for glider kits as described in § 1037.635.

(ii) If you certify vehicles to the custom-chassis standards specified in § 1037.105(h), run GEM by identifying the vehicle type and entering “NA” instead of what would otherwise apply for, tire revolutions per mile, engine information, transmission information, drive axle ratio, axle efficiency, and aerodynamic improvement as specified in paragraphs (c)(1), (f), (g)(1) and (3), (i), and (m) of this section, respectively. Incorporate other GEM inputs as specified in this section.

(b) *Coefficient of aerodynamic drag and drag area for tractors.* Determine the appropriate drag area, C_dA , for tractors as described in this paragraph (b). Use the recommended method or an alternate method to establish a value for C_dA , expressed in m^2 to one decimal place, as specified in § 1037.525. Where we allow you to group multiple configurations together, measure C_dA of the worst-case configuration.

(1) Except as specified in paragraph (b)(2) of this section, determine the Phase 1 bin level for your vehicle based on measured C_dA values as shown in the following tables:

TABLE 1 TO § 1037.520— C_d INPUTS FOR PHASE 1 HIGH-ROOF TRACTORS

Tractor type	Bin level	If your measured C_dA (m^2) is ...	Then your C_d input is ...
High-Roof Day Cabs	Bin I	≥ 8.0	0.79
	Bin II	7.1-7.9	0.72
	Bin III	6.2-7.0	0.63
	Bin IV	5.6-6.1	0.56
	Bin V	≤ 5.5	0.51
High-Roof Sleeper Cabs	Bin I	≥ 7.6	0.75
	Bin II	6.8-7.5	0.68
	Bin III	6.3-6.7	0.60
	Bin IV	5.6-6.2	0.52
	Bin V	≤ 5.5	0.47

TABLE 2 TO § 1037.520(b)— C_d INPUTS FOR PHASE 1 LOW-ROOF AND MID-ROOF TRACTORS

Tractor type	Bin level	If your measured C_dA (m^2) is ...	Then your C_d input is ...
Low-Roof Day and Sleeper Cabs	Bin I	≥ 5.1	0.77
	Bin II	≤ 5.0	0.71
Mid-Roof Day and Sleeper Cabs	Bin I	≥ 5.6	0.87
	Bin II	≤ 5.5	0.82

(2) For Phase 1 low- and mid-roof tractors, you may instead determine your drag area bin based on the drag area bin of an equivalent high-roof tractor. If the high-roof tractor is in Bin I or Bin II, then you may assume your equivalent low- and mid-roof tractors are in Bin I. If the high-roof tractor is in Bin III, Bin IV, or Bin V, then you may assume your equivalent low- and mid-roof tractors are in Bin II.

(3) For Phase 2 [and Phase 3 later](#) tractors other than heavy-haul tractors, determine bin levels and C_dA inputs as follows:

(i) Determine bin levels for high-roof tractors based on aerodynamic test results as specified in § 1037.525 and summarized in the following table:

TABLE 3 TO [PARAGRAPH \(b\)\(3\)\(i\) OF § 1037.520](#)—BIN DETERMINATIONS FOR PHASE 2 [AND PHASE 3 LATER](#) HIGH-ROOF TRACTORS BASED ON AERODYNAMIC TEST RESULTS (C_dA in m^2)

Tractor type	Bin I	Bin II	Bin III	Bin IV	Bin V	Bin VI	Bin VII
Day Cabs	≥ 7.2	6.6-7.1	6.0-6.5	5.5-5.9	5.0-5.4	4.5-4.9	≤ 4.4
Sleeper Cabs	≥ 6.9	6.3-6.8	5.7-6.2	5.2-5.6	4.7-5.1	4.2-4.6	≤ 4.1

(ii) For low- and mid-roof tractors, you may either use the same bin level that applies for an equivalent high-roof tractor as shown in [Table 3](#) of this section, or you may determine your bin level based on aerodynamic test results as described in [Table 4](#) of this section.

TABLE 4 TO [PARAGRAPH \(b\)\(3\)\(ii\) OF § 1037.520](#)—BIN DETERMINATIONS FOR PHASE 2 [AND LATER PHASE 3](#) LOW-ROOF AND MID-ROOF TRACTORS BASED ON AERODYNAMIC TEST RESULTS (C_dA in m^2)

Tractor type	Bin I	Bin II	Bin III	Bin IV	Bin V	Bin VI	Bin VII
Low-Roof Cabs	≥ 5.4	4.9-5.3	4.5-4.8	4.1-4.4	3.8-4.0	3.5-3.7	≤ 3.4
Mid-Roof Cabs	≥ 5.9	5.5-5.8	5.1-5.4	4.7-5.0	4.4-4.6	4.1-4.3	≤ 4.0

(iii) Determine the C_dA input according to the tractor's bin level as described in the following table:

TABLE 5 TO [PARAGRAPH \(b\)\(3\)\(iii\) OF § 1037.520](#)—PHASE 2 [AND LATER PHASE 3](#) C_dA TRACTOR INPUTS BASED ON BIN LEVEL

Tractor type	Bin I	Bin II	Bin III	Bin IV	Bin V	Bin VI	Bin VII
High-Roof Day Cabs	7.45	6.85	6.25	5.70	5.20	4.70	4.20
High-Roof Sleeper Cabs	7.15	6.55	5.95	5.40	4.90	4.40	3.90
Low-Roof Cabs	6.00	5.60	5.15	4.75	4.40	4.10	3.80
Mid-Roof Cabs	7.00	6.65	6.25	5.85	5.50	5.20	4.90

(4) Note that, starting in model year 2027, GEM internally reduces C_dA for high-roof tractors by $0.3 m^2$ to simulate adding a rear fairing to the standard trailer.

(c) *Tire revolutions per mile and rolling resistance.* You must have a tire revolutions per mile (TRPM) and a tire rolling resistance level (TRRL) for each tire configuration. For purposes of this section, you may consider tires with the same SKU number to be the same configuration. Determine TRRL input values separately for drive and steer tires; determine TRPM only for drive tires.

(1) Use good engineering judgment to determine a tire's revolutions per mile to the nearest whole number as specified in SAE J1025 (incorporated by reference, [see-in](#) § 1037.810). Note that for tire sizes that you do not test, we will treat your analytically derived revolutions per mile the same as test results, and we may perform our own testing to verify your values. We may require you to test a sample of additional tire sizes that we select.

(2) Measure tire rolling resistance in newton per kilonewton as specified in ISO 28580 (incorporated by reference, [see-in](#) § 1037.810), except as specified in this paragraph (c). Use good engineering judgment to ensure that your test results are not biased low. You may ask us to identify a reference test laboratory to which you may correlate your test results. Prior to beginning the test procedure in Section 7 of ISO 28580 for a new bias-ply tire, perform a break-in procedure by running the tire at the specified test speed, load, and pressure for (60 ± 2) minutes.

(3) For each tire design tested, measure rolling resistance of at least three different tires of that specific design and size. Perform the test at least once for each tire. Calculate the arithmetic mean of these results to the nearest 0.1 N/kN and use this value or any higher

value as your GEM input for TRRL. You must test at least one tire size for each tire model, and may use engineering analysis to determine the rolling resistance of other tire sizes of that model. Note that for tire sizes that you do not test, we will treat your analytically derived rolling resistances the same as test results, and we may perform our own testing to verify your values. We may require you to test a small sub-sample of untested tire sizes that we select.

(4) If you obtain your test results from the tire manufacturer or another third party, you must obtain a signed statement from the party supplying those test results to verify that tests were conducted according to the requirements of this part. Such statements are deemed to be submissions to EPA.

(5) For tires marketed as light truck tires that have load ranges C, D, or E, use as the GEM input TRRL multiplied by 0.87.

(6) For vehicles with at least three drive axles or for vehicles with more than three axles total, use good engineering judgment to combine tire rolling resistance into three values (steer, drive 1, and drive 2) for use in GEM. This may require performing a weighted average of tire rolling resistance from multiple axles based on the typical load on each axle. For liftable axles, calculate load- and time-weighted values to represent the load and the amount of time these tires are in contact with the ground during typical in-use operation.

(7) For vehicles with a single rear axle, enter "NA" as the TRRL value for drive axle 2.

(d) *Vehicle speed limit.* If the vehicles will be equipped with a vehicle speed limiter, input the maximum vehicle speed to which the vehicle will be limited (in miles per hour rounded to the nearest 0.1 mile per hour) as specified in § 1037.640. Use good engineering judgment to ensure the limiter is tamper resistant. We may require you to obtain preliminary approval for your designs.

(e) *Vehicle weight reduction.* Develop a weight-reduction as a GEM input as described in this paragraph (e). Enter the sum of weight reductions as described in this paragraph (e), or enter zero if there is no weight reduction. For purposes of this paragraph (e), high-strength steel is steel with tensile strength at or above 350 MPa.

(1) Vehicle weight reduction inputs for wheels are specified relative to dual-wide tires with conventional steel wheels. For purposes of this paragraph (e)(1), an aluminum alloy qualifies as light-weight if a dual-wide drive wheel made from this material weighs at least 21 pounds less than a comparable conventional steel wheel. The inputs are listed in Table 6 of this section. For example, a tractor or vocational vehicle with aluminum steer wheels and eight (4×2) dual-wide aluminum drive wheels would have an input of 210 pounds (2×21 + 8×21).

TABLE 6 TO § 1037.520—WHEEL-RELATED WEIGHT REDUCTIONS

Weight-reduction technology Tire type	Material	Weight reduction— Phase 1 (#-pounds per wheel)	Weight reduction— Phase 2 and Phase 3 Later (#-pounds per wheel)
Wide-Base Single Drive Tire with . . . ^a	Steel Wheel	84	84
	Aluminum Wheel	139	147
	Light-Weight Aluminum Alloy Wheel	147	147
Steer Tire or ; Dual-wide Drive Tire, or Dual-wide Trailer Tire with . . .	High-Strength Steel Wheel	8	8
	Aluminum Wheel	21	25
	Light-Weight Aluminum Alloy Wheel	30	25

^aThe weight reduction for wide-base tires accounts for reduced tire weight relative to dual-wide tires.

(2) Weight reduction inputs for tractor components other than wheels are specified in the following table:

TABLE 7 TO § 1037.520—NONWHEEL-RELATED WEIGHT REDUCTIONS FROM ALTERNATIVE MATERIALS FOR TRACTORS (POUNDS)

Weight reduction technologies	Aluminum	High-strength steel	Thermoplastic
Door	20	6	
Roof	60	18	
Cab rear wall	49	16	
Cab floor	56	18	
Hood Support Structure System	15	3	
Hood and Front Fender			65
Day Cab Roof Fairing			18
Sleeper Cab Roof Fairing	75	20	40
Aerodynamic Side Extender			10
Fairing Support Structure System	35	6	
Instrument Panel Support Structure	5	1	
Brake Drums – Drive (set of 4)	140	74	
Brake Drums – Non Drive (set of 2)	60	42	
Frame Rails	440	87	
Crossmember – Cab	15	5	
Crossmember – Suspension	25	6	
Crossmember – Non Suspension (set of 3)	15	5	
Fifth Wheel	100	25	
Radiator Support	20	6	
Fuel Tank Support Structure	40	12	
Steps	35	6	
Bumper	33	10	
Shackles	10	3	
Front Axle	60	15	
Suspension Brackets, Hangers	100	30	
Transmission Case	50	12	
Clutch Housing	40	10	
Fairing Support Structure System	35	6	
Drive Axle Hubs (set of 4)	80	20	
Non Drive Hubs (2)	40	5	
Two-piece driveshaft	20	5	
Transmission/Clutch Shift Levers	20	4	

(3) Weight-reduction inputs for vocational-vehicle components other than wheels are specified in the following table:

TABLE 8 TO § 1037.520—NONWHEEL-RELATED WEIGHT REDUCTIONS FROM ALTERNATIVE MATERIALS FOR PHASE 2 AND LATER PHASE 3 VOCATIONAL VEHICLES (POUNDS)^A

Component	Material	Vehicle type		
		Light HDV	Medium HDV ^b	Heavy HDV
Axle Hubs - Non-Drive	Aluminum		40	40
Axle Hubs - Non-Drive	High Strength Steel		5	5
Axle - Non-Drive	Aluminum		60	60
Axle - Non-Drive	High Strength Steel		15	15
Brake Drums - Non-Drive	Aluminum		60	60
Brake Drums - Non-Drive	High Strength Steel		42	42
Axle Hubs – Drive	Aluminum		40	80
Axle Hubs – Drive	High Strength Steel		10	20
Brake Drums - Drive	Aluminum		70	140
Brake Drums - Drive	High Strength Steel		37	74
Suspension Brackets, Hangers	Aluminum		67	100
Suspension Brackets, Hangers	High Strength Steel		20	30
Crossmember – Cab	Aluminum	10	15	15
Crossmember – Cab	High Strength Steel	2	5	5
Crossmember - Non-Suspension	Aluminum	15	15	15
Crossmember - Non-Suspension	High Strength Steel	5	5	5
Crossmember -Suspension	Aluminum	15	25	25
Crossmember -Suspension	High Strength Steel	6	6	6
Driveshaft	Aluminum	12	40	50
Driveshaft	High Strength Steel	5	10	12
Frame Rails	Aluminum	120	300	440
Frame Rails	High Strength Steel	40	40	87

^aWeight-reduction values apply per vehicle unless otherwise noted.

^bFor Medium HDV with 6×4 or 6×2 axle configurations, use the values for Heavy HDV.

(4) Apply vehicle weight inputs for changing technology configurations as follows:

(i) For Class 8 tractors or for Class 8 vocational vehicles with a permanent 6×2 axle configuration, apply a weight reduction input of 300 pounds. However, apply no weight reduction for coach buses certified to custom-chassis standards under § 1037.105(h).

(ii) For Class 8 tractors with 4×2 axle configuration, apply a weight reduction input of 400 pounds.

(iii) For tractors with installed engines with displacement below 14.0 liters, apply a weight reduction of 300 pounds.

(iv) For tractors with single-piece driveshafts with a total length greater than 86 inches, apply a weight reduction of 43 pounds for steel driveshafts and 63 pounds for aluminum driveshafts.

(5) You may ask to apply the off-cycle technology provisions of § 1037.610 for weight reductions not covered by this paragraph (e).

(f) *Engine characteristics.* Enter information from the engine manufacturer to describe the installed engine and its operating parameters as described in 40 CFR 1036.505. Note that you do not need fuel consumption at idle for tractors.

(g) *Vehicle characteristics.* Enter the following information to describe the vehicle and its operating parameters:

(1) *Transmission make, model, and type.* Also identify the gear ratio for every available forward gear to two decimal places, the input torque limit for each of the forward gears, and,

if applicable, the lowest gear involving a locked torque converter. Count forward gears as being available only if the vehicle has the hardware and software to allow operation in those gears. For vehicles with a manual transmission, GEM applies a 2 % emission increase relative to automated manual transmissions. If your vehicle has a dual-clutch transmission, use good engineering judgment to determine if it can be accurately represented in GEM as an automated manual transmission. We may require you to perform a powertrain test with dual-clutch transmissions to show that they can be properly simulated as an automated manual transmission.

(2) *Drive axle make, model, and configuration.* Select a drive axle configuration to represent your vehicle for modeling.

(i) 4×2: One drive axle and one non-drive axle. This includes vehicles with two drive axles where one of the drive axles is disconnectable and that disconnectable drive axle is designed to be connected only when the vehicle is driven off-road or in slippery conditions if at least one of the following is true:

(A) The input and output of the disconnectable axle is mechanically disconnected from the drive shaft and the wheels when the axle is in 4×2 configuration.

(B) You provide power loss data generated according to § 1037.560 for the combination of both drive axles, where the disconnectable drive axle is in the disconnected configuration.

(ii) 6×2: One drive axle and two non-drive axles.

(iii) 6×4: Two or more drive axles, or more than three total axles. Note that this includes, for example, a vehicle with two drive axles out of four total axles (otherwise known as an 8×4 configuration).

(iv) 6×4D: One non-drive axle and two drive axles where one of the two drive axles is automatically disconnectable such that the axle can switch between 6×2 and 6×4 configurations. You may select this configuration only if at least one of the following is true:

(A) The input and output of the disconnectable axle is mechanically disconnected from the drive shaft and the wheels when the axle is in the 6×2 configuration.

(B) You provide power loss data generated according to § 1037.560 for the combination of both drive axles, where the disconnectable drive axle is in the disconnected configuration.

(3) *Drive axle ratio, k_a .* If a vehicle is designed with two or more user-selectable axle ratios, use the drive axle ratio that is expected to be engaged for the greatest driving distance. If the vehicle does not have a drive axle, such as a hybrid vehicle with direct electric drive, let $k_a = 1$.

(4) GEM inputs associated with powertrain testing include powertrain family, transmission calibration identifier, test data from [40 CFR § 10367.5450](#), and the powertrain test configuration (dynamometer connected to transmission output or wheel hub). You do not need to identify or provide inputs for transmission gear ratios, fuel map data, or engine torque curves, which would otherwise be required under paragraph (f) of this section.

(h) *Idle speed and idle-reduction technologies.* The following provisions apply for engine idling:

(1) For engines with no adjustable warm idle speed, input vehicle idle speed as the manufacturer's declared warm idle speed. For engines with adjustable warm idle speed, input your vehicle idle speed as follows:

If your vehicle is a...	And your engine is subject to...	Your default vehicle idle speed is... ^a
(i) Heavy HDV	compression-ignition or spark-ignition standards	600 r/min.
(ii) Medium HDV tractor	compression-ignition standards	700 r/min.
(iii) Light HDV or Medium HDV vocational vehicle	compression-ignition standards	750 r/min.
(iv) Light HDV or Medium HDV	spark-ignition standards	600 r/min.

^aIf the default idle speed is above or below the engine manufacturer's whole range of declared warm idle speeds, use the manufacturer's maximum or minimum declared warm idle speed, respectively, instead of the default value.

(2) Identify whether your vehicle has qualifying idle-reduction technologies, subject to the qualifying criteria in § 1037.660, as follows:

(i) Stop-start technology and automatic engine shutdown systems apply for vocational vehicles. See paragraph (j) of this section for automatic engine shutdown systems for tractors.

(ii) Neutral idle applies for tractors and vocational vehicles.

(i) *Axle, transmission, and torque converter characterization.* You may characterize the axle, transmission, and torque converter using axle efficiency maps as described in § 1037.560, transmission efficiency maps as described in § 1037.565, and torque converter capacity factors and torque ratios as described in § 1037.570 to replace the default values in GEM. If you obtain your test results from the axle manufacturer, transmission manufacturer, torque converter manufacturer or another third party, you must obtain a signed statement from the party supplying those test results to verify that tests were conducted according to the requirements of this part. Such statements are deemed to be submissions to EPA.

(j) *Additional reduction technologies.* Enter input values in GEM as follows to characterize the percentage CO₂ emission reduction corresponding to certain technologies and vehicle configurations, or enter 0:

(1) *Intelligent controls.* Enter 2 for tractors with predictive cruise control. This includes any cruise control system that incorporates satellite-based global-positioning data for controlling operator demand. For tractors without predictive cruise control and for all vocational vehicles, enter 1.5 if they have neutral coasting or the installed engine deactivates all cylinders closing all intake and exhaust valves when operator demand is zero while the vehicle is in motion~~full-cylinder deactivation when coasting~~, unless good engineering judgment indicates that a lower percentage should apply.

(2) *Accessory load.* Enter the following values related to accessory loads; if more than one item applies, enter the sum of those values:

(i) If vocational vehicles have electrically powered pumps for steering, enter 0.5 for vocational vehicles certified with the Regional duty cycle, and enter 1 for other vocational vehicles.

(ii) If tractors have electrically powered pumps for both steering and engine cooling, enter 1.

(iii) If vehicles have a high-efficiency air conditioning compressor, enter 0.5 for tractors, 0.5 for ~~and~~ vocational Heavy HDV, and enter ~~1~~ for other vocational vehicles. This includes all electrically powered compressors. It also include mechanically powered compressors if the coefficient of performance improves by 10 percent or greater over the baseline design, consistent with the provisions for improved evaporators and condensers in 40 CFR 86.1868-12(h)(5).

(3) *Tire-pressure systems*. Enter 1.2 for vehicles with automatic tire inflation systems on all axles (1.1 for Multi-Purpose and Urban vocational vehicles). Enter 1.0 for vehicles with tire pressure monitoring systems on all axles (0.9 for Multi-Purpose and Urban vocational vehicles). If vehicles use a mix of the two systems, treat them as having only tire pressure monitoring systems.

(4) *Extended-idle reduction*. Enter values as shown in the following table for sleeper cabs equipped with idle-reduction technology meeting the requirements of § 1037.660 that are designed to automatically shut off the main engine after 300 seconds or less:

TABLE 9 TO § 1037.520—GEM INPUT VALUES FOR AES SYSTEMS

Technology	GEM input values	
	Adjustable	Tamper-resistant
Standard AES system	1	4
With diesel APU	3	4
With battery APU	5	6
With automatic stop-start	3	3
With fuel-operated heater (FOH)	2	3
With diesel APU and FOH	4	5
With battery APU and FOH	5	6
With stop-start and FOH	4	5

(5) *Other*. Additional GEM inputs may apply as follows:

(i) Enter 0.9 and 1.7, respectively, for school buses and coach buses that have at least seven available forward gears.

(ii) If we approve off-cycle technology under § 1037.610 in the form of an improvement factor, enter the improvement factor expressed as a percentage reduction in CO₂ emissions. (Note: In the case of approved off-cycle technologies whose benefit is quantified as a g/ton-mile credit, apply the credit to the GEM result, not as a GEM input value.)

(k) *Vehicles with hybrid power take-off*. For vocational vehicles, determine the delta PTO emission result of your engine and hybrid power take-off system as described in § 1037.540.

(l) [Reserved]

(m) *Aerodynamic improvements for vocational vehicles*. For vocational vehicles certified using the Regional duty cycle, enter $\Delta C_d A$ values to account for using aerodynamic devices as follows:

(1) Enter 0.2 for vocational vehicles with an installed rear fairing if the vehicle is at least 7 m long with a minimum frontal area of 8 m².

(2) For vehicles at least 11 m long with a minimum frontal area of 9 m², enter 0.5 if the vehicle has both skirts and a front fairing, and enter 0.3 if it has only one of those devices.

(3) You may determine input values for these or other technologies based on aerodynamic measurements as described in § 1037.527.

(n) *Alternate fuels*. For fuels other than those identified in GEM, perform the simulation by identifying the vehicle as being diesel-fueled if the engine is subject to the compression-ignition standard, or as being gasoline-fueled if the engine is subject to the spark-ignition standards. Correct the engine or powertrain fuel map for mass-specific net energy content as described in 40 CFR 1036.535(b).

§ 1037.525 Aerodynamic measurements for tractors.

This section describes a methodology for quantifying aerodynamic drag for use in determining input values for tractors as described in § 1037.520. This coastdown testing is the reference method for aerodynamic measurements.

(a) *General provisions.* The GEM input for a tractor's aerodynamic performance is a C_d value for Phase 1 and a C_dA value for Phase 2 [and Phase 3 later](#). The input value is measured or calculated for a tractor in a specific test configuration with a trailer, such as a high-roof tractor with a box van meeting the requirements for the standard trailer.

(1) Aerodynamic measurements may involve any of several different procedures. Measuring with different procedures introduces variability, so we identify the coastdown method in § 1037.528 as the primary (or reference) procedure. You may use other procedures with our advance approval as described in paragraph (d) of this section, but we require that you adjust your test results from other test methods to correlate with coastdown test results. All adjustments must be consistent with good engineering judgment. Submit information describing how you quantify aerodynamic drag from coastdown testing, whether or not you use an alternate method.

(2) Test high-roof tractors with a standard trailer as described in § 1037.501(g)(1). Note that the standard trailer for Phase 1 tractors is different from that of later model years. Note also that GEM may model a different configuration than the test configuration, but accounts for this internally. Test low-roof and mid-roof tractors without a trailer; however, you may test low-roof and mid-roof tractors with a trailer to evaluate off-cycle technologies.

(b) *Adjustments to correlate with coastdown testing.* Adjust aerodynamic drag values from alternate methods to be equivalent to the corresponding values from coastdown measurements as follows:

(1) Determine the functional relationship between your alternate method and coastdown testing. Specify this functional relationship as $F_{\text{alt-aero}}$ for a given alternate drag measurement method. The effective yaw angle, ψ_{eff} , is assumed to be zero degrees for Phase 1. For Phase 2 [and Phase 3 later](#), determine ψ_{eff} from coastdown test results using the following equation:

$$F_{\text{alt-aero}} = \frac{C_d A_{\text{coastdown}}(\psi_{\text{eff}})}{C_d A_{\text{alt}}(\psi_{\text{eff}})}$$

Eq. 1037.525-1

Where:

$C_d A_{\text{coastdown}}(\psi_{\text{eff}})$ = the average drag area measured during coastdown at an effective yaw angle, ψ_{eff} .

$C_d A_{\text{alt}}(\psi_{\text{eff}})$ = the average drag area calculated from an alternate drag measurement method at an effective yaw angle, ψ_{eff} .

(2) Unless good engineering judgment dictates otherwise, assume that coastdown drag is proportional to drag measured using alternate methods and apply a constant adjustment factor, $F_{\text{alt-aero}}$, for a given alternate drag measurement method of similar vehicles.

(3) Determine $F_{\text{alt-aero}}$ by performing coastdown testing and applying your alternate method on the same vehicles. Consider all applicable test data including data collected during selective enforcement audits. Unless we approve another vehicle, one vehicle must be a Class 8 high-roof sleeper cab with a full aerodynamics package pulling a standard trailer. Where you have more than one tractor model meeting these criteria, use the tractor model with the

highest projected sales. If you do not have such a tractor model, you may use your most comparable tractor model with our prior approval. In the case of alternate methods other than those specified in this subpart, good engineering judgment may require you to determine your adjustment factor based on results from more than the specified minimum number of vehicles.

(4) Measure the drag area using your alternate method for a Phase 2 and Phase 3 later tractor used to determine $F_{\text{alt-aero}}$ with testing at yaw angles of 0° , $\pm 1^\circ$, $\pm 3^\circ$, $\pm 4.5^\circ$, $\pm 6^\circ$, and $\pm 9^\circ$ (you may include additional angles), using direction conventions described in Figure 2 of SAE J1252 (incorporated by reference, see in § 1037.810). Also, determine the drag area at the coastdown effective yaw angle, $C_{dA_{\text{alt}}}(\psi_{\text{eff}})$, by taking the average drag area at ψ_{eff} and $-\psi_{\text{eff}}$ for your vehicle using the same alternate method.

(5) For Phase 2 and later Phase 3 testing, determine separate values of $F_{\text{alt-aero}}$ for at least one high-roof day cab and one high-roof sleeper cab for model year 2021, at least two high-roof day cabs and two high-roof sleeper cabs for model year 2024, and at least three high-roof day cabs and three high-roof sleeper cabs for model year 2027. These test requirements are cumulative; for example, you may meet these requirements by testing two vehicles to support model year 2021 certification and four additional vehicles to support model year 2023 certification. For any untested tractor models, apply the value of $F_{\text{alt-aero}}$ from the tested tractor model that best represents the aerodynamic characteristics of the untested tractor model, consistent with good engineering judgment. Testing under this paragraph (b)(5) continues to be valid for later model years until you change the tractor model in a way that causes the test results to no longer represent production vehicles. You must also determine unique values of $F_{\text{alt-aero}}$ for low-roof and mid-roof tractors if you determine C_{dA} values based on low or mid-roof tractor testing as shown in Table 4 of § 1037.520(b)(3)(ii). For Phase 1 testing, if good engineering judgment allows it, you may calculate a single, constant value of $F_{\text{alt-aero}}$ for your whole product line by dividing the coastdown drag area, $C_{dA_{\text{coastdown}}}$, by drag area from your alternate method, $C_{dA_{\text{alt}}}$.

(6) Determine $F_{\text{alt-aero}}$ to at least three decimal places. For example, if your coastdown testing results in a drag area of 6.430, but your wind tunnel method results in a drag area of 6.200, $F_{\text{alt-aero}}$ would be 1.037 (or a higher value you declare).

(7) If a tractor and trailer cannot be configured to meet the gap requirements specified in § 1037.501(g)(1)(ii), test with the trailer positioned as close as possible to the specified gap dimension and use good engineering judgment to correct the results to be equivalent to a test configuration meeting the specified gap dimension. For example, we may allow you to correct your test output using an approved alternate method or substitute a test vehicle that is capable of meeting the required specifications and is otherwise aerodynamically equivalent. This allowance applies for certification, confirmatory testing, SEA, and all other testing to demonstrate compliance with standards.

(8) You may ask us for preliminary approval of your coastdown testing under § 1037.210. We may witness the testing.

(c) *Yaw sweep corrections.* Aerodynamic features can have a different effectiveness for reducing wind-averaged drag than is predicted by zero-yaw drag. The following procedures describe how to determine a tractor's C_{dA} values to account for wind-averaged drag as specified in § 1037.520:

(1) Apply the following method for all Phase 2 and Phase 3 later testing with an alternate method:

(i) Calculate the wind-averaged drag area from the alternate method, $C_{dA_{\text{wa-alt}}}$, using an average of measurements at -4.5 and $+4.5$ degrees.

(ii) Determine your wind-averaged drag area, $C_d A_{wa}$, rounded to one decimal place, using the following equation:

$$C_d A_{wa} = C_d A_{wa-alt} \cdot F_{alt-aero}$$

Eq. 1037.525-2

(2) Apply the following method for Phase 2 and Phase 3 later coastdown testing other than coastdown testing used to establish $F_{alt-aero}$:

(i) Determine your drag area at the effective yaw angle from coastdown,

$$C_d A_{coastdown}(\psi_{eff}).$$

(ii) Use an alternate method to calculate the ratio of the wind-averaged drag area, $C_d A_{wa-alt}$ (using an average of measurements at -4.5 and $+4.5$ degrees) to the drag area at the effective yaw angle, $C_d A_{alt}(\psi_{eff})$.

(iii) Determine your wind-averaged drag area, $C_d A_{wa}$, rounded to one decimal place, using the following equation:

$$C_d A_{wa} = C_d A_{coastdown}(\psi_{eff}) \cdot \frac{C_d A_{wa-alt}}{C_d A_{alt}(\psi_{eff})}$$

Eq. 1037.525-3

(3) Different approximations apply for Phase 1. For Phase 1 testing, you may correct your zero-yaw drag area as follows if the ratio of the zero-yaw drag area divided by yaw-sweep drag area for your vehicle is greater than 0.8065 (which represents the ratio expected for a typical Class 8 high-roof sleeper cab):

(i) Determine the zero-yaw drag area, $C_d A_{zero-yaw}$, and the yaw-sweep drag area for your vehicle using the same alternate method as specified in this subpart. Measure the drag area for 0° , -6° , and $+6^\circ$. Use the arithmetic mean of the -6° and $+6^\circ$ drag areas as the $\pm 6^\circ$ drag area, $C_d A_{\pm 6}$.

(ii) Calculate your yaw-sweep correction factor, CF_{ys} , using the following equation:

$$CF_{ys} = \frac{C_d A_{\pm 6} \cdot 0.8065}{C_d A_{zero-yaw}}$$

Eq. 1037.525-4

(iii) Calculate your corrected drag area for determining the aerodynamic bin by multiplying the measured zero-yaw drag area by CF_{ys} , as determined using Eq. 1037.525-4, as applicable. You may apply the correction factor to drag areas measured using other procedures. For example, apply CF_{ys} to drag areas measured using the coastdown method. If you use an alternate method, apply an alternate correction, $F_{alt-aero}$, and calculate the final drag area using the following equation:

$$C_d A = F_{alt-aero} \cdot CF_{ys} \cdot C_d A_{zero-alt}$$

Eq. 1037.525-5

(iv) You may ask us to apply CF_{ys} to similar vehicles incorporating the same design features.

(v) As an alternative, you may calculate the wind-averaged drag area according to SAE J1252 (incorporated by reference, [see in](#) § 1037.810) and substitute this value into Eq. 1037.525-4 for the $\pm 6^\circ$ drag area.

(d) *Approval of alternate methods.* You must obtain preliminary approval before using any method other than coastdown testing to quantify aerodynamic drag. We will approve your request if you show that your procedures produce data that are the same as or better than

coastdown testing with respect to repeatability and unbiased correlation. Note that the correlation is not considered to be biased if there is a bias before correction, but you remove the bias using $F_{\text{alt-aero}}$. Send your request for approval to the Designated Compliance Officer. Keep records of the information specified in this paragraph (d). Unless we specify otherwise, include this information with your request. You must provide any information we require to evaluate whether you may apply the provisions of this section. Include additional information related to your alternate method as described in §§ 1037.530 through 1037.534. If you use a method other than those specified in this subpart, include all the following information, as applicable:

- (1) Official name/title of the procedure.
- (2) Description of the procedure.
- (3) Cited sources for any standardized procedures that the method is based on.
- (4) Description and rationale for any modifications/deviations from the standardized procedures.
- (5) Data comparing the procedure to the coastdown reference procedure.
- (6) Additional information specified for the alternate methods described in §§ 1037.530 through 1037.534 as applicable to this method (*e.g.*, source location/address, background/history).

§ 1037.526 Aerodynamic measurements for trailers.

~~This section describes a methodology for determining aerodynamic drag area, C_dA for use in determining input values for box vans as described in §§ 1037.515 and 1037.520.~~

~~(a) A trailer's aerodynamic performance for demonstrating compliance with standards is based on a ΔC_dA value relative to a baseline trailer. Determine these ΔC_dA values by performing A to B testing, as follows:~~

~~(1) Determine a baseline C_dA value for a standard tractor pulling a test trailer representing a production configuration; use a 53-foot test trailer to represent long trailers and a 28-foot test trailer to represent short trailers. Repeat this testing with the same tractor and the applicable baseline trailer. For testing long trailers, the baseline trailer is a trailer meeting the specifications for a Phase 1 standard trailer in § 1037.501(g)(1); for testing refrigerated box vans, use a baseline trailer with an installed HVAC unit that properly represents a baseline configuration correlated with the production configuration. For testing short trailers, use a 28-foot baseline trailer with a single axle that meets the same specifications as the Phase 1 standard trailer, except as needed to accommodate the reduced trailer length.~~

~~(2) Use good engineering judgment to perform paired tests that accurately demonstrate the reduction in aerodynamic drag associated with the improved design. For example, the gap dimension should be the same for all paired tests, and effective yaw angle between paired tests should differ by no more than 1.0°.~~

~~(3) Measure C_dA in m^2 to two decimal places. Calculate ΔC_dA by subtracting the drag area for the test trailer from the drag area for the baseline trailer.~~

~~(b) The default method for measuring is the wind-tunnel procedure as specified in § 1037.530. You may test using alternate methods as follows:~~

~~(1) If we approve it in advance, you may instead use one of the alternate methods specified in §§ 1037.528 through 1037.532, consistent with good engineering judgment, which may require that you adjust your test results from the alternate test method to correlate with the primary method. If you request our approval to determine ΔC_dA using an alternate method, you must submit additional information as described in paragraph (d) of this section.~~

~~(2) The principles of 40 CFR 1065.10(c)(1) apply for aerodynamic test methods. Specifically, we may require that you use coastdown measurements if we determine that certain technologies are not suited to evaluation with wind tunnel testing or CFD, such as nonrigid materials whose physical characteristics change in scaled-model testing. You may similarly reference 40 CFR 1065.10(c)(1) in your request to use coastdown testing as an alternate method.~~

~~(c) The following provisions apply for combining multiple devices under this section for the purpose of certifying trailers:~~

~~(1) If the device manufacturer establishes a ΔC_dA value in a single test with multiple aerodynamic devices installed, trailer manufacturers may use that ΔC_dA value directly for the same combination of aerodynamic devices installed on production trailers.~~

~~(2) Trailer manufacturers may combine ΔC_dA values for aerodynamic devices that are not tested together, as long as each device does not significantly impair the effectiveness of another, consistent with good engineering judgment. To approximate the overall benefit of multiple devices, calculate a composite ΔC_dA value for multiple aerodynamic devices by applying the full ΔC_dA value for the device with the greatest aerodynamic improvement, adding the second highest ΔC_dA value multiplied by 0.9, and adding any other ΔC_dA values multiplied by 0.8.~~

~~(d) You must send us a description of your plan to perform testing under this section before you start testing. We will evaluate whether plans for wind tunnel testing meet the specifications of § 1037.530, and will tell you if you may or must use any other method to determine drag coefficients. We will approve your request to use an alternate method if you show that your procedures produce data that are the same as or better than wind tunnel testing with respect to repeatability and unbiased correlation. Note that the correlation is not considered to be biased if there is a bias before correction, but you apply a correction to remove the bias. Send your testing plan to the Designated Compliance Officer. Keep records of the information specified in this paragraph (d). Unless we specify otherwise, include this information with your request. You must provide any information we require to evaluate whether you may apply the provisions of this section. Include additional information related to your alternate method as described in §§ 1037.528 through 1037.534.~~

§ 1037.527 Aerodynamic measurements for vocational vehicles.

~~This section describes a methodology for determining aerodynamic drag area, C_dA , for use in determining input values for vocational vehicles as described in § 1037.520. This measurement is optional.~~

~~(a) Determine ΔC_dA values by performing A to B testing as described for trailers in § 1037.526, with any appropriate adjustments, consistent with good engineering judgment.~~

~~(b) [Reserved] This section describes a methodology for determining vocational vehicle aerodynamic input values for as described in § 1037.520. This measurement is optional. This section describes an optional methodology for determining improved aerodynamic drag area, C_dA , for vocational vehicles, as described in § 1037.520(m), rather than using the assigned values. A vocational vehicle's aerodynamic performance is based on a ΔC_dA value relative to a baseline vehicle. Determine a ΔC_dA value by performing A to B testing as follows:~~

~~(a) Use any of the procedures described in this subpart, with appropriate adjustments, for calculating drag area.~~

(b) Determine a baseline C_dA value for a vehicle representing a production configuration without the aerodynamic improvement. Repeat this testing and measure C_dA for a vehicle with the improved aerodynamic design.

(c) Use good engineering judgment to perform paired tests that accurately demonstrate the reduction in aerodynamic drag associated with the improved design.

(d) Measure C_dA in m^2 to two decimal places. Calculate ΔC_dA by subtracting the drag area for the test vehicle from the drag area for the baseline vehicle.

§ 1037.528 Coastdown procedures for calculating drag area (C_dA).

This section describes the reference method for calculating drag area, C_dA , for tractors using coastdown testing. The coastdown procedures in this section describe how to calculate drag area, C_dA , for Phase 2 tractors, trailers, and vocational vehicles, subject to the provisions of §§ 1037.525 through and 1037.527. These procedures are considered the reference method for tractors, but an alternate method for trailers. Follow the provisions of Sections 1 through 9 of SAE J2263 (incorporated by reference, ~~see in~~ § 1037.810), with the clarifications and exceptions described in this section. Several of these exceptions are from SAE J1263 (incorporated by reference, ~~see in~~ § 1037.810). The coastdown procedures in 40 CFR 1066.310 apply instead of the provisions of this section for Phase 1 tractors.

(a) The terms and variables identified in this section have the meaning given in SAE J1263 and SAE J2263 unless specified otherwise.

(b) To determine C_dA values for a ~~tractor~~, perform coastdown testing with a tractor-trailer combination using the manufacturer's tractor and a standard trailer. ~~To determine C_dA values for a trailer, perform coastdown testing with a tractor-trailer combination using a standard tractor.~~

Prepare ~~the tractor-trailer combination vehicles~~ tractors and trailers for testing as follows:

(1) Install instrumentation for performing the specified measurements.

(2) After adding vehicle instrumentation, verify that there is no brake drag or other condition that prevents the wheels from rotating freely. Do not apply the parking brake at any point between this inspection and the end of the measurement procedure.

(3) Install tires mounted on steel rims in a dual configuration (except for steer tires). The tires must—

(i) Be SmartWay-Verified or have a coefficient of rolling resistance at or below 5.1 kg/metric ton.

(ii) Have accumulated at least 2,000 miles but have no less than 50 percent of their original tread depth, as specified for truck cabs in SAE J1263.

(iii) Not be retreads or have any apparent signs of chunking or uneven wear.

(iv) Be size 295/75R22.5 or 275/80R22.5.

(v) Be inflated to the proper tire pressure as specified in Sections 6.6 and 8.1 of SAE J2263.

(vi) Be of the same tire model for a given axle.

(4) Perform an inspection or wheel alignment for both the tractor and the trailer to ensure that wheel position is within the manufacturer's specifications.

(c) The test condition specifications described in Sections 7.1 through 7.4 of SAE J1263 apply, with certain exceptions and additional provisions as described in this paragraph (c). These conditions apply to each run separately.

(1) We recommend that you not perform coastdown testing if winds are expected to exceed 6.0 mi/hr.

- (2) The average of the component of the wind speed parallel to the road must not exceed 6.0 mi/hr. This constraint is in addition to those in Section 7.3 of SAE J1263.
 - (3) If road grade is greater than 0.02 % over the length of the test surface, you must determine elevation as a function of distance along the length of the test surface and incorporate this into the analysis.
 - (4) Road grade may exceed 0.5 % for limited portions of the test surface as long as it does not affect coastdown results, consistent with good engineering judgment.
 - (5) The road surface temperature must be at or below 50 °C. Use good engineering judgment to measure road surface temperature.
- (d) C_aA calculations are based on measured speed values while the vehicle coasts down through a high-speed range from 70 to 60 mi/hr, and through a low-speed range from 20 to 10 mi/hr. Disable any vehicle speed limiters that prevent travel above 72 mi/hr. Measure vehicle speed at a minimum recording frequency of 10 Hz, in conjunction with time-of-day data. Determine vehicle speed using either of the following methods:
- (1) *Complete coastdown runs*. Operate the vehicle at a top speed above 72.0 mi/hr and allow the vehicle to coast down to 8.0 mi/hr or lower. Collect data for the high-speed range over a test segment that includes speeds from 72.0 down to 58.0 mi/hr, and collect data for the low-speed range over a test segment that includes speeds from 22.0 down to 8.0 mi/hr.
 - (2) *Split coastdown runs*. Collect data during a high-speed coastdown while the vehicle coasts through a test segment that includes speeds from 72.0 mi/hr down to 58.0 mi/hr. Similarly, collect data during a low-speed coastdown while the vehicle coasts through a test segment that includes speeds from 22.0 mi/hr down to 8.0 mi/hr. Perform one high-speed coastdown segment or two consecutive high-speed coastdown segments in one direction, followed by the same number of low-speed coastdown segments in the same direction, and then perform that same number of measurements in the opposite direction. You may not split runs as described in Section 9.3.1 of SAE J2263 except as allowed under this paragraph (d)(2).
- (e) Measure wind speed, wind direction, air temperature, and air pressure at a recording frequency of 10 Hz, in conjunction with time-of-day data. Use at least one stationary anemometer and suitable data loggers meeting SAE J1263 specifications, subject to the following additional specifications for the anemometer placed along the test surface:
- (1) You must start a coastdown measurement within 24 hours after completing zero-wind and zero-angle calibrations.
 - (2) Place the anemometer at least 50 feet from the nearest tree and at least 25 feet from the nearest bush (or equivalent features). Position the anemometer adjacent to the test surface, near the midpoint of the length of the track, between 2.5 and 3.0 body widths from the expected location of the test vehicle's centerline as it passes the anemometer. Record the location of the anemometer along the test track, to the nearest 10 feet.
 - (3) Mount the anemometer at a height that is within 6 inches of half the test vehicle's body height.
 - (4) The height of vegetation surrounding the anemometer may not exceed 10 % of the anemometer's mounted height, within a radius equal to the anemometer's mounted height.
- (f) Measure air speed and relative wind direction (yaw angle) onboard the vehicle at a minimum recording frequency of 10 Hz, in conjunction with time-of-day data, using an anemometer and suitable data loggers that meet the requirements of Sections 5.4 of SAE J2263. The yaw angle must be measured to a resolution and accuracy of $\pm 0.5^\circ$. Mount the anemometer such that it measures air speed at 1.5 meters above the top of the leading edge of the trailer. If obstructions at

the test site do not allow for this mounting height, then mount the anemometer such that it measures air speed at least 0.85 meters above the top of the leading edge of the trailer.

(g) Perform the following calculations to filter and correct measured data:

(1) For any measured values not identified as outliers, use those measured values directly in the calculations specified in this section. Filter air speed, yaw angle, wind speed, wind direction, and vehicle speed measurements to replace outliers for every measured value as follows:

(i) Determine a median measured value to represent the measurement point and the measurements 3 seconds before and after that point. In the first and last three seconds of the coastdown run, use all available data to determine the median measured value. The measurement window for determining the median value will accordingly include 61 measurements in most cases, and will always include at least 31 measurements (for 10 Hz recording frequency).

(ii) Determine the median absolute deviation corresponding to each measurement window from paragraph (g)(1)(i) of this section. This generally results from calculating 61 absolute deviations from the median measured value and determining the median from those 61 deviations. Calculate the standard deviation for each measurement window by multiplying the median absolute deviation by 1.4826; calculate three standard deviations by multiplying the median absolute deviation by 4.4478. Note that the factor 1.4826 is a statistical constant that relates median absolute deviations to standard deviations.

(iii) A measured value is an outlier if the measured value at a given point differs from the median measured value by more than three standard deviations. Replace each outlier with the median measured value from paragraph (g)(1)(i) of this section. This technique for filtering outliers is known as the Hampel method.

(2) For each high-speed and each low-speed segment, correct measured air speed using the wind speed and wind direction measurements described in paragraph (e) of this section as follows:

(i) Calculate the theoretical air speed, $v_{\text{air,th}}$, for each 10-Hz set of measurements using the following equation:

$$v_{\text{air,th}} = \sqrt{w^2 + v^2 + 2 \cdot v \cdot w \cdot \cos(\phi_w + \phi_{\text{veh}})}$$

Eq. 1037.528-1

Where:

w = filtered wind speed.

v = filtered vehicle speed.

ϕ_w = filtered wind direction. Let $\phi_w = 0^\circ$ for air flow in the first travel direction, with values increasing counterclockwise. For example, if the vehicle starts by traveling eastbound, then $\phi_w = 270^\circ$ means a wind from the south.

ϕ_{veh} = the vehicle direction. Use $\phi_{\text{veh}} = 0^\circ$ for travel in the first direction, and use $\phi_{\text{veh}} = 180^\circ$ for travel in the opposite direction.

Example:

$w = 7.1$ mi/hr

$v = 64.9$ mi/hr

$\phi_w = 47.0^\circ$

$\phi_{\text{veh}} = 0^\circ$

$$v_{\text{air,th}} = \sqrt{7.1^2 + 64.9^2 + 2 \cdot 64.9 \cdot 7.1 \cdot \cos(47 + 0)}$$

$$v_{\text{air,th}} = 69.93 \text{ mi/hr}$$

(ii) Perform a linear regression using paired values of $v_{\text{air,th}}$ and measured air speed, $v_{\text{air,meas}}$, to determine the air-speed correction coefficients, α_0 and α_1 , based on the following equation:

$$v_{\text{air,th}} = \alpha_0 + \alpha_1 \cdot v_{\text{air,meas}}$$

Eq. 1037.528-2

(iii) Correct each measured value of air speed using the following equation:

$$v_{\text{air}} = \alpha_0 + \alpha_1 \cdot v_{\text{air,meas}}$$

Eq. 1037.528-3

(3) Correct measured air direction from all the high-speed segments using the wind speed and wind direction measurements described in paragraph (e) of this section as follows:

(i) Calculate the theoretical air direction, $\psi_{\text{air,th}}$, using the following equation:

$$\psi_{\text{air,th}} = \arctan\left(\frac{w \cdot \sin(\phi_w + \phi_{\text{veh}})}{v + w \cdot \cos(\phi_w + \phi_{\text{veh}})}\right)$$

Eq. 1037.528-4

Example:

$$w = 7.1 \text{ mi/hr}$$

$$v = 64.9 \text{ mi/hr}$$

$$\phi_w = 47.0^\circ$$

$$\phi_{\text{veh}} = 0^\circ$$

$$\psi_{\text{air,th}} = \arctan\left(\frac{7.1 \cdot \sin(47.0 + 0)}{64.9 + 7.1 \cdot \cos(47.0 + 0)}\right)$$

$$\psi_{\text{air,th}} = 4.26^\circ$$

(ii) Perform a linear regression using paired values of $\psi_{\text{air,th}}$ and measured air direction, $\psi_{\text{air,meas}}$, to determine the air-direction correction coefficients, β_0 and β_1 , based on the following equation:

$$\psi_{\text{air,th}} = \beta_0 + \beta_1 \cdot \psi_{\text{air,meas}}$$

Eq. 1037.528-5

(iii) Correct each measured value of air direction using the following equation:

$$\psi_{\text{air}} = \beta_0 + \beta_1 \cdot \psi_{\text{air,meas}}$$

Eq. 1037.528-6

(h) Determine drag area, C_dA , using the following procedure instead of the procedure specified in Section 10 of SAE J1263:

(1) Calculate the vehicle's effective mass, M_e , to account for rotational inertia by adding 56.7 kg to the measured vehicle mass, M , (in kg) for each tire making road contact.

(2) Operate the vehicle and collect data over the high-speed range and low-speed range as specified in paragraph (d)(1) or (2) of this section. If the vehicle has a speed limiter that prevents it from exceeding 72 mi/hr, you must disable the speed limiter for testing.

(3) Calculate mean vehicle speed at each speed start point (70 and 20 mi/hr) and end point (60 and 10 mi/hr) as follows:

(i) Calculate the mean vehicle speed to represent the start point of each speed range as the arithmetic average of measured speeds throughout the continuous time interval that begins when measured vehicle speed is less than 2.00 mi/hr above the nominal starting speed point and ends when measured vehicle speed reaches 2.00 mi/hr below the nominal starting speed point, expressed to at least two decimal places. Calculate the timestamp corresponding to the starting point of each speed range as the average timestamp of the interval.

(ii) Repeat the calculations described in paragraph (h)(3)(i) of this section corresponding to the end point speed (60 or 10 mi/hr) to determine the time at which the vehicle reaches the end speed, and the mean vehicle speed representing the end point of each speed range.

(iii) If you incorporate grade into your calculations, use the average values for the elevation and distance traveled over each interval.

(4) Calculate the road-load force, F , for each speed range using the following equation:

$$F = -M_e \cdot \frac{\bar{v}_{\text{start}} - \bar{v}_{\text{end}}}{\bar{t}_{\text{start}} - \bar{t}_{\text{end}}} + M \cdot a_g \cdot \frac{\bar{h}_{\text{start}} - \bar{h}_{\text{end}}}{|\bar{D}_{\text{start}} - \bar{D}_{\text{end}}|}$$

Eq. 1037.528-7

Where:

M_e = the vehicle's effective mass.

\bar{v} = average vehicle speed at the start or end of each speed range, as described in paragraph (h)(3) of this section.

\bar{t} = timestamp at which the vehicle reaches the starting or ending speed expressed to at least one decimal place.

M = the vehicle's measured mass.

a_g = acceleration of Earth's gravity, as described in 40 CFR 1065.630.

\bar{h} = average elevation at the start or end of each speed range expressed to at least two decimal places.

\bar{D} = distance traveled on the road surface from a fixed reference location along the road to the start or end of each speed range expressed to at least one decimal place.

Example:

$M_e = 17,129$ kg (18 tires in contact with the road surface)

$\bar{v}_{\text{start}} = 69.97$ mi/hr = 31.28 m/s

$\bar{v}_{\text{end}} = 59.88$ mi/hr = 26.77 m/s

$\bar{t}_{\text{start}} = 3.05$ s

$\bar{t}_{\text{end}} = 19.11$ s

$M = 16,108$ kg

$a_g = 9.8061$ m/s²

$\bar{h}_{\text{start}} = 0.044$ m

$\bar{h}_{\text{end}} = 0.547$ m

$\bar{D}_{\text{start}} = 706.8$ ft = 215.4 m

$\bar{D}_{\text{end}} = 2230.2$ ft = 697.8 m

$$F = -17129 \cdot \frac{31.28 - 26.77}{3.05 - 19.11} + 16108 \cdot 9.8061 \cdot \frac{0.044 - 0.547}{|215.4 - 697.8|}$$

$$F = 4645.5 \text{ N}$$

(5) ~~C~~For tractor testing, calculate the drive-axle spin loss force at high and low speeds, $F_{\text{spin}[\text{speed}]}$, and determine ΔF_{spin} as follows:

- (i) Use the results from the axle efficiency test described in § 1037.560 for the drive axle model installed in the tractor being tested for this coastdown procedure.
- (ii) Perform a second-order regression of axle power loss in W from only the zero-torque test points with wheel speed, f_{wheel} , in r/s from the axle efficiency test to determine coefficients c_0 , c_1 , and c_2 .

$$P_{\text{loss}} = c_0 + c_1 \cdot f_{\text{wheel}} + c_2 \cdot f_{\text{wheel}}^2$$

Eq. 1037.528-8

(iii) Calculate $F_{\text{spin}[\text{speed}]}$ using the following equation:

$$F_{\text{spin}[\text{speed}]} = \frac{1}{\bar{v}_{\text{seg}[\text{speed}]}} \left[c_0 + c_1 \cdot \bar{v}_{\text{seg}[\text{speed}]} \cdot TRPM + c_2 \cdot (\bar{v}_{\text{seg}[\text{speed}]} \cdot TRPM)^2 \right]$$

Eq. 1037.528-9

Where:

$\bar{v}_{\text{seg}[\text{speed}]}$ = the mean vehicle speed of all vehicle speed measurements in each low-speed and high-speed segment.

$TRPM$ = tire revolutions per mile for the drive tire model installed on the tractor being tested according to § 1037.520(c)(1).

Example:

$$\bar{v}_{\text{seghi}} = 28.86 \text{ m/s}$$

$$\bar{v}_{\text{seglo}} = 5.84 \text{ m/s}$$

$$TRPM = 508 \text{ r/mi} = 0.315657 \text{ r/m}$$

$$c_0 = -206.841 \text{ W}$$

$$c_1 = 239.8279 \text{ W}\cdot\text{s/r}$$

$$c_2 = 21.27505 \text{ W}\cdot\text{s}^2/\text{r}^2$$

$$F_{\text{spinhi}} = \frac{1}{28.86} \cdot [-206.841 + 239.8279 \cdot 28.86 \cdot 0.315657 + 21.27505 \cdot (28.86 \cdot 0.315657)^2]$$

$$F_{\text{spinhi}} = 129.7 \text{ N}$$

$$F_{\text{spinlo}} = 52.7 \text{ N}$$

(iv) Calculate ΔF_{spin} using the following equation:

$$\Delta F_{\text{spin}} = F_{\text{spinhi}} - F_{\text{spinlo}}$$

$$\text{Eq. 1037.528-10}$$

Example:

$$\Delta F_{\text{spin}} = 129.7 - 52.7$$

$$= 77.0 \text{ N} \quad \Delta F_{\text{spin}} = 77.0 \text{ N}$$

(6) ~~For tractor testing, e~~ Calculate the tire rolling resistance force at high and low speeds for steer, drive, and trailer axle positions, $F_{TRR[speed,axle]}$, and determine ΔF_{TRR} , the rolling resistance difference between 65 mi/hr and 15 mi/hr, for each tire as follows:

(i) Conduct a stepwise coastdown tire rolling resistance test with three tires for each tire model installed on the vehicle using SAE J2452 (incorporated by reference, [see in § 1037.810](#)) for the following test points (which replace the test points in Table 3 of SAE J2452):

TABLE 1 OF § 1037.528—STEPWISE COASTDOWN TEST POINTS FOR DETERMINING TIRE ROLLING RESISTANCE AS A FUNCTION OF SPEED

Step #	Load (% of Max)	Inflation pressure (% of max)
1	20	100
2	55	70
3	85	120
4	85	100
5	100	95

(ii) Calculate $F_{TRR[speed,axle]}$ using the following equation:

$$F_{TRR[speed,axle]} = n_{t,[axle]} \cdot p_{[axle]}^{\alpha} \cdot \left(\frac{L_{[axle]}}{n_{t,[axle]}} \right)^{\beta_{[axle]}} \cdot (a_{[axle]} + b_{[axle]} \cdot \bar{v}_{seg[speed]} + c_{[axle]} \cdot \bar{v}_{seg[speed]}^2)$$

Eq. 1037.528-11

Where:

$n_{t,[axle]}$ = number of tires at the axle position.

$p_{[axle]}$ = the inflation pressure set and measured on the tires at the axle position at the beginning of the coastdown test.

$L_{[axle]}$ = the load over the axle at the axle position on the coastdown test Vehicle.

$\alpha_{[axle]}$, $\beta_{[axle]}$, $a_{[axle]}$, $b_{[axle]}$, and $c_{[axle]}$ = regression coefficients from SAE J2452 that are specific to axle position.

Example:

$$n_{t,steer} = 2$$

$$p_{steer} = 758.4 \text{ kPa}$$

$$L_{steer} = 51421.2 \text{ N}$$

$$\alpha_{steer} = -0.2435$$

$$\beta_{steer} = 0.9576$$

$$a_{steer} = 0.0434$$

$$b_{steer} = 5.4 \cdot 10^{-5}$$

$$c_{steer} = 5.53 \cdot 10^{-7}$$

$$n_{t,drive} = 8$$

$$p_{drive} = 689.5 \text{ kPa}$$

$$L_{drive} = 55958.4 \text{ N}$$

$$\alpha_{drive} = -0.3146$$

$$\beta_{drive} = 0.9914$$

$$\begin{aligned}
a_{\text{drive}} &= 0.0504 \\
b_{\text{drive}} &= 1.11 \cdot 10^{-4} \\
c_{\text{drive}} &= 2.86 \cdot 10^{-7} \\
n_{\text{t,trailer}} &= 8 \\
p_{\text{trailer}} &= 689.5 \text{ kPa} \\
L_{\text{trailer}} &= 45727.5 \text{ N} \\
\alpha_{\text{trailer}} &= -0.3982 \\
\beta_{\text{trailer}} &= 0.9756 \\
a_{\text{trailer}} &= 0.0656 \\
b_{\text{trailer}} &= 1.51 \cdot 10^{-4} \\
c_{\text{trailer}} &= 2.94 \cdot 10^{-7} \\
\bar{v}_{\text{seghi}} &= 28.86 \text{ m/s} = 103.896 \text{ km/hr} \\
\bar{v}_{\text{seglo}} &= 5.84 \text{ m/s} = 21.024 \text{ km/hr} \\
F_{\text{TRRhi,steer}} &= 2 \cdot 758.4^{-0.2435} \cdot \left(\frac{51421.2}{2} \right)^{0.9576} \\
&\quad \cdot (0.0434 + 5.4 \cdot 10^5 \cdot 103.896 + 5.53 \cdot 10^{-7} \cdot 103.896^2) \\
F_{\text{TRRhi,steer}} &= 365.6 \text{ N} \\
F_{\text{TRRhi,drive}} &= 431.4 \text{ N} \\
F_{\text{TRRhi,trailer}} &= 231.7 \text{ N} \\
F_{\text{TRRlo,steer}} &= 297.8 \text{ N} \\
F_{\text{TRRlo,drive}} &= 350.7 \text{ N} \\
F_{\text{TRRlo,trailer}} &= 189.0 \text{ N}
\end{aligned}$$

(iii) Calculate $F_{\text{TRR[speed]}}$ by summing the tire rolling resistance calculations at a given speed for each axle position:

$$F_{\text{TRR[speed]}} = F_{\text{TRR,[speed]steer}} + F_{\text{TRR,[speed]drive}} + F_{\text{TRR,[speed]trailer}}$$

Eq. 1037.528-12

Example:

$$\begin{aligned}
F_{\text{TRRhi}} &= 365.6 + 431.4 + 231.7 = 1028.7 \text{ N} \\
F_{\text{TRRlo}} &= 297.8 + 350.7 + 189.0 = 837.5 \text{ N}
\end{aligned}$$

(iv) Adjust $F_{\text{TRR[speed]}}$ to the ambient temperature during the coastdown segment as follows:

$$F_{\text{TRRadj[speed]}} = F_{\text{TRR,[speed]}} [1 + 0.006 \cdot (24 - \bar{T}_{\text{seg[speed]}})]$$

Eq. 1037.528-13

Where:

$\bar{T}_{\text{seg[speed]}}$ = the average ambient temperature during the coastdown segment, in °C.

Example:

$$\begin{aligned}
F_{\text{TRRhi}} &= 1028.7 \text{ N} \\
F_{\text{TRRlo}} &= 837.5 \text{ N} \\
\bar{T}_{\text{seghi}} &= 25.5 \text{ °C}
\end{aligned}$$

$$\bar{T}_{\text{seglo}} = 25.1 \text{ }^{\circ}\text{C}$$

$$F_{\text{TRRhi,adj}} = 1028.7 \cdot [1 + 0.006 \cdot (24 - 25.5)] = 1019.4 \text{ N}$$

$$F_{\text{TRRlo,adj}} = 837.5 \cdot [1 + 0.006 \cdot (24 - 25.1)] = 832.0 \text{ N}$$

(v) Determine the difference in rolling resistance between 65 mph and 15 mph, ΔF_{TRR} , for each tire. Use good engineering judgment to consider the multiple results. For example, you may ignore the test results for the tires with the highest and lowest differences and use the result from the remaining tire. Determine ΔF_{TRR} as follows:

$$\Delta F_{\text{TRR}} = F_{\text{TRRhi,adj}} - F_{\text{TRRlo,adj}}$$

Eq. 1037.528-14

Example:

$$\Delta F_{\text{TRR}} = 1019.4 - 832.0 = 187.4 \text{ N}$$

~~(7) For trailer testing, determine ΔF_{TRR} using a default value adjusted to the ambient temperature instead of performing a rolling resistance test, as follows:~~

~~$$\Delta F_{\text{TRR}} = \Delta F_{\text{TRR,def}} [1 + 0.006 \cdot (24 - \bar{T}_{\text{coast}})]$$~~

~~Eq. 1037.528-15~~

~~Where:~~

~~$\Delta F_{\text{TRR,def}}$ = default rolling resistance force speed adjustment; Use 215 N for long box vans and 150 N for short box vans.~~

~~\bar{T}_{coast} = the average ambient temperature during both low and high speed segments.~~

~~*Example:*~~

~~$$\Delta F_{\text{TRR,def}} = 215 \text{ N}$$~~

~~$$\bar{T}_{\text{coast}} = 25.5 \text{ }^{\circ}\text{C}$$~~

~~$$F_{\text{TRR}} = 215 \cdot [1 + 0.006 \cdot (24 - 25.5)] = 213.1 \text{ N}$$~~

~~(8) Square the air speed measurements and calculate average squared air speed during each speed range for each run, $\bar{v}_{\text{air,hi}}^2$ and $\bar{v}_{\text{air,lo}}^2$.~~

~~(9) Average the F_{lo} and $\bar{v}_{\text{air,lo}}^2$ values for each pair of runs in opposite directions. If running complete coastdowns as described in paragraph (d)(1) or one high-speed segment per direction as described in paragraph (d)(2), average every two F_{lo} and $\bar{v}_{\text{air,lo}}^2$ values. If running two high-speed segments per direction as described in paragraph (d)(2), average every four F_{lo} and $\bar{v}_{\text{air,lo}}^2$ values. Use these values as $F_{\text{lo,pair}}$ and $\bar{v}_{\text{air,lo,pair}}^2$ in the calculations in this paragraph (h) to apply to each of the two or four high-speed segments from the same runs as the low-speed segments used to determine $F_{\text{lo,pair}}$ and $\bar{v}_{\text{air,lo,pair}}^2$.~~

~~(10) Calculate average air temperature \bar{T} and air pressure \bar{p}_{act} during each high-speed run.~~

~~(11) Calculate drag area, C_dA , in m^2 for each high-speed segment using the following equation, expressed to at least three decimal places:~~

~~$$C_dA = \frac{2 \cdot (F_{\text{hi}} - F_{\text{lo,pair}} - \Delta F_{\text{spin}} - \Delta F_{\text{TRR}})}{(\bar{v}_{\text{air,hi}}^2 - \bar{v}_{\text{air,lo,pair}}^2)} \cdot \frac{R \cdot \bar{T}}{\bar{p}_{\text{act}}}$$~~

~~Eq. 1037.528-16~~

~~Where:~~

~~F_{hi} = road load force at high speed determined from Eq. 1037.528-7.~~

$F_{lo,pair}$ = the average of F_{lo} values for a pair of opposite direction runs calculated as described in paragraph (h)(9) of this section.

ΔF_{spin} = the difference in drive-axle spin loss force between high-speed and low-speed coastdown segments. ~~This is as~~ described in paragraph (h)(5) of this section ~~for tractor testing. Let $\Delta F_{spin} = 110$ N for trailer testing.~~

ΔF_{TRR} = the difference in tire rolling resistance force between high-speed and low-speed coastdown segments as described in paragraphs (h)(6) ~~or (7)~~ of this section.

$\bar{v}_{air,lo,pair}^2$ = the average of $\bar{v}_{air,lo}^2$ values for a pair of opposite direction runs calculated as described in paragraph (h)(9) of this section.

R = specific gas constant = 287.058 J/(kg·K).

\bar{T} = mean air temperature expressed to at least one decimal Place.

\bar{p}_{act} = mean absolute air pressure expressed to at least one decimal place.

Example:

$$F_{hi} = 4645.5 \text{ N}$$

$$F_{lo,pair} = 1005.0 \text{ N}$$

$$\Delta F_{spin} = 77.0 \text{ N}$$

$$\Delta F_{TRR} = 187.4 \text{ N}$$

$$\bar{v}_{air,hi}^2 = 933.4 \text{ m}^2/\text{s}^2$$

$$\bar{v}_{air,lo,pair}^2 = 43.12 \text{ m}^2/\text{s}^2$$

$$R = 287.058 \text{ J}/(\text{kg} \cdot \text{K})$$

$$\bar{T} = 285.97 \text{ K}$$

$$\bar{p}_{act} = 101.727 \text{ kPa} = 101727 \text{ Pa}$$

$$C_{dA} = \frac{2 \cdot (4640.5 - 1005.0 - 77.0 - 187.4)}{(933.4 - 43.12)} \cdot \frac{287.058 \cdot 285.97}{101727}$$

$$C_{dA} = 6.120 \text{ m}^2$$

(1~~1~~2) Calculate your final C_{dA} value from the high-speed segments as follows:

- (i) Eliminate all points where there were known equipment problems or other measurement problems.
- (ii) Of the remaining points, calculate the median of the absolute value of the yaw angles, ψ_{med} , and eliminate all C_{dA} values that differ by more than 1.0° from ψ_{med} .
- (iii) Of the remaining points, calculate the mean and standard deviation of C_{dA} and eliminate all values that differ by more than 2.0 standard deviations from the mean value.
- (iv) There must be at least 24 points remaining. Of the remaining points, recalculate the mean yaw angle. Round the mean yaw angle to the nearest 0.1° . This final result is the effective yaw angle, ψ_{eff} , for coastdown testing.
- (v) For the same set of points, recalculate the mean C_{dA} . This is the final result of the coastdown test, $C_{dA_{coastdown}}(\psi_{eff})$.

(i) [Reserved]

(j) Include the following information in your application for certification:

(1) The name, location, and description of your test facilities, including background/history, equipment and capability, and track and facility elevation, along with the grade and size/length of the track.

(2) Test conditions for each test result, including date and time, wind speed and direction, ambient temperature and humidity, vehicle speed, driving distance, manufacturer name, test

vehicle/model type, model year, applicable family, tire type and rolling resistance, weight of tractor-trailer (as tested), and driver identifier(s).

(3) Average C_dA and yaw angle results and all the individual run results (including voided or invalid runs).

§ 1037.530 Wind-tunnel procedures for calculating drag area (C_dA).

This section describes an alternate method for calculating drag area, C_dA , for tractors using wind tunnel testing. ~~The wind tunnel procedure specified in this section is considered to be the primary procedure for trailers, but is an alternate procedure for tractors.~~

(a) You may measure drag areas consistent with published SAE procedures as described in this section using any wind tunnel recognized by the Subsonic Aerodynamic Testing Association, subject to the provisions of §§ 1037.525 ~~through and 1037.527~~. If your wind tunnel does not meet the specifications described in this section, you may ask us to approve it as an alternate method under § 1037.525(d) ~~or § 1037.526(d)~~. All wind tunnels and wind tunnel tests must meet the specifications described in SAE J1252 (incorporated by reference, see in § 1037.810), with the following exceptions and additional provisions:

(1) The Overall Vehicle Reynolds number, $Re_w^\#$, must be at least $1.0 \cdot 10^6$. Tests for Reynolds effects described in Section 7.1 of SAE J1252 are not required.

(2) For full-scale wind tunnel ~~tractor~~ testing, use good engineering judgment to select a trailer that is a reasonable representation of the trailer used for reference coastdown testing. For example, where your wind tunnel is not long enough to test the tractor with a standard 53 foot box van, it may be appropriate to use a shorter box van. In such a case, the correlation developed using the shorter trailer would only be valid for testing with the shorter trailer.

(3) For reduced-scale wind tunnel testing, use a one-eighth or larger scale model of a tractor and trailer that is sufficient to simulate airflow through the radiator inlet grill and across an engine geometry that represents engines commonly used in your test vehicle.

(b) Open-throat wind tunnels must also meet the specifications of SAE J2071 (incorporated by reference, see in § 1037.810).

(c) To determine C_dA values for certifying tractors, perform wind-tunnel testing with a tractor-trailer combination using the manufacturer's tractor and a standard trailer. ~~To determine C_dA values for certifying trailers, perform wind tunnel testing with a tractor-trailer combination using a standard tractor.~~ Use a moving/rolling floor if the facility has one. For Phase 1 tractors, conduct the wind tunnel tests at a zero yaw angle. For Phase 2 and Phase 3 later vehicles, conduct the wind tunnel tests by measuring the drag area at yaw angles of $+4.5^\circ$ and -4.5° and calculating the average of those two values.

(d) In your request to use wind-tunnel testing for tractors, ~~or in your application for certification for trailers~~, describe how you meet all the specifications that apply under this section, using terminology consistent with SAE J1594 (incorporated by reference, see in § 1037.810). If you request our approval to use wind-tunnel testing even though you do not meet all the specifications of this section, describe how your method nevertheless qualifies as an alternate method under § 1037.525(d) ~~or 1037.526(d)~~ and include all the following information:

(1) Identify the name and location of the test facility for your wind-tunnel method.

(2) Background and history of the wind tunnel.

(3) The wind tunnel's layout (with diagram), type, and construction (structural and material).

(4) The wind tunnel's design details: the type and material for corner turning vanes, air settling specification, mesh screen specification, air straightening method, tunnel volume, surface area, average duct area, and circuit length.

(5) Specifications related to the wind tunnel's flow quality: temperature control and uniformity, airflow quality, minimum airflow velocity, flow uniformity, angularity and stability, static pressure variation, turbulence intensity, airflow acceleration and deceleration times, test duration flow quality, and overall airflow quality achievement.

(6) Test/working section information: test section type (*e.g.*, open, closed, adaptive wall) and shape (*e.g.*, circular, square, oval), length, contraction ratio, maximum air velocity, maximum dynamic pressure, nozzle width and height, plenum dimensions and net volume, maximum allowed model scale, maximum model height above road, strut movement rate (if applicable), model support, primary boundary layer slot, boundary layer elimination method, and photos and diagrams of the test section.

(7) Fan section description: fan type, diameter, power, maximum angular speed, maximum speed, support type, mechanical drive, and sectional total weight.

(8) Data acquisition and control (where applicable): acquisition type, motor control, tunnel control, model balance, model pressure measurement, wheel drag balances, wing/body panel balances, and model exhaust simulation.

(9) Moving ground plane or rolling road (if applicable): construction and material, yaw table and range, moving ground length and width, belt type, maximum belt speed, belt suction mechanism, platen instrumentation, temperature control, and steering.

(10) Facility correction factors and purpose.

§ 1037.532 Using computational fluid dynamics ~~to calculate~~for calculating drag area (C_dA).

This section describes an alternate method for calculating drag area, C_dA , for tractors using commercially available computational fluid dynamics (CFD) software. ~~This section describes how to use commercially available computational fluid dynamics (CFD) software to determine C_dA values, subject to the provisions of §§ 1037.525 through and 1037.527. This is considered to be an alternate method for both tractors and trailers.~~

(a) For Phase 2 ~~and Phase 3~~later vehicles, use SAE J2966 (incorporated by reference, ~~see in~~ § 1037.810), with the following clarifications and exceptions:

(1) Vehicles are subject to the requirement to meet standards based on the average of testing at yaw angles of $+4.5^\circ$ and -4.5° ; however, you may submit your application for certification with CFD results based on only one of those yaw angles.

(2) For CFD code with a Navier-Stokes based solver, follow the additional steps in paragraph (d) of this section. For Lattice-Boltzmann based CFD code, follow the additional steps in paragraph (e) of this section.

(3) Simulate a Reynolds number of 5.1 million (based on a 102-inch trailer width) and an air speed of 65 mi/hr.

(4) Perform an open-road simulation (not the Wind Tunnel Simulation).

(5) Use a free stream turbulence intensity of 0.0 %.

(6) Choose time steps that can accurately resolve intrinsic flow instabilities, consistent with good engineering judgment.

(7) The result must be drag area (C_dA), not drag coefficient (C_d), based on an air speed of 65 mi/hr.

(8) Submit information as described in paragraph (g) of this section.

(b) For Phase 1 tractors, apply the procedures as specified in paragraphs (c) through (f) of this section. Paragraphs (c) through (f) of section apply for Phase 2 ~~and Phase 3~~later vehicles only as specified in paragraph (a) of this section.

- (c) To determine C_dA values ~~for certifying a tractor, perform CFD modeling based on a tractor-trailer combination using the manufacturer's tractor and a standard trailer. To determine C_dA values for certifying a trailer, perform CFD modeling based on a tractor-trailer combination using a standard tractor.~~ Perform all CFD modeling as follows:
- (1) Specify a blockage ratio at or below 0.2 % to simulate open-road conditions.
 - (2) Assume zero yaw angle.
 - (3) Model the tractor with an open grill and representative back pressures based on available data describing the tractor's pressure characteristics.
 - (4) Enable the turbulence model and mesh deformation.
 - (5) Model tires and ground plane in motion to simulate a vehicle moving forward in the direction of travel.
 - (6) Apply the smallest cell size to local regions on the tractor and trailer in areas of high flow gradients and smaller-geometry features (e.g., the A-pillar, mirror, visor, grille and accessories, trailer-leading edge, trailer-trailing edge, rear bogey, tires, and tractor-trailer gap).
 - (7) Simulate a vehicle speed of 55 mi/hr.
- (d) Take the following steps for CFD code with a Navier-Stokes formula solver:
- (1) Perform an unstructured, time-accurate analysis using a mesh grid size with a total volume element count of at least 50 million cells of hexahedral and/or polyhedral mesh cell shape, surface elements representing the geometry consisting of no less than 6 million elements, and a near-wall cell size corresponding to a y^+ value of less than 300.
 - (2) Perform the analysis with a turbulence model and mesh deformation enabled (if applicable) with boundary layer resolution of ± 95 %. Once the results reach this resolution, demonstrate the convergence by supplying multiple, successive convergence values for the analysis. The turbulence model may use k -epsilon (k - ϵ), shear stress transport k -omega (SST k - ω), or other commercially accepted methods.
- (e) For Lattice-Boltzmann based CFD code, perform an unstructured, time-accurate analysis using a mesh grid size with total surface elements of at least 50 million cells using cubic volume elements and triangular and/or quadrilateral surface elements with a near-wall cell size of no greater than 6 mm on local regions of the tractor and trailer in areas of high flow gradients and smaller geometry features, with cell sizes in other areas of the mesh grid starting at twelve millimeters and increasing in size from this value as the distance from the tractor and trailer increases.
- (f) You may ask us to allow you to perform CFD analysis using parameters and criteria other than those specified in this section, consistent with good engineering judgment. In your request, you must demonstrate that you are unable to perform modeling based on the specified conditions (for example, you may have insufficient computing power, or the computations may require inordinate time), or you must demonstrate that different criteria (such as a different mesh cell shape and size) will yield better results. In your request, you must also describe your recommended alternative parameters and criteria, and describe how this approach will produce results that adequately represent a vehicle's in-use performance. We may require that you supply data demonstrating that your selected parameters and criteria will provide a sufficient level of detail to yield an accurate analysis. If you request an alternative approach because it will yield better results, we may require that you perform CFD analysis using both your recommended criteria and parameters and the criteria and parameters specified in this section to compare the resulting key aerodynamic characteristics, such as pressure profiles, drag build-up, and turbulent/laminar flow at key points around the tractor-trailer combination.
- (g) Include the following information in your request to determine C_dA values using CFD:

- (1) The name of the software.
- (2) The date and version number of the software.
- (3) The name of the company producing the software and the corresponding address, phone number, and website.
- (4) Identify whether the software uses Navier-Stokes or Lattice-Boltzmann equations.
- (5) Describe the input values you will use to simulate the vehicle's aerodynamic performance for comparing to coastdown results.

§ 1037.534 Constant-speed procedure for calculating drag area (C_dA).

This section describes an alternate method for calculating drag area, C_dA , for tractors using constant-speed aerodynamic drag testing. ~~This section describes how to use constant-speed aerodynamic drag testing to determine C_dA values, subject to the provisions of § 1037.525. This is considered to be an alternate method for tractors.~~

- (a) *Test track.* Select a test track that meets the specifications described in § 1037.528(c)(3).
- (b) *Ambient conditions.* At least two tests are required. For one of the tests, ambient conditions must remain within the specifications described in § 1037.528(c) throughout the preconditioning and measurement procedure. The other tests must also meet those specifications except for the wind conditions. The wind conditions must be such that 80 percent of the values of yaw angle, $\bar{\psi}_{\text{air}}$, from the 50 mi/hr and 70 mi/hr test segments are between 4° and 10° or between -4° and -10° .
- (c) *Vehicle preparation.* Perform testing with a tractor-trailer combination using the manufacturer's tractor and a standard trailer. Prepare the tractor-trailer combination ~~tractors and trailers~~ for testing as described in § 1037.528(b). Install measurement instruments meeting the requirements of 40 CFR part 1065, subpart C, that have been calibrated as described in 40 CFR part 1065, subpart D, as follows:
 - (1) Measure torque at each of the drive wheels using a hub torque meter or a rim torque meter. If testing a tractor with two drive axles, you may disconnect one of the drive axles from receiving torque from the driveshaft, in which case you would measure torque at only the wheels that receive torque from the driveshaft. Set up instruments to read engine speed for calculating angular speed at the point of the torque measurements, or install instruments for measuring the angular speed of the wheels directly.
 - (2) Install instrumentation to measure vehicle speed at 10 Hz, with an accuracy and resolution of 0.1 mi/hr. Also install instrumentation for reading engine speed from the engine's onboard computer.
 - (3) Mount an anemometer on the trailer as described in § 1037.528(f).
 - (4) Fill the vehicle's fuel tanks so they are at maximum capacity at the start of the measurement procedure.
 - (5) Measure the weight over each axle to the nearest 20 kg, with a full fuel tank, including the driver and any passengers that will be in the vehicle during the test.
- (d) *Measurement procedure.* The measurement sequence consists of vehicle preconditioning followed by stabilization and measurement over five consecutive constant-speed test segments with three different speed setpoints (10, 50, and 70 mi/hr). Each test segment is divided into smaller increments for data analysis.
 - (1) Precondition the vehicle and zero the torque meters as follows:

- (i) If you are using rim torque meters, zero the torque meters by lifting each instrumented axle and recording torque signals for at least 30 seconds, and then drive the vehicle at 50 mi/hr for at least 30 minutes.
 - (ii) If you are using any other kind of torque meter, drive the vehicle at 50 mi/hr for at least 30 minutes, and then allow the vehicle to coast down from full speed to a complete standstill while the clutch is disengaged or the transmission is in neutral, without braking. Zero the torque meters within 60 seconds after the vehicle stops moving by recording the torque signals for at least 30 seconds, and directly resume vehicle preconditioning at 50 mi/hr for at least 1.25 mi.
 - (iii) You may calibrate instruments during the preconditioning drive.
 - (2) Perform testing as described in paragraph (d)(3) of this section over a sequence of test segments at constant vehicle speed as follows:
 - (i) (300 ±30) seconds in each direction at 10 mi/hr.
 - (ii) (450 ±30) seconds in each direction at 70 mi/hr.
 - (iii) (450 ±30) seconds in each direction at 50 mi/hr.
 - (iv) (450 ±30) seconds in each direction at 70 mi/hr.
 - (v) (450 ±30) seconds in each direction at 50 mi/hr.
 - (vi) (300 ±30) seconds in each direction at 10 mi/hr.
 - (3) When the vehicle preconditioning described in paragraph (d)(1) of this section is complete, stabilize the vehicle at the specified speed for at least 200 meters and start taking measurements. The test segment starts when you start taking measurements for all parameters.
 - (4) During the test segment, continue to operate the vehicle at the speed setpoint, maintaining constant speed and torque within the ranges specified in paragraph (e) of this section. Drive the vehicle straight with minimal steering; do not change gears. Perform measurements as follows during the test segment:
 - (i) Measure the angular speed of the driveshaft, axle, or wheel where the torque is measured, or calculate it from engine speed in conjunction with gear and axle ratios, as applicable.
 - (ii) Measure vehicle speed in conjunction with time-of-day data.
 - (iii) Measure ambient conditions, air speed, and air direction as described in § 1037.528(e) and (f). Correct air speed and air direction as described in paragraphs (f)(1) and (2) of this section.
 - (5) You may divide a test segment into multiple passes by suspending and resuming measurements. Stabilize vehicle speed before resuming measurements for each pass as described in paragraph (d)(3) of this section. Analyze the data from multiple passes by combining them into a single sequence of measurements for each test segment.
 - (6) Divide measured values into even 10 second increments. If the last increment for each test segment is less than 10 seconds, disregard measured values from that increment for all calculations under this section.
- (e) *Validation criteria.* Analyze measurements to confirm that the test is valid. Analyze vehicle speed and drive torque by calculating the mean speed and torque values for each successive 1 second increment, for each successive 10 second increment, and for each test segment. The test is valid if the data conform to all the following specifications:
- (1) *Vehicle speed.* The mean vehicle speed for the test segment must be within 1.00 mi/hr of the speed setpoint. In addition, for testing at 50 mi/hr and 70 mi/hr, all ten of the 1 second mean vehicle speeds used to calculate a corresponding 10 second mean vehicle speed must

be within ± 0.2 mi/hr of that 10 second mean vehicle speed. Perform the same data analysis for testing at 10 mi/hr, but apply a validation threshold of ± 0.1 mi/hr.

(2) *Drive torque.* All ten of the 1 second mean torque values used to calculate a corresponding 10 second mean torque value must be within $\pm 50\%$ of that 10 second mean torque value.

(3) *Torque drift.* Torque meter drift may not exceed $\pm 1\%$. Determine torque meter drift by repeating the procedure described in paragraph (d)(1) of this section after testing is complete, except that driving the vehicle is necessary only to get the vehicle up to 50 mi/hr as part of coasting to standstill.

(f) *Calculations.* Analyze measured data for each time segment after time-aligning all the data. Use the following calculations to determine C_dA :

(1) *Onboard air speed.* Correct onboard anemometer measurements for air speed using onboard measurements and measured ambient conditions as described in § 1037.528(f), except that you must first divide the test segment into consecutive 10 second increments. Disregard data from the final increment of the test segment if it is less than 10 seconds. This analysis results in the following equation for correcting air speed measurements:

$$v_{\text{air}} = \alpha_0 + \alpha_1 \cdot v_{\text{air,meas}}$$

Eq. 1037.534-1

(2) *Yaw angle.* Correct the onboard anemometer measurements for air direction for each test segment as follows:

(i) Calculate arithmetic mean values for vehicle speed, \bar{v} , wind speed, \bar{w} , and wind direction, $\bar{\phi}_w$, over each 10 second increment for each test segment. Disregard data from the final increment of the test segment if it is less than 10 seconds.

(ii) Calculate the theoretical air direction, $\bar{\psi}_{\text{air,th}}$, for each 10 second increment using the following equation:

$$\bar{\psi}_{\text{air,th}} = \arctan\left(\frac{\bar{w} \cdot \sin(\bar{\phi}_w + \phi_{\text{veh}})}{\bar{v} + \bar{w} \cdot \cos(\bar{\phi}_w + \phi_{\text{veh}})}\right)$$

Eq. 1037.534-2

Where:

ϕ_{veh} = the vehicle direction, as described in § 1037.528(f)(2).

Example:

$$\bar{w} = 7.1 \text{ mi/hr}$$

$$\bar{v} = 69.9 \text{ mi/hr}$$

$$\bar{\phi}_w = 47.0^\circ$$

$$\phi_{\text{veh}} = 0^\circ$$

$$\bar{\psi}_{\text{air,th}} = \arctan\left(\frac{7.1 \cdot \sin(47.0 + 0)}{69.9 + 7.1 \cdot \cos(47.0 + 0)}\right)$$

$$\bar{\psi}_{\text{air,th}} = 3.97^\circ$$

(iii) Perform a linear regression using paired values of $\bar{\psi}_{\text{air,th}}$ and measured air direction, $\bar{\psi}_{\text{air,meas}}$, from each 10 second increment for all 50 mi/hr and 70 mi/hr test segments to determine the air-direction correction coefficients, β_0 and β_1 , based on the following equation:

$$\bar{\psi}_{\text{air,th}} = \beta_0 + \beta_1 \cdot \bar{\psi}_{\text{air,meas}}$$

Eq. 1037.534-3

(iv) For all 50 mi/hr and 70 mi/hr test segments, correct each measured value of air direction using the following equation:

$$\psi_{\text{air}} = \beta_0 + \beta_1 \cdot \psi_{\text{air,meas}}$$

Eq. 1037.534-4

(3) *Road load force.* (i) Average the sum of the corrected torques, the average of the wheel speed measurements, and the vehicle speed over every 10 second increment to determine \bar{T}_{total} , \bar{f}_{wheel} , and \bar{v} .

(ii) Calculate a mean road load force, $\bar{F}_{\text{RL}[\text{speed}]}$, for each 10 second increment using the following equation:

$$\bar{F}_{\text{RL}[\text{speed}]} = \frac{\bar{T}_{\text{total}}}{\bar{v}} \cdot \frac{\bar{f}_{\text{wheel}} \cdot \pi}{30} + M \cdot a_g \cdot \frac{h_{\text{inc,start}} - h_{\text{inc,end}}}{|D_{\text{inc,start}} - D_{\text{inc,end}}|}$$

Eq. 1037.534-5

Where:

\bar{T}_{total} = mean of all corrected torques at a point in time.

\bar{v} = mean vehicle Speed.

\bar{f}_{wheel} = mean wheel speed.

M = the measured vehicle mass.

a_g = acceleration of Earth's gravity, as described in 40 CFR 1065.630.

h_{inc} = elevation at the start or end of each 10 second increment expressed to at least two decimal places.

D_{inc} = distance traveled on the road surface from a fixed reference location along the road to the start or end of each 10 second increment, expressed to at least one decimal place.

Example:

$$\bar{T}_{\text{total}} = 2264.9 \text{ N}\cdot\text{m}$$

$$\bar{v} = 31.6 \text{ m/s}$$

$$\bar{f}_{\text{wheel}} = 598.0 \text{ r/min}$$

$$M = 16508 \text{ kg}$$

$$a_g = 9.8061 \text{ m/s}^2$$

$$h_{\text{inc,start}} = 0.044 \text{ m}$$

$$h_{\text{inc,end}} = 0.574 \text{ m}$$

$$D_{\text{inc,start}} = 215.4 \text{ m}$$

$$D_{\text{inc,end}} = 697.8 \text{ m}$$

$$\bar{F}_{\text{RL}70} = \frac{2264.9}{31.6} \cdot \frac{598.0 \cdot \pi}{30} + 16508 \cdot 9.8061 \cdot \frac{0.044 - 0.574}{|215.4 - 697.8|}$$

$$\bar{F}_{\text{RL}70} = 4310.6 \text{ N}$$

(4) *Determination of drag area.* Calculate a vehicle's drag area as follows:

- (i) Calculate the mean road load force from all 10 second increments from the 10 mi/hr test segments from the test that was within the wind limits specified in § 1037.528(c), $\bar{F}_{RL10,test}$. This value represents the mechanical drag force acting on the vehicle.
- (ii) Calculate the mean aerodynamic force for each 10 second increment, $\bar{F}_{aero[speed]}$, from the 50 mi/hr and 70 mi/hr test segments by subtracting $\bar{F}_{RL10,test}$ from $\bar{F}_{RL[speed]}$.
- (iii) Average the corrected air speed and corrected yaw angle over every 10 second segment from the 50 mi/hr and 70 mi/hr test segments to determine \bar{v}_{air} and $\bar{\psi}_{air}$.
- (iv) Calculate C_dA for each 10 second increment from the 50 mi/hr and 70 mi/hr test segments using the following equation:

$$C_dA_{i[speed]} = \left[\frac{2 \cdot \bar{F}_{aero[speed]}}{\bar{v}_{air[speed]}^2} \cdot \frac{R \cdot \bar{T}}{\bar{p}_{act}} \right]_i$$

Eq. 1037.534-6

Where:

$C_dA_{i[speed]}$ = the mean drag area for each 10 second increment, i .

$\bar{F}_{aero[speed]}$ = mean aerodynamic force over a given 10 second increment = $\bar{F}_{RL[speed]} - \bar{F}_{RL10,Test}$.

$\bar{v}_{air[speed]}$ = mean aerodynamic force over a given 10 second increment.

R = specific gas constant = 287.058 J/(kg·K).

\bar{T} = mean air temperature.

\bar{p}_{act} = mean absolute air pressure.

Example:

$$\bar{F}_{RL70} = 4310.6 \text{ N}$$

$$\bar{F}_{RL10,test} = 900.1 \text{ N}$$

$$\bar{F}_{aero70} = 4310.6 - 900.1 = 3410.5 \text{ N}$$

$$\bar{v}_{air70}^2 = 1089.5 \text{ m}^2/\text{s}^2$$

$$R = 287.058 \text{ J}/(\text{kg} \cdot \text{K})$$

$$\bar{T} = 293.68 \text{ K}$$

$$\bar{p}_{act} = 101300 \text{ Pa}$$

$$C_dA_{i70} = \left[\frac{2 \cdot 3410.5}{1089.5} \cdot \frac{287.058 \cdot 293.68}{101300} \right]_i$$

$$C_dA_{i70} = 5.210 \text{ m}^2$$

- (v) Plot all C_dA values from the 50 mi/hr and 70 mi/hr test segments against the corresponding values for corrected yaw angle for each 10 second increment. Create a regression based on a fourth-order polynomial regression equation of the following form:

$$C_dA = C_dA_{ZeroYaw} + a_1 \cdot \bar{\psi}_{air} + a_2 \cdot \bar{\psi}_{air}^2 + a_3 \cdot \bar{\psi}_{air}^3 + a_4 \cdot \bar{\psi}_{air}^4$$

Eq. 1037.534-7

- (vi) Determine C_dA_{wa-alt} as the average of C_dA values at 4.5° and -4.5° by applying Eq. 1037.534-7 at those angles.

- (g) *Documentation.* Keep the following records related to the constant-speed procedure for calculating drag area:

- (1) The measurement data for calculating C_dA as described in this section.
- (2) A general description and pictures of the vehicle tested.
- (3) The vehicle's maximum height and width.
- (4) The measured vehicle mass.
- (5) Mileage at the start of the first test segment and at the end of the last test segment.
- (6) The date of the test, the starting time for the first test segment, and the ending time for the last test segment.
- (7) The transmission gear used for each test segment.
- (8) The data describing how the test was valid relative to the specifications and criteria described in paragraphs (b) and (e) of this section.
- (9) A description of any unusual events, such as a vehicle passing the test vehicle, or any technical or human errors that may have affected the C_dA determination without invalidating the test.

§ 1037.540 Special procedures for testing vehicles with hybrid power take-off.

This section describes optional procedures for quantifying the reduction in greenhouse gas emissions for vehicles as a result of running power take-off (PTO) devices with a hybrid energy delivery system. See [40 CFR § 10367.54501036.545](#) for powertrain testing requirements that apply for drivetrain hybrid systems. The procedures are written to test the PTO by ensuring that the engine produces all of the energy with no net change in stored energy (charge-sustaining), and for plug-in hybrid electric vehicles, also allowing for drawing down the stored energy (charge-depleting). The full charge-sustaining test for the hybrid vehicle is from a fully charged rechargeable energy storage system (RESS) to a depleted RESS and then back to a fully charged RESS. You must include all hardware for the PTO system. You may ask us to modify the provisions of this section to allow testing hybrid vehicles that use a technology other than batteries for storing energy other than battery electric hybrids, consistent with good engineering judgment. For plug-in hybrid electric vehicles, use a utility factor to properly weight charge-sustaining and charge-depleting operation as described in paragraph (f)(3) of this section.

- (a) Select two vehicles for testing as follows:
 - (1) Select a vehicle with a hybrid energy delivery system to represent the range of PTO configurations that will be covered by the test data. If your test data will represent more than one PTO configuration, use good engineering judgment to select the configuration with the maximum number of PTO circuits that has the smallest potential reduction in greenhouse gas emissions.
 - (2) Select an equivalent conventional vehicle as specified in § 1037.615.
- (b) Measure PTO emissions from the fully warmed-up conventional vehicle as follows:
 - (1) Without adding a restriction, instrument the vehicle with pressure transducers at the outlet of the hydraulic pump for each circuit. Perform pressure measurements with a frequency of at least 1 Hz.
 - (2) Operate the PTO system with no load for at least 15 seconds. Measure gauge pressure and record the average value over the last 10 seconds (\bar{p}_{\min}). For hybrid PTO systems the measured pressure with no load is typically zero. Apply maximum operator demand to the PTO system until the pressure relief valve opens and pressure stabilizes; measure gauge pressure and record the average value over the last 10 seconds (\bar{p}_{\max}).
 - (3) Denormalize the PTO duty cycle in appendix B of this part using the following equation:

$$p_{\text{ref}i} = p_i \cdot (\bar{p}_{\max} - \bar{p}_{\min}) + \bar{p}_{\min}$$

Eq. 1037.540-1

Where:

p_{refi} = the reference pressure at each point i in the PTO cycle.

p_i = the normalized pressure at each point i in the PTO cycle (relative to \bar{p}_{max}).

\bar{p}_{max} = the mean maximum pressure measured in paragraph (b)(2) of this section.

\bar{p}_{min} = the mean minimum pressure measured in paragraph (b)(2) of this section.

(4) If the PTO system has two circuits, repeat paragraph (b)(2) and (3) of this section for the second PTO circuit.

(5) Install a system to control pressures in the PTO system during the cycle.

(6) Start the engine.

(7) Depending on the number of circuits the PTO system has, operate the vehicle over one or concurrently over both of the denormalized PTO duty cycles in appendix B of this part. Measure emissions during operation over each duty cycle using the provisions of 40 CFR part 1066.

(8) Measured pressures must meet the cycle-validation specifications in the following table for each test run over the duty cycle:

TABLE 1 TO PARAGRAPH (b)(8) OF § 1037.540—STATISTICAL CRITERIA FOR VALIDATING EACH TEST RUN OVER THE DUTY CYCLE

Parameter ^a	Pressure
Slope, a_1	$0.950 \leq a_1 \leq 1.030$.
Absolute value of intercept, $ a_0 $	≤ 2.0 % of maximum mapped pressure.
Standard error of the estimate, SEE	≤ 10 % of maximum mapped pressure.
Coefficient of determination, r^2	≥ 0.970 .

^aDetermine values for specified parameters as described in 40 CFR 1065.514(e) by comparing measured values to denormalized pressure values from the duty cycle in appendix B of this part.

(c) Measure PTO emissions from the fully warmed-up hybrid vehicle as follows:

(1) Perform the steps in paragraphs (b)(1) through (5) of this section.

(2) Prepare the vehicle for testing by operating it as needed to stabilize the RESS at a full state of charge (or equivalent for vehicles that use a technology other than batteries for storing energy non-electric RESS).

(i) For plug-in hybrid electric vehicles, we recommend charging the battery with an external electrical source.

(ii) For other vehicles, we recommend running back-to-back PTO tests until engine operation is initiated to charge the RESS. The RESS should be fully charged once engine operation stops. The ignition should remain in the “on” position.

(3) Turn the vehicle and PTO system off while the sampling system is being prepared.

(4) Turn the vehicle and PTO system on such that the PTO system is functional, whether it draws power from the engine or a battery.

(5) Operate the vehicle over one or both of the denormalized PTO duty cycles without turning the vehicle off, until the engine starts and then shuts down. This may require running multiple repeats of the PTO duty cycles. For non-PHEV systems that are not plug-in hybrid systems, the test cycle is completed once the engine shuts down. For plug-in hybrid systems, continue running until the PTO hybrid is running in a charge-sustaining mode such that the

“End of Test” requirements defined in 40 CFR 1066.501(a)(3) are met. Measure emissions as described in paragraph (b)(7) of this section. Use good engineering judgment to minimize the variability in testing between the two types of vehicles.

(6) For plug-in hybrid electric vehicles, follow 40 CFR 1066.501(a)(3) to divide the test into charge-depleting and charge-sustaining operation.

(7) Apply cycle-validation criteria as described in paragraph (b)(8) of this section to both charge-sustaining and charge-depleting operation.

(d) Calculate the equivalent distance driven based on operating time for each section of the PTO portion of the test as applicable by determining the time of the test and applying the conversion factor in paragraph (d)(4) of this section. For testing where fractions of a cycle were run (for example, where three cycles are completed and the halfway point of a fourth PTO cycle is reached before the engine starts and shuts down again), calculate the time of the test, t_{test} , as follows:

(1) Add up the time run for all complete tests.

(2) For fractions of a test, use the following equation to calculate the time:

$$t_{\text{test-partial}} = \frac{\sum_{i=1}^N (p_{\text{circuit-1},i} + p_{\text{circuit-2},i}) \cdot \Delta t}{\bar{p}_{\text{circuit-1}} + \bar{p}_{\text{circuit-2}}}$$

Eq. 1037.540-2

Where:

i = an indexing variable that represents one recorded value.

N = number of measurement intervals.

$p_{\text{circuit-1},i}$ = normalized pressure command from circuit 1 of the PTO cycle for each point, i , starting from $i = 1$.

$p_{\text{circuit-2},i}$ = normalized pressure command from circuit 2 of the PTO cycle for each point, i , starting from $i = 1$. Let $p_{\text{circuit-2}} = 0$ if there is only one circuit.

$\bar{p}_{\text{circuit-1}}$ = the mean normalized pressure command from circuit 1 over the entire PTO Cycle.

$\bar{p}_{\text{circuit-2}}$ = the mean normalized pressure command from circuit 2 over the entire PTO cycle.

Let $\bar{p}_{\text{circuit-2}} = 0$ if there is only one circuit.

Δt = the time interval between measurements. For example, at 100 Hz, $\Delta t = 0.0100$ seconds.

(3) Sum the time from the complete cycles and from the partial cycle.

(4) Divide the total PTO operating time from paragraph (d)(3) of this section by a conversion factor of 0.0144 hr/mi for Phase 1 and 0.0217 hr/mi for Phase 2 ~~and Phase 3~~ later to determine the equivalent distance driven. The conversion factors are based on estimates of average vehicle speed and PTO operating time as a percentage of total engine operating time; the Phase 2 ~~and Phase 3~~ later conversion factor is calculated from an average speed of 27.1 mi/hr and PTO operation 37 % of engine operating time, as follows:

$$Factor = \frac{37\%}{(100\% - 37\%) \cdot 27.1\text{mi/hr}} = 0.0217\text{hr/mi}$$

(e) For Phase 1, calculate combined cycle-weighted emissions of the four duty cycles for vocational vehicles, for both the conventional and hybrid PTO vehicle tests, as follows:

(1) Calculate the CO₂ emission rates in grams per test without rounding for both the conventional vehicle and the charge-sustaining and charge-depleting portions of the test for the hybrid vehicle as applicable.

(2) Divide the CO₂ mass from the PTO cycle by the distance determined in paragraph (d)(4) of this section and the standard payload as defined in § 1037.801 to get the CO₂ emission rate in g/ton-mile. For plug-in hybrid electric vehicles follow paragraph (f)(3) of this section to calculate utility factor weighted CO₂ emissions in g/ton-mile.

(3) Calculate the g/ton-mile emission rate for the driving portion of the test specified in § 1037.510 and add this to the CO₂ g/ton-mile emission rate for the PTO portion of the test.

(4) Follow the provisions of § 1037.615 to calculate improvement factors and benefits for advanced technologies.

(f) For Phase 2 [and Phase 3 later](#), calculate the delta PTO fuel results for input into GEM during vehicle certification as follows:

(1) Determine fuel consumption by calculating the mass of fuel for each test in grams, m_{fuelPTO} , without rounding, as described in 40 CFR 1036.540(d)(12) for both the conventional vehicle and the charge-sustaining and charge-depleting portions of the test for the hybrid vehicle as applicable.

(2) Divide the fuel mass by the applicable distance determined in paragraph (d)(4) of this section and the appropriate standard payload as defined in § 1037.801 to determine the fuel-consumption rate in g/ton-mile.

(3) For plug-in hybrid electric vehicles calculate the utility factor weighted fuel-consumption rate in g/ton-mile, as follows:

(i) Determine the utility factor fraction for the PTO system from the table in appendix E of this part using interpolation based on the total time of the charge-depleting portion of the test as determined in paragraphs (c)(6) and (d)(3) of this section.

(ii) Weight the emissions from the charge-sustaining and charge-depleting portions of the test to determine the utility factor-weighted fuel mass, $m_{\text{fuelUF[cycle]plug-in}}$, using the following equation:

$$m_{\text{fuelPTOplug-in}} = \sum_{i=1}^N [m_{\text{fuelPTOCD}i} \cdot (UF_{\text{DCD}i} - UF_{\text{DCD}i-1})] + \sum_{j=1}^M [m_{\text{fuelPTOCS}j}] \cdot \frac{(1 - UF_{\text{RCD}})}{M}$$

Eq. 1037.540-3

Where:

i = an indexing variable that represents one test interval.

N = total number of charge-depleting test intervals.

$m_{\text{fuelPTOCD}}$ = total mass of fuel per ton-mile in the charge-depleting portion of the test for each test interval, i , starting from $i = 1$.

$UF_{\text{DCD}i}$ = utility factor fraction at time $t_{\text{CD}i}$ as determined in paragraph (f)(3)(i) of this section for each test interval, i , starting from $i = 1$.

j = an indexing variable that represents one test interval.

M = total number of charge-sustaining test intervals.

$m_{\text{fuelPTOCS}}$ = total mass of fuel per ton-mile in the charge-sustaining portion of the test for each test interval, j , starting from $j = 1$.

UF_{RCD} = utility factor fraction at the full charge-depleting time, t_{CD} , as determined by interpolating the [approved](#) utility factor curve [in appendix E to this part](#). t_{CD} is the sum of the time over N charge-depleting test intervals.

(4) Calculate the difference between the conventional PTO emissions result and the hybrid PTO emissions result for input into GEM.

(g) If the PTO system has more than two circuits, apply the provisions of this section using good engineering judgment.

§ 1037.551 Engine-based simulation of powertrain testing.

~~40 CFR Section 10367.5450~~ describes how to measure fuel consumption over specific duty cycles with an engine coupled to a transmission; ~~40 CFR§ 10367.5450(a)(5)~~ describes how to create equivalent duty cycles for repeating those same measurements with just the engine. This ~~section § 1037.551~~ describes how to perform this engine testing to simulate the powertrain test. These engine-based measurements may be used for selective enforcement audits as described in § 1037.301, as long as the test engine's operation represents the engine operation observed in the powertrain test. If we use this approach for confirmatory testing, when making compliance determinations, we will consider the uncertainty associated with this approach relative to full powertrain testing. Use of this approach for engine SEAs is optional for engine manufacturers.

(a) Use the procedures of 40 CFR part 1065 to set up the engine, measure emissions, and record data. Measure individual parameters and emission constituents as described in this section.

Measure NO_x emissions for each sampling period in grams. You may perform these measurements using a NO_x emission-measurement system that meets the requirements of 40 CFR part 1065, subpart J. Include these measured NO_x values any time you report to us your greenhouse gas emissions or fuel consumption values from testing under this section. If a system malfunction prevents you from measuring NO_x emissions during a test under this section but the test otherwise gives valid results, you may consider this a valid test and omit the NO_x emission measurements; however, we may require you to repeat the test if we determine that you inappropriately voided the test with respect to NO_x emission measurement. For hybrid powertrains, correct for the net energy change of the energy storage device as described in 40 CFR 1066.501(a)(3).

(b) Operate the engine over the applicable engine duty cycles corresponding to the vehicle cycles specified in § 1037.510(a)(2) for powertrain testing over the applicable vehicle simulations described in ~~40 CFR§ 10367.5450(j)~~. Warm up the engine to prepare for the transient test or one of the highway cruise cycles by operating it one time over one of the simulations of the corresponding duty cycle. Warm up the engine to prepare for the idle test by operating it over a simulation of the 65-mi/hr highway cruise cycle for 600 seconds. Within 60 seconds after concluding the warm up cycle, start emission sampling while the engine operates over the duty cycle. You may perform any number of test runs directly in succession once the engine is warmed up. Perform cycle validation as described in 40 CFR 1065.514 for engine speed, torque, and power.

(c) Calculate the mass of fuel consumed as described in ~~40 CFR§ 10367.5450(n)~~ and (o). Correct each measured value for the test fuel's mass-specific net energy content as described in 40 CFR 1036.550. Use these corrected values to determine whether the engine's emission levels conform to the declared fuel-consumption rates from the powertrain test.

§ 1037.555 Special procedures for testing Phase 1 hybrid systems.

This section describes a powertrain testing procedure for simulating a chassis test with a pre-transmission or post-transmission hybrid system to perform A to B testing of Phase 1 vehicles. These procedures may also be used to perform A to B testing with non-hybrid systems. See ~~40 CFR§ 10371036.5450~~ for Phase 2 ~~and Phase 3~~ later hybrid systems.

(a) Set up the engine according to 40 CFR 1065.110 to account for work inputs and outputs and accessory work.

- (b) Collect CO₂ emissions while operating the system over the test cycles specified in § 1037.510(a)(1).
- (c) Collect and measure emissions as described in 40 CFR part 1066. Calculate emission rates in grams per ton-mile without rounding. Determine values for *A*, *B*, *C*, and *M* for the vehicle being simulated as specified in 40 CFR part 1066. If you will apply an improvement factor or test results to multiple vehicle configurations, use values of *A*, *B*, *C*, *M*, *k_a*, and *r* that represent the vehicle configuration with the smallest potential reduction in greenhouse gas emissions as a result of the hybrid capability.
- (d) Calculate the transmission output shaft's angular speed target for the driver model, $f_{\text{ref},\text{driver}}$, from the linear speed associated with the vehicle cycle using the following equation:

$$f_{\text{ref},\text{driver}} = \frac{v_{\text{cycle}i} \cdot k_a}{2 \cdot \pi \cdot r}$$

Eq. 1037.555-1

Where:

$v_{\text{cycle}i}$ = vehicle speed of the test cycle for each point, *i*, starting from *i* = 1.

k_a = drive axle ratio, as declared by the manufacturer.

r = radius of the loaded tires, as declared by the manufacturer.

- (e) Use speed control with a loop rate of at least 100 Hz to program the dynamometer to follow the test cycle, as follows:

- (1) Calculate the transmission output shaft's angular speed target for the dynamometer, $f_{\text{ref},\text{dyno}}$, from the measured linear speed at the dynamometer rolls using the following equation:

$$f_{\text{ref},\text{dyno}} = \frac{v_{\text{ref}i} \cdot k_a}{2 \cdot \pi \cdot r}$$

Eq. 1037.555-2

Where:

$$v_{\text{ref}i} = \left(\frac{k_a \cdot T_{i-1}}{r} - (A + B \cdot v_{\text{ref},i-1} + C \cdot v_{\text{ref},i-1}^2) - F_{\text{brake},i-1} \right) \cdot \frac{t_i - t_{i-1}}{M} + v_{\text{ref},i-1}$$

Eq. 1037.555-3

T = instantaneous measured torque at the transmission output shaft.

F_{brake} = instantaneous brake force applied by the driver model to add force to slow down the Vehicle.

t = elapsed time in the driving schedule as measured by the dynamometer, in seconds.

- (2) For each test, validate the measured transmission output shaft's speed with the corresponding reference values according to 40 CFR 1065.514(e). You may delete points when the vehicle is stopped. Perform the validation based on speed values at the transmission output shaft. For steady-state tests (55 mi/hr and 65 mi/hr cruise), apply cycle-validation criteria by treating the sampling periods from the two tests as a continuous sampling period. Perform this validation based on the following parameters:

TABLE 1 OF § 1037.555 – STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES

Parameter	Speed Control
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Slope, a_1	$0.950 \leq a_1 \leq 1.030$
Absolute value of intercept, $ a_0 $	≤ 2.0 % of maximum test speed
Standard error of the estimate, SEE	≤ 5 % of maximum test speed
Coefficient of determination, r^2	≥ 0.970

- (f) Send a brake signal when operator demand is equal to zero and vehicle speed is greater than the reference vehicle speed from the test cycle. Set a delay before changing the brake state to prevent the brake signal from dithering, consistent with good engineering judgment.
- (g) The driver model should be designed to follow the cycle as closely as possible and must meet the requirements of § 1037.510 for steady-state testing and 40 CFR 1066.425 for transient testing. The driver model should be designed so that the brake and throttle are not applied at the same time.
- (h) Correct for the net energy change of the energy storage device as described in 40 CFR 1066.501(a)(3).
- (i) Follow the provisions of § 1037.510 to weight the cycle results and § 1037.615 to calculate improvement factors and benefits for advanced technologies for Phase 1 vehicles.

§ 1037.560 Axle efficiency test.

This section describes a procedure for mapping axle efficiency through a determination of axle power loss.

- (a) You may establish axle power loss maps based on testing any number of axle configurations within an axle family as specified in § 1037.232. You may share data across a family of axle configurations, as long as you test the axle configuration with the lowest efficiency from the axle family; this will generally involve testing the axle with the highest axle ratio. For vehicles with tandem drive axles, always test each drive axle separately. For tandem axles that can be disconnected, test both single-drive and tandem axle configurations. This includes 4×4 axles where one of the axles is disconnectable. Alternatively, you may analytically derive power loss maps for untested configurations within the same axle family as described in paragraph (h) of this section.
- (b) Prepare an axle assembly for testing as follows:
- (1) Select an axle assembly with less than 500 hours of operation before testing. Assemble the axle in its housing, along with wheel ends and bearings.
 - (2) If you have a family of axle assemblies with different axle ratios, you may test multiple configurations using a common axle housing, wheel ends, and bearings.
 - (3) Install the axle assembly on the dynamometer with an input shaft angle perpendicular to the axle.
 - (i) For axle assemblies with or without a locking main differential, test the axle assembly using one of the following methods:
 - (A) Lock the main differential and test it with one electric motor on the input shaft and a second electric motor on the output side of the output shaft that has the speed-reduction gear attached to it.
 - (B) Test with the main differential unlocked and with one electric motor on the input shaft and electric motors on the output sides of each of the output shafts.
 - (ii) For drive-through tandem-axle setups, lock the longitudinal and inter-wheel differentials.

(4) Add gear oil according to the axle manufacturer's instructions. If the axle manufacturer specifies multiple gear oils, select the one with the highest viscosity at operating temperature. You may use a lower-viscosity gear oil if we approve that as critical emission-related maintenance under § 1037.125. Fill the gear oil to a level that represents in-use operation. You may use an external gear oil conditioning system, as long as it does not affect measured values.

(5) Install equipment for measuring the bulk temperature of the gear oil in the oil sump or a similar location. Report temperature to the nearest 0.1 °C.

(6) Break in the axle assembly using good engineering judgment. Maintain gear oil temperature at or below 100 °C throughout the break-in period.

(7) You may drain the gear oil following the break-in procedure and repeat the filling procedure described in paragraph (b)(4) of this section. We will follow your practice for our testing.

(c) Measure input and output speed and torque as described in 40 CFR 1065.210(b). You must use a speed-measurement system that meets an accuracy of ± 0.05 % of point. Use torque transducers that meet an accuracy requirement of ± 1.0 N·m for unloaded test points and ± 0.2 % of the maximum tested axle input torque or output torque, respectively, for loaded test points. Calibrate and verify measurement instruments according to 40 CFR part 1065, subpart D. Command speed and torque at a minimum of 10 Hz, and record all data, including bulk oil temperature, at a minimum of 1 Hz mean values.

(d) The test matrix consists of test points representing output torque and wheel speed values meeting the following specifications:

(1) Output torque includes both loaded and unloaded operation. For measurement involving unloaded output torque, also called spin loss testing, the wheel end is not connected to the dynamometer and is left to rotate freely; in this condition the input torque (to maintain constant wheel speed) equals the power loss. Test axles at a range of output torque values, as follows:

(i) 0, 500, 1000, 2000, 3000, and 4000 N·m for single drive axle applications for tractors and for vocational Heavy HDV with a single drive axle.

(ii) 0, 250, 500, 1000, 1500, and 2000 N·m for tractors, for vocational Heavy HDV with tandem drive axles, and for all vocational Light HDV or vocational Medium HDV.

(iii) You may exclude values that exceed your axle's maximum torque rating.

(2) Determine maximum wheel speed corresponding to a vehicle speed of 65 mi/hr based on the smallest tire (as determined using § 1037.520(c)(1)) that will be used with the axle. If you do not know the smallest tire size, you may use a default size of 650 r/mi. Use wheel angular speeds for testing that include 50 r/min and speeds in 100 r/min increments that encompass the maximum wheel speed (150, 250, etc.).

(3) You may test the axle assembly at additional speed and torque setpoints.

(e) Determine axle efficiency using the following procedure:

(1) Maintain ambient temperature between (15 and 35) °C throughout testing. Measure ambient temperature within 1.0 m of the axle assembly. Verify that critical axle settings (such as bearing preload, backlash, and oil sump level) are within specifications before and after testing.

(2) Maintain gear oil temperature at (81 to 83) °C. You may alternatively specify a lower range by shifting both temperatures down by the same amount for any or all test points or on a test point by test point basis. We will test your axle assembly using the same temperature range(s) you specify for your testing. If you use interpolation for mapping, use the same

temperature range for all test points used in the interpolation. You may use an external gear oil conditioning system, as long as it does not affect measured values.

(3) Use good engineering judgment to warm up the axle assembly by operating it until the gear oil is within the specified temperature range.

(4) Stabilize operation at each point in the test matrix for at least 10 seconds, then measure the input torque, output torque, and wheel angular speed for at least 10 seconds. Record arithmetic mean values for all three parameters over the measurement period. Calculate power loss as described in paragraph (f) of this section based on these values for mean input torque, \bar{T}_{in} , mean output torque, \bar{T}_{out} , and mean wheel angular speed, \bar{f}_{nwheel} , at each test point.

(5) Perform the map sequence described in paragraph (e)(4) of this section three times. Remove torque from the input shaft and allow the axle to come to a full stop before each repeat measurement.

(6) You may need to perform additional testing at a given test point based on a calculation of a confidence interval to represent repeatability at a 95 % confidence level for that test point. If the confidence limit is greater than 0.10 % for loaded tests or greater than 0.05 % for unloaded tests, perform another repeat of measurements at that test point and recalculate the repeatability for the whole set of test results. Continue testing until the confidence interval is at or below the specified values for all test points. Calculate a confidence interval representing the repeatability in establishing a 95 % confidence level using the following equation:

$$Confidence\ Interval = \frac{1.96 \cdot \sigma_{P_{loss}}}{\sqrt{N} \cdot P_{max}} \cdot 100 \%$$

Eq. 1037.560-1

Where:

$\sigma_{P_{loss}}$ = standard deviation of power loss values at a given torque-speed setting (see 40 CFR 1065.602(c)).

N = number of repeat tests.

P_{max} = maximum output torque setting from the test matrix.

Example:

$$\sigma_{P_{loss}} = 0.1650 \text{ kW}$$

$$N = 3$$

$$P_{max} = 314.2000 \text{ kW}$$

$$Confidence\ Interval = \frac{1.96 \cdot 0.1650}{\sqrt{3} \cdot 314.2000} \cdot 100 \%$$

$$Confidence\ Interval = 0.0594 \%$$

(f) Calculate the mean power loss, \bar{P}_{loss} , at each test point as follows:

(1) Calculate \bar{P}_{loss} for each measurement at each test point as follows:

$$\bar{P}_{loss} = \bar{T}_{in} \cdot \bar{f}_{nwheel} \cdot k_a - \bar{T}_{out} \cdot \bar{f}_{nwheel}$$

Eq. 1037.560-2

Where:

\bar{T}_{in} = mean input torque from paragraph (e)(4) of this section.

\bar{f}_{nwheel} = mean wheel angular speed from paragraph (e)(4) of this section in rad/s.

k_a = drive axle ratio, expressed to at least the nearest 0.001.

\bar{T}_{out} = mean output torque from paragraph (e)(4) of this section. Let $\bar{T}_{out} = 0$ for all unloaded tests.

(2) Calculate \bar{P}_{loss} as the mean power loss from all measurements at a given test point.

(3) The following example illustrates a calculation of \bar{P}_{loss} :

$$\bar{T}_{in,1} = 845.10 \text{ N}\cdot\text{m}$$

$$\bar{f}_{nwheel,1} = 100.0 \text{ r/min} = 10.472 \text{ rad/s}$$

$$k_a = 3.731$$

$$\bar{T}_{out,1} = 3000.00 \text{ N}\cdot\text{m}$$

$$\bar{P}_{loss,1} = 845.10 \cdot 10.472 \cdot 3.731 - 3000.00 \cdot 10.472$$

$$\bar{P}_{loss,1} = 1602.9 \text{ W} = 1.6029 \text{ kW}$$

$$\bar{P}_{loss,2} = 1601.9 \text{ W} = 1.6019 \text{ kW}$$

$$\bar{P}_{loss,3} = 1603.9 \text{ W} = 1.6039 \text{ kW}$$

$$\bar{P}_{loss} = \frac{1.6029 + 1.6019 + 1.6039}{3} = 1.6029 \text{ kW}$$

(g) Create a table with the mean power loss, \bar{P}_{loss} , corresponding to each test point for input into GEM. Express wheel angular speed in r/min to one decimal place; express output torque in N·m to two decimal places; express power loss in kW to four decimal places.

(1) Record \bar{P}_{loss} , \bar{T}_{out} , and \bar{f}_{nin} for each test point. Calculate \bar{T}_{out} and \bar{f}_{nin} for each test point by calculating the arithmetic average of \bar{T}_{out} and \bar{f}_{nin} for all the repeat tests at that test point.

(2) Record declared mean power loss values at or above the corresponding value calculated in paragraph (f) of this section. Use good engineering judgment to select values that will be at or above the mean power loss values for your production axles. Vehicle manufacturers will use these declared mean power loss values for certification. For vehicles with tandem drive axles, the GEM input is the sum of the power loss and output torque from the individual axles. For vehicles with a disconnectable axle, GEM uses separate inputs for single and tandem drive axle configurations.

(h) You may analytically derive axle power loss maps for untested configurations within an axle family as follows:

(1) Test at least three axle assemblies within the same family representing at least the smallest axle ratio, the largest axle ratio, and an axle ratio closest to the arithmetic mean from the two other tested axle assemblies. Test each axle assembly as described in this section at the same speed and torque setpoints. [Test all axle assemblies using the same gear oil temperature range for each setpoint as described in paragraph \(e\)\(2\) of this section.](#)

(2) Perform a second-order least-squares regression between declared power loss and axle ratio using each speed and torque setpoint described in paragraph (d) of this section for your tested axle assemblies. Use the declared power loss values from paragraph (g) of this section; however, for purposes of analytically deriving power loss maps under this paragraph (h), you must select declared values for the largest and smallest axle ratios in the axle family that are adjusted relative to the calculated values for mean power loss by the same multiplier. If the coefficient of the second-order term is negative, include testing from additional axle ratios, or

increase your declared power loss for the largest and smallest axle ratios by the same multiplier as needed for the second-order term to become positive.

(3) Determine \bar{P}_{loss} of untested axles for each speed and torque setpoint based on a linear relationship between your declared power loss and axle ratio as follows:

(i) Determine the slope of the correlation line by connecting the declared power loss values for the smallest and largest axle ratios.

(ii) Fix the intercept for the correlation line by shifting it upward as needed so all the declared power loss values are on the correlation line or below it. Note that for cases involving three tested axle assemblies, the correlation line will always include the declared power loss for the smallest and largest axle ratio.

(4) Select declared values of \bar{P}_{loss} for untested configurations that are at or above the values you determined in paragraph (h)(3) of this section.

§ 1037.565 Transmission efficiency test.

This section describes a procedure for mapping transmission efficiency through a determination of transmission power loss.

(a) You may establish transmission power loss maps based on testing any number of transmission configurations within a transmission family as specified in § 1037.232. You may share data across any configurations within the family, as long as you test the transmission configuration with the lowest efficiency from the transmission family. Alternatively, you may ask us to approve analytically derived power loss maps for untested configurations within the same transmission family (see § 1037.235(h)).

(b) Prepare a transmission for testing as follows:

(1) Select a transmission with less than 500 hours of operation before testing.

(2) Mount the transmission to the dynamometer such that the geared shaft in the transmission is aligned with the input shaft from the dynamometer.

(3) Add transmission oil according to the transmission manufacturer's instructions. If the transmission manufacturer specifies multiple transmission oils, select the one with the highest viscosity at operating temperature. You may use a lower-viscosity transmission oil if we approve it as critical emission-related maintenance under § 1037.125. Fill the transmission oil to a level that represents in-use operation. You may use an external transmission oil conditioning system, as long as it does not affect measured values.

(4) Include any internal and external pumps for hydraulic fluid and lubricating oil in the test. Determine the work required to drive an external pump according to 40 CFR 1065.210.

(5) Install equipment for measuring the bulk temperature of the transmission oil in the oil sump or a similar location.

(6) If the transmission is equipped with a torque converter, lock it for all testing performed in this section.

(7) Break in the transmission using good engineering judgment. Maintain transmission oil temperature at (87 to 93) °C for automatic transmissions and transmissions having more than two friction clutches, and at (77 to 83) °C for all other transmissions. You may ask us to approve a different range of transmission oil temperatures if you have data showing that it better represents in-use operation.

(c) Measure input and output shaft speed and torque as described in 40 CFR 1065.210(b). You must use a speed measurement system that meets an accuracy of ± 0.05 % of point. Accuracy requirements for torque transducers depend on the highest loaded transmission input and output torque as described in paragraph (d)(2) of this section. Use torque transducers for torque input

measurements that meet an accuracy requirement of $\pm 0.2\%$ of the highest loaded transmission input for loaded test points and $\pm 0.1\%$ of the highest loaded transmission input torque for unloaded test points. For torque output measurements, torque transducers must meet an accuracy requirement of $\pm 0.2\%$ of the highest loaded transmission output torque for each gear ratio. Calibrate and verify measurement instruments according to 40 CFR part 1065, subpart D. Command speed and torque at a minimum of 10 Hz, and record all data, including bulk oil temperature, at a minimum of 1 Hz mean values.

(d) Test the transmission at input shaft speeds and torque setpoints as described in this paragraph (d). You may exclude lower gears from testing; however, you must test all the gears above the highest excluded gear. GEM will use default values for any untested gears. The test matrix consists of test points representing transmission input shaft speeds and torque setpoints meeting the following specifications for each tested gear:

(1) Test at the following transmission input shaft speeds:

- (i) 600.0 r/min or transmission input shaft speed when paired with the engine operating at idle.
- (ii) The transmission's maximum rated input shaft speed. You may alternatively select a value representing the highest expected in-use transmission input shaft speed.
- (iii) Three equally spaced intermediate speeds. The intermediate speed points may be adjusted to the nearest 50 or 100 r/min. You may test any number of additional speed setpoints to improve accuracy.

(2) Test at certain transmission input torque setpoints as follows:

- (i) Include one unloaded (zero-torque) setpoint.
- (ii) Include one loaded torque setpoint between 75 % and 105 % of the transmission's maximum rated input shaft torque. However, you may use a lower torque setpoint as needed to avoid exceeding dynamometer torque limits, as long as testing accurately represents in-use performance. If your loaded torque setpoint is below 75 % of the transmission's maximum rated input shaft torque, you must demonstrate that the sum of time for all gears where demanded engine torque is between your maximum torque setpoint and 75 % of the transmission's maximum rated input shaft torque is no more than 10 % of the time for each vehicle drive cycle specified in this subpart. This demonstration must be made available upon request.
- (iii) You may test at any number of additional torque setpoints to improve accuracy.
- (iv) Note that GEM calculates power loss between tested or default values by linear interpolation, except that GEM may extrapolate outside of measured values to account for testing at torque setpoints below 75 % as specified in paragraph (d)(2)(ii) of this section.

(3) In the case of transmissions that automatically go into neutral when the vehicle is stopped, also perform tests at 600 r/min and 800 r/min with the transmission in neutral and the transmission output fixed at zero speed.

(e) Determine transmission efficiency using the following procedure:

- (1) Maintain ambient temperature between (15 and 35) °C throughout testing. Measure ambient temperature within 1.0 m of the transmission.
- (2) Maintain transmission oil temperature as described in paragraph (b)(7) of this section.
- (3) Use good engineering judgment to warm up the transmission according to the transmission manufacturer's specifications.
- (4) Perform unloaded transmission tests by disconnecting the transmission output shaft from the dynamometer and letting it rotate freely. If the transmission adjusts pump pressure based

on whether the vehicle is moving or stopped, set up the transmission for unloaded tests to operate as if the vehicle is moving.

(5) For transmissions that have multiple configurations for a given gear ratio, such as dual-clutch transmissions that can pre-select an upshift or downshift, set the transmission to operate in the configuration with the greatest power loss. Alternatively, test in each configuration and use good engineering judgment to calculate a weighted power loss for each test point under this section based on field data that characterizes the degree of in-use operation in each configuration.

(6) For a selected gear, operate the transmission at one of the test points from paragraph (d) of this section for at least 10 seconds. Measure the speed and torque of the input and output shafts for at least 10 seconds. You may omit measurement of output shaft speeds if your transmission is configured to not allow slip. Calculate arithmetic mean values for mean input shaft torque, \bar{T}_{in} , mean output shaft torque, \bar{T}_{out} , mean input shaft speed, \bar{f}_{nin} , and mean output shaft speed, \bar{f}_{nout} , for each point in the test matrix for each test. Repeat this stabilization, measurement, and calculation for the other speed and torque setpoints from the test matrix for the selected gear in any sequence. Calculate power loss as described in paragraph (f) of this section based on mean speed and torque values at each test point.

(7) Repeat the procedure described in paragraph (e)(6) of this section for all gears, or for all gears down to a selected gear. This section refers to an “operating condition” to represent operation at a test point in a specific gear.

(8) Perform the test sequence described in paragraphs (e)(6) and (7) of this section three times. You may do this repeat testing at any given test point before you perform measurements for the whole test matrix. Remove torque from the transmission input shaft and bring the transmission to a complete stop before each repeat measurement.

(9) You may need to perform additional testing at a given operating condition based on a calculation of a confidence interval to represent repeatability at a 95 % confidence level at that operating condition. If the confidence interval is greater than 0.10 % for loaded tests or greater than 0.05 % for unloaded tests, perform another measurement at that operating condition and recalculate the repeatability for the whole set of test results. Continue testing until the confidence interval is at or below the specified values for all operating conditions. As an alternative, for any operating condition that does not meet this repeatability criterion, you may determine a maximum power loss instead of calculating a mean power loss as described in paragraph (g) of this section. Calculate a confidence interval representing the repeatability in establishing a 95 % confidence level using the following equation:

$$\text{Confidence Interval} = \frac{1.96 \cdot \sigma_{\text{Ploss}}}{\sqrt{N} \cdot P_{\text{rated}}} \cdot 100 \%$$

Eq. 1037.565-1

Where:

σ_{Ploss} = standard deviation of power loss values at a given operating condition (see 40 CFR 1065.602(c)).

N = number of repeat tests for an operating condition.

P_{rated} = the transmission’s rated input power for a given gear. For testing in neutral, use the value of P_{rated} for the top gear.

Example:

$$\sigma_{\text{Ploss}} = 0.1200 \text{ kW}$$

$$N = 3$$

$$P_{\text{rated}} = 314.2000 \text{ kW}$$

$$\text{Confidence Interval} = \frac{1.96 \cdot 0.1650}{\sqrt{3} \cdot 314.2000} \cdot 100 \%$$

$$\text{Confidence Interval} = 0.0432 \%$$

(f) Calculate the mean power loss, $\bar{\bar{P}}_{\text{loss}}$, at each operating condition as follows:

(1) Calculate \bar{P}_{loss} for each measurement at each operating condition as follows:

$$\bar{P}_{\text{loss}} = \bar{T}_{\text{in}} \cdot \bar{f}_{\text{nin}} - \bar{T}_{\text{out}} \cdot \bar{f}_{\text{nout}}$$

Eq. 1037.565-2

Where:

\bar{T}_{in} = mean input shaft torque from paragraph (e)(6) of this section.

\bar{f}_{nin} = mean input shaft speed from paragraph (e)(6) of this section in rad/s.

\bar{T}_{out} = mean output shaft torque from paragraph (e)(6) of this section. Let $\bar{T}_{\text{out}} = 0$ for all unloaded Tests.

\bar{f}_{nout} = mean output shaft speed from paragraph (e)(6) of this section in rad/s. Let $\bar{f}_{\text{nout}} = 0$ for all tests with the transmission in neutral. See paragraph (f)(2) of this section for calculating \bar{f}_{nout} as a function of \bar{f}_{nin} instead of measuring f_{nout} .

(2) For transmissions that are configured to not allow slip, you may calculate \bar{f}_{nout} based on the gear ratio using the following equation:

$$\bar{f}_{\text{nout}} = \frac{\bar{f}_{\text{nin}}}{k_g}$$

Eq. 1037.565-3

Where:

k_g = transmission gear ratio, expressed to at least the nearest 0.001.

(3) Calculate $\bar{\bar{P}}_{\text{loss}}$ as the mean power loss from all measurements at a given operating condition.

(4) The following example illustrates a calculation of $\bar{\bar{P}}_{\text{loss}}$:

$$\bar{T}_{\text{in},1} = 1000.0 \text{ N}\cdot\text{m}$$

$$\bar{f}_{\text{nin},1} = 1000 \text{ r/min} = 104.72 \text{ rad/sec}$$

$$\bar{T}_{\text{out},1} = 2654.5 \text{ N}\cdot\text{m}$$

$$\bar{f}_{\text{nout},1} = 361.27 \text{ r/min} = 37.832 \text{ rad/s}$$

$$\bar{P}_{\text{loss},1} = 1000.0 \cdot 104.72 - 2654.5 \cdot 37.832$$

$$\bar{P}_{\text{loss},1} = 4295 \text{ W} = 4.295 \text{ kW}$$

$$\bar{P}_{\text{loss},2} = 4285 \text{ W} = 4.285 \text{ kW}$$

$$\bar{P}_{\text{loss},3} = 4292 \text{ W} = 4.292 \text{ kW}$$

$$\bar{\bar{P}}_{\text{loss}} = \frac{4.295 + 4.285 + 4.292}{3} = 4.291 \text{ kW}$$

(g) Create a table with the mean power loss, \bar{P}_{loss} , corresponding to each operating condition for input into GEM. Also include power loss in neutral for each tested engine's speed, if applicable. Express transmission input speed in r/min to one decimal place; express input torque in N·m to two decimal places; express power loss in kW to four decimal places. Record the following values:

(1) Record \bar{P}_{loss} , \bar{T}_{in} , and \bar{f}_{nin} for each operating condition meeting the repeatability criterion in paragraph (e)(9) of this section. Calculate \bar{T}_{in} and \bar{f}_{nin} for each operating condition by calculating the arithmetic average of \bar{T}_{in} and \bar{f}_{nin} for all the repeat tests at that operating condition.

(2) For any operating condition not meeting the repeatability criterion in paragraph (e)(9) of this section, record the maximum value of \bar{P}_{loss} for that operating condition along with the corresponding values of \bar{T}_{in} and \bar{f}_{nin} .

(h) Record declared power loss values at or above the corresponding value calculated in paragraph (f) of this section. Use good engineering judgment to select values that will be at or above the mean power loss values for your production transmissions. Vehicle manufacturers will use these declared mean power loss values for certification.

§ 1037.570 Procedures to characterize torque converters.

GEM includes input values related to torque converters. This section describes a procedure for mapping a torque converter's capacity factors and torque ratios over a range of operating conditions. You may ask us to approve analytically derived input values based on this testing for additional untested configurations as described in § 1037.235(h).

(a) Prepare a torque converter for testing as follows:

(1) Select a torque converter with less than 500 hours of operation before the start of testing.

(2) If the torque converter has a locking feature, unlock it for all testing performed under this section. If the torque converter has a slipping lockup clutch, you may ask us to approve a different strategy based on data showing that it represents better in-use operation.

(3) Mount the torque converter with a transmission to the dynamometer in series or parallel arrangement or mount the torque converter without a transmission to represent a series configuration.

(4) Add transmission oil according to the torque converter manufacturer's instructions, with the following additional specifications:

(i) If the torque converter manufacturer specifies multiple transmission oils, select the one with the highest viscosity at operating temperature. You may use a lower-viscosity transmission oil if we approve that as critical emission-related maintenance under § 1037.125.

(ii) Fill the transmission oil to a level that represents in-use operation. If you are testing the torque converter without the transmission, keep output pressure and the flow rate of transmission oil into the torque converter within the torque converter manufacturer's limits.

(iii) You may use an external transmission oil conditioning system, as long as it does not affect measured values.

(5) Install equipment for measuring the bulk temperature of the transmission oil in the oil sump or a similar location and at the torque converter inlet. If the torque converter is tested without a transmission, measure the oil temperature at the torque converter inlet.

(6) Break in the torque converter and transmission (if applicable) using good engineering judgment. Maintain transmission oil temperature at (87 to 93) °C. You may ask us to approve

a different range of transmission oil temperatures if you have data showing that it better represents in-use operation.

(b) Measure pump and turbine shaft speed and torque as described in 40 CFR 1065.210(b). You must use a speed measurement system that meets an accuracy of $\pm 0.1\%$ of point or ± 1 r/min, whichever is greater. Use torque transducers that meet an accuracy of $\pm 1.0\%$ of the torque converter's maximum rated input and output torque, respectively. Calibrate and verify measurement instruments according to 40 CFR part 1065, subpart D. Command speed and torque at a minimum of 10 Hz. Record all speed and torque data at a minimum of 1 Hz mean values. Note that this section relies on the convention of describing the input shaft as the pump and the output shaft as the turbine shaft.

(c) Determine torque converter characteristics based on a test matrix using either constant input speed or constant input torque as follows:

(1) *Constant input speed.* Test at constant input speed as follows:

(i) Select a fixed pump speed, f_{npum} , between (1000 and 2000) r/min.

(ii) Test the torque converter at multiple speed ratios, ν , in the range of $\nu = 0.00$ to $\nu = 0.95$. Use a step width of 0.10 for the range of $\nu = 0.00$ to 0.60 and 0.05 for the range of $\nu = 0.60$ to 0.95. Calculate speed ratio, ν , as turbine shaft speed divided by pump speed.

(2) *Constant input torque.* Test at constant input torque as follows:

(i) Set the pump torque, T_{pum} , to a fixed positive value at $f_{npum} = 1000$ r/min with the torque converter's turbine shaft locked in a non-rotating state (i.e., turbine's speed, n_{tur} , = 0 r/min).

(ii) Test the torque converter at multiple speed ratios, ν , in the range of $\nu = 0.00$ up to a value of f_{ntur} that covers the usable range of ν . Use a step width of 0.10 for the range of $\nu = 0.00$ to 0.60 and 0.05 for the range of $\nu = 0.60$ to 0.95.

(3) You may limit the maximum speed ratio to a value below 0.95 if you have data showing this better represents in-use operation. You must use the step widths defined in paragraph (c)(1) or (2) of this section and include the upper limit as a test point. If you choose a value less than 0.60, you must test at least seven evenly distributed points between $\nu = 0$ and your new upper speed ratio.

(d) Characterize the torque converter using the following procedure:

(1) Maintain ambient temperature between (15 and 35) °C throughout testing. Measure ambient temperature within 1.0 m of the torque converter.

(2) Maintain transmission oil temperature as described in paragraph (a)(6) of this section. You may use an external transmission oil conditioning system, as long as it does not affect measured values.

(3) Use good engineering judgment to warm up the torque converter according to the torque converter manufacturer's specifications.

(4) Test the torque converter at constant input speed or constant input torque as described in paragraph (c) of this section. Operate the torque converter at $\nu = 0.00$ for (5 to 60) seconds, then measure pump torque, turbine shaft torque, angular pump speed, angular turbine shaft speed, and the transmission oil temperature at the torque converter inlet for (5 to 15) seconds. Calculate arithmetic mean values for pump torque, \bar{T}_{pum} , turbine shaft torque, \bar{T}_{tur} , angular pump speed, \bar{f}_{npum} , and angular turbine shaft speed, \bar{f}_{ntur} , over the measurement period.

Repeat this stabilization, measurement, and calculation for the other speed ratios from the test matrix in order of increasing speed ratio. Adjust the speed ratio by increasing the angular turbine shaft speed.

(5) Complete a test run by performing the test sequence described in paragraph (d)(4) of this section two times.

(6) Invalidate the test run if the difference between the pair of mean torque values for the repeat tests at any test point differ by more than ± 1 N·m or by more than ± 5 % of the average of those two values. This paragraph (d)(6) applies separately for mean pump torque and mean turbine shaft torque at each test point.

(7) Invalidate the test run if any calculated value for mean angular pump speed does not stay within ± 5 r/min of the speed setpoint or if any calculated value for mean pump torque does not stay within ± 5 N·m of the torque setpoint.

(e) Calculate the mean torque ratio, $\bar{\mu}$, at each tested speed ratio, v , as follows:

(1) Calculate $\bar{\mu}$ at each tested speed ratio as follows:

$$\bar{\mu} = \frac{\bar{T}_{\text{tur}}}{\bar{T}_{\text{pum}}}$$

Eq. 1037.570-1

Where:

\bar{T}_{tur} = mean turbine shaft torque from paragraph (d)(4) of this section.

\bar{T}_{pum} = mean pump torque from paragraph (d)(4) of this section.

(2) Calculate $\bar{\mu}$ as the average of the two values of $\bar{\mu}$ at each tested speed ratio.

(3) The following example illustrates a calculation of $\bar{\mu}$:

$$\bar{T}_{\text{tur},v=0,1} = 332.4 \text{ N}\cdot\text{m}$$

$$\bar{T}_{\text{pum},v=0,1} = 150.8 \text{ N}\cdot\text{m}$$

$$\bar{T}_{\text{tur},v=0,2} = 333.6 \text{ N}\cdot\text{m}$$

$$\bar{T}_{\text{pum},v=0,2} = 150.3 \text{ N}\cdot\text{m}$$

$$\bar{\mu}_{v=0,1} = \frac{332.4}{150.8} = 2.20$$

$$\bar{\mu}_{v=0,2} = \frac{333.6}{150.3} = 2.22$$

$$\bar{\mu}_{v=0} = \frac{2.20 + 2.22}{2} = 2.21$$

(f) Calculate the mean capacity factor, \bar{K} , at each tested speed ratio, v , as follows:

(1) Calculate \bar{K} at each tested speed ratio as follows:

$$\bar{K} = \frac{\bar{f}_{\text{npum}}}{\sqrt{\bar{T}_{\text{pum}}}}$$

Eq. 1037.570-2

Where:

\bar{f}_{npum} = mean angular pump speed from paragraph (d)(4) of this section.

\bar{T}_{pum} = mean pump torque from paragraph (d)(4) of this section.

(2) Calculate \bar{K} as the average of the two values of \bar{K} at each tested speed ratio.

(3) The following example illustrates a calculation of \bar{K} :

$$\bar{f}_{\text{npum},v=0,1} = \bar{f}_{\text{npum},v=0,2} = 1000.0 \text{ r/min}$$

$$\begin{aligned}\bar{T}_{\text{pum},v=0,1} &= 150.8 \text{ N}\cdot\text{m} \\ \bar{K}_{v=0,1} &= \frac{1000.0}{\sqrt{150.8}} = 81.43 \text{ r}/(\text{min} \cdot (\text{N} \cdot \text{m})^{0.5}) \\ \bar{T}_{\text{pum},v=0,2} &= 150.4 \text{ N}\cdot\text{m} \\ \bar{K}_{v=0,2} &= \frac{1000.0}{\sqrt{150.4}} = 81.54 \text{ r}/(\text{min} \cdot (\text{N} \cdot \text{m})^{0.5}) \\ \bar{K}_{v=0} &= \frac{81.43 + 81.54}{2} = 81.49 \text{ r}/(\text{min} \cdot (\text{N} \cdot \text{m})^{0.5})\end{aligned}$$

(g) Create a table of GEM inputs showing $\bar{\mu}$ and \bar{K} at each tested speed ratio, v . Express $\bar{\mu}$ to two decimal places; express \bar{K} to one decimal place; express v to two decimal places.

Subpart G—Special Compliance Provisions

§ 1037.601 General compliance provisions.

(a) Engine and vehicle manufacturers, as well as owners and operators of vehicles subject to the requirements of this part, and all other persons, must observe the provisions of this part, the applicable provisions of 40 CFR part 1068, and the applicable provisions of the Clean Air Act. The provisions of 40 CFR part 1068 apply for heavy-duty vehicles as specified in that part, subject to the provisions:

(1) Except as specifically allowed by this part or 40 CFR part 1068, it is a violation of 40 CFR 1068.101(a)(1) to introduce into U.S. commerce either a tractor or vocational vehicle that is not certified to the applicable requirements of this part or a tractor or vocational vehicle containing an engine that is not certified to the applicable requirements of 40 CFR part 86 or 1036. Further, it is a violation to introduce into U.S. commerce a Phase 1 tractor containing an engine not certified for use in tractors; or to introduce into U.S. commerce a vocational vehicle containing a Light HDE or Medium HDE not certified for use in vocational vehicles. These prohibitions apply especially to the vehicle manufacturer. Note that this paragraph (a)(1) allows the use of Heavy heavy-duty tractor engines in vocational vehicles.

(2) The provisions of 40 CFR 1068.105(a) apply for vehicle manufacturers installing engines certified under 40 CFR part 1036 as further limited by this paragraph (a)(2). If new engine emission standards apply in a given model year, you may install normal inventories of engines from the preceding model year under the provisions of 40 CFR 1068.105(a) through March 31 of that year without our approval; you may not install such engines after March 31 of that year unless we approve it in advance. Installing such engines after March 31 without our prior approval is considered to be prohibited stockpiling of engines. In a written request for our approval, you must describe how your circumstances led you and your engine supplier to have normal inventories of engines that were not used up in the specified time frame. We will approve your request for up to three additional months to install engines under this paragraph (a)(2) if we determine that the excess inventory is a result of unforeseeable circumstances and should not be considered circumvention of emission standards. We will limit this approval to a certain number of engines consistent with your normal production and inventory practices. Note that 40 CFR 1068.105(a) allows vehicle manufacturers to use up only normal inventories of engines meeting less stringent standards; if, for example, a vehicle manufacturer's normal practice is to receive a shipment of engines

every two weeks, it will deplete its potential to install previous-tier engines under this paragraph (a)(2) well before March 31 in the year that new standards apply.

(3) The exemption provisions of 40 CFR 1068.201 through 1068.230, 1068.240, and 1068.260 through 265 apply for heavy-duty motor vehicles. Other exemption provisions, which are specific to nonroad engines, do not apply for heavy-duty vehicles or heavy-duty engines.

(4) The tampering prohibition in 40 CFR 1068.101(b)(1) applies for alternative fuel conversions as specified in 40 CFR part 85, subpart F.

(5) The warranty-related prohibitions in section 203(a)(4) of the Act (42 U.S.C. 7522(a)(4)) apply to manufacturers of new heavy-duty highway vehicles in addition to the prohibitions described in 40 CFR 1068.101(b)(6). We may assess a civil penalty up to \$44,539 for each engine or vehicle in violation.

(6) A vehicle manufacturer that completes assembly of a vehicle at two or more facilities may ask to use as the date of manufacture for that vehicle the date on which manufacturing is completed at the place of main assembly, consistent with provisions of 49 CFR 567.4. Note that such staged assembly is subject to the corresponding provisions of 40 CFR 1068.260. Include your request in your application for certification, along with a summary of your staged-assembly process. You may ask to apply this allowance to some or all of the vehicles in your vehicle family. Our approval is effective when we grant your certificate. We will not approve your request if we determine that you intend to use this allowance to circumvent the intent of this part.

(7) The provisions for selective enforcement audits apply as described in 40 CFR part 1068, subpart E, and subpart D of this part.

(b) Vehicles exempted from the applicable standards of 40 CFR part 86 [or 40 CFR part 1036](#) other than glider vehicles are exempt from the standards of this part without request. Similarly, vehicles other than glider vehicles are exempt without request if the installed engine is exempted from the applicable standards in 40 CFR part 86 [or 40 CFR part 1036](#).

(c) The prohibitions of 40 CFR 1068.101 apply for vehicles subject to the requirements of this part. The following specific provisions apply:

(1) The actions prohibited under this provision include introducing into U.S. commerce a complete or incomplete vehicle subject to the standards of this part where the vehicle is not covered by a valid certificate of conformity or exemption.

(2) Applying a Clean Idle sticker to a vehicles with an installed engine that is not certified to the NO_x standard of 40 CFR 1036.104(b) violates the prohibition in 40 CFR 1068.101(b)(7)(iii).

(d) The emergency vehicle field modification provisions of 40 CFR 85.1716 apply with respect to the standards of this part.

(e) Under § 1037.801, certain vehicles are considered to be new vehicles when they are imported into the United States, even if they have previously been used outside the country. Independent Commercial Importers may use the provisions of 40 CFR part 85, subpart P, and 40 CFR 85.1706(b) to receive a certificate of conformity for engines and vehicles meeting all the requirements of 40 CFR part 1036 and this part 1037.

(f) Standards apply to multi-fuel vehicles as described for engines in 40 CFR 1036.601(d).

§ 1037.605 Installing engines certified to alternate standards for specialty vehicles.

(a) *General provisions.* This section allows vehicle manufacturers to introduce into U.S. commerce certain new motor vehicles using engines certified to alternate emission standards

specified in 40 CFR 1036.605 for motor vehicle engines used in specialty vehicles. You may not install an engine certified to these alternate standards if there is an engine certified to the full set of requirements of 40 CFR part 1036 that has the appropriate physical and performance characteristics to power the vehicle. Note that, although these alternate emission standards are mostly equivalent to standards that apply for nonroad engines under 40 CFR part 1039 or 1048, they are specific to motor vehicle engines. The provisions of this section apply for the following types of specialty vehicles:

(1) All-terrain motor vehicles with portal axles (i.e., axles that are offset from the corresponding wheel centerline by a gear assembly) or any axle configuration involving gear reduction such that the wheels rotate more slowly than the axle.

(2) Amphibious vehicles.

(3) Vehicles with maximum speed at or below 45 miles per hour. If your vehicle is speed-limited to meet this specification by reducing maximum speed below what is otherwise possible, this speed limitation must be programmed into the engine or vehicle's electronic control module in a way that is tamper-proof. If your vehicles are not inherently limited to a maximum speed at or below 45 miles per hour, they may qualify under this paragraph (a)(3) only if we approve your design to limit maximum speed as being tamper-proof in advance.

(4) Through model year 2027, vehicles with a hybrid powertrain in which the engine provides energy only for the Rechargeable Energy Storage System.

(b) *Notification and reporting requirements.* Send the Designated Compliance Officer written notification describing your plans before using the provisions of this section. In addition, by February 28 of each calendar year (or less often if we tell you), send the Designated Compliance Officer a report with all the following information:

(1) Identify your full corporate name, address, and telephone number.

(2) List the vehicle models for which you used this exemption in the previous year and identify the engine manufacturer and engine model for each vehicle model. Also identify the total number of vehicles produced in the previous year.

(c) *Production limits.* You may produce up to 1,000 hybrid vehicles in a given model year through model year 2027, and up to 200 of each type of vehicle identified in paragraph (a)(1) through (3) of this section in a given model year. This includes vehicles produced by affiliated companies. If you exceed this limit, the number of vehicles that exceed the limit for the model year will not be covered by a valid certificate of conformity. For the purpose of this paragraph (c), we will count all vehicles labeled or otherwise identified as exempt under this section.

(d) *Vehicle standards.* The vehicle standards of this part apply as follows for these vehicles:

(1) Vehicles qualifying under paragraphs (a)(1) through (3) of this section are subject to evaporative and refueling emission standards of § 1037.103, but are exempt from the other requirements of this part, except as specified in this section and in § 1037.601. These vehicles must include a label as specified in § 1037.135(a) with the information from § 1037.135(c)(1) and (2) and the following statement: "THIS VEHICLE IS EXEMPT FROM GREENHOUSE GAS STANDARDS UNDER 40 CFR 1037.605."

(2) Hybrid vehicles using the provisions of this section remain subject to the vehicle standards and all other requirements of this part 1037. For example, you may need to use GEM in conjunction with powertrain testing to demonstrate compliance with emission standards under subpart B of this part.

§ 1037.610 Vehicles with off-cycle technologies.

(a) You may ask us to apply the provisions of this section for CO₂ emission reductions resulting from vehicle technologies that were not in common use with heavy-duty vehicles before model year 2010 that are not reflected in GEM. While you are not required to prove that such technologies were not in common use with heavy-duty vehicles before model year 2010, we will not approve your request if we determine that they do not qualify. These may be described as off-cycle or innovative technologies. You may apply these provisions for CO₂ emission reductions reflected in the specified test procedures if they are not reflected in GEM, except as allowed under paragraph (g) of this section. We will apply these provisions only for technologies that will result in measurable, demonstrable, and verifiable real-world CO₂ emission reductions.

(b) The provisions of this section may be applied as either an improvement factor or as a separate credit, consistent with good engineering judgment. Note that the term “credit” in this section describes an additive adjustment to emission rates and is not equivalent to an emission credit in the ABT program of subpart H of this part. We recommend that you base your credit/adjustment on A to B testing of pairs of vehicles differing only with respect to the technology in question.

(1) Calculate improvement factors as the ratio of in-use emissions with the technology divided by the in-use emissions without the technology. Use the improvement-factor approach where good engineering judgment indicates that the actual benefit will be proportional to emissions measured over the test procedures specified in this part.

(2) Calculate separate credits (g/ton-mile) based on the difference between the in-use emission rate with the technology and the in-use emission rate without the technology.

Subtract this value from your GEM result and use this adjusted value to determine your FEL. Use the separate-credit approach where good engineering judgment indicates that the actual benefit will not be proportional to emissions measured over the test procedures specified in this part.

(3) We may require you to discount or otherwise adjust your improvement factor or credit to account for uncertainty or other relevant factors.

(c) You may perform A to B testing by measuring emissions from the vehicles during chassis testing or from in-use on-road testing. You may also ask to use modified powertrain testing. If you use on-road testing, we recommend that you test according to SAE J1321, Fuel Consumption Test Procedure – Type II, revised February 2012, or SAE J1526, SAE Fuel Consumption Test Procedure (Engineering Method), Revised September 2015 (see § 1037.810 for information on availability of SAE standards), subject to the following provisions:

(1) The minimum route distance is 100 miles.

(2) The route selected must be representative in terms of grade. We will take into account published and relevant research in determining whether the grade is representative.

(3) Control vehicle speed over the route to be representative of the drive-cycle weighting adopted for each regulatory subcategory, as specified in § 1037.510(c), or apply a correction to account for the appropriate weighting. For example, if the route selected for an evaluation of a combination tractor with a sleeper cab contains only interstate driving at 65 mi/hr, the improvement factor would apply only to 86 percent of the weighted result.

(4) The ambient air temperature must be between (5 and 35) °C, unless the technology requires other temperatures for demonstration.

(5) We may allow you to use a Portable Emissions Measurement System (PEMS) device for measuring CO₂ emissions during the on-road testing.

(d) Send your request to the Designated Compliance Officer. We recommend that you do not begin collecting test data (for submission to EPA) before contacting us. For technologies for

which the engine manufacturer could also claim credits (such as transmissions in certain circumstances), we may require you to include a letter from the engine manufacturer stating that it will not seek credits for the same technology. Your request must contain the following items:

- (1) A detailed description of the off-cycle technology and how it functions to reduce CO₂ emissions under conditions not represented on the duty cycles required for certification.
 - (2) A list of the vehicle configurations that will be equipped with the technology.
 - (3) A detailed description and justification of the selected test vehicles.
 - (4) All testing and simulation data required under this section, plus any other data you have considered in your analysis. You may ask for our preliminary approval of your test plan under § 1037.210.
 - (5) A complete description of the methodology used to estimate the off-cycle benefit of the technology and all supporting data, including vehicle testing and in-use activity data. Also include a statement regarding your recommendation for applying the provisions of this section for the given technology as an improvement factor or a credit.
 - (6) An estimate of the off-cycle benefit by vehicle model, and the fleetwide benefit based on projected sales of vehicle models equipped with the technology.
 - (7) A demonstration of the in-use durability of the off-cycle technology, based on any available engineering analysis or durability testing data (either by testing components or whole vehicles).
 - (8) A recommended method for auditing production vehicles consistent with the intent of 40 CFR part 1068, subpart E. We may approve your recommended method or specify a different method.
- (e) We may seek public comment on your request, consistent with the provisions of 40 CFR 86.1866. However, we will generally not seek public comment on credits or adjustments based on A to B chassis testing performed according to the duty-cycle testing requirements of this part or in-use testing performed according to paragraph (c) of this section.
- (f) We may approve an improvement factor or credit for any configuration that is properly represented by your testing.
- (1) For model years before 2021, you may continue to use an approved improvement factor or credit for any appropriate vehicle families in future model years through 2020.
 - (2) For model years 2021 and later, you may not rely on an approval for model years before 2021. You must separately request our approval before applying an improvement factor or credit under this section for Phase 2 [and Phase 3 later](#) vehicles, even if we approved an improvement factor or credit for similar vehicle models before model year 2021. Note that Phase 2 [and Phase 3 later](#) approval may carry over for multiple years.
- (g) You normally may not calculate off-cycle credits or improvement factors under this section for technologies represented by GEM, but we may allow you to do so by averaging multiple GEM runs for special technologies for which a single GEM run cannot accurately reflect in-use performance. For example, if you use an idle-reduction technology that is effective 80 percent of the time, we may allow you to run GEM with the technology active and with it inactive, and then apply an 80 % weighting factor to calculate the off-cycle credit or improvement factor. You may need to perform testing to establish proper weighting factors or otherwise quantify the benefits of the special technologies.

§ 1037.615 Advanced technologies.

- (a) This section [describes how to calculate emission credits for advanced technologies. You may calculate ~~applies in~~ Phase 1 advanced technology credits through model year 2020](#) for hybrid

vehicles with regenerative braking, vehicles equipped with Rankine-cycle engines, battery electric vehicles, and fuel cell electric vehicles. ~~You may calculate, and in~~ Phase 2 advanced technology credits through model year 2026~~7~~ for plug-in hybrid electric vehicles, battery electric vehicles, and fuel cell electric vehicles. ~~You may calculate Phase 3 advanced technology credits for model year 2027 for plug-in hybrid electric vehicles, battery electric vehicles, and fuel cell electric vehicles.~~ You may not generate credits for Phase 1 engine technologies for which the engines generate CO₂ credits under 40 CFR part 1036.

(b) Generate Phase 1 advanced-technology credits for vehicles other than battery electric vehicles as follows:

(1) Measure the effectiveness of the advanced system by chassis-testing a vehicle equipped with the advanced system and an equivalent conventional vehicle, or by testing the hybrid systems and the equivalent non-hybrid systems as described in § 1037.555. Test the vehicles as specified in subpart F of this part. For purposes of this paragraph (b), a conventional vehicle is considered to be equivalent if it has the same footprint (as defined in 40 CFR 86.1803), vehicle service class, aerodynamic drag, and other relevant factors not directly related to the hybrid powertrain. If you use § 1037.540 to quantify the benefits of a hybrid system for PTO operation, the conventional vehicle must have the same number of PTO circuits and have equivalent PTO power. If you do not produce an equivalent vehicle, you may create and test a prototype equivalent vehicle. The conventional vehicle is considered Vehicle A and the advanced vehicle is considered Vehicle B. We may specify an alternate cycle if your vehicle includes a power take-off.

(2) Calculate an improvement factor and g/ton-mile benefit using the following equations and parameters:

(i) Improvement Factor = [(Emission Rate A) – (Emission Rate B)]/(Emission Rate A).

(ii) g/ton-mile benefit = Improvement Factor × (GEM Result B).

(iii) Emission Rates A and B are the g/ton-mile CO₂ emission rates of the conventional and advanced vehicles, respectively, as measured under the test procedures specified in this section. GEM Result B is the g/ton-mile CO₂ emission rate resulting from emission modeling of the advanced vehicle as specified in § 1037.520.

(3) If you apply an improvement factor to multiple vehicle configurations using the same advanced technology, use the vehicle configuration with the smallest potential reduction in greenhouse gas emissions resulting from the hybrid capability.

(4) Use the equations in § 1037.705 to convert the g/ton-mile benefit to emission credits (in Mg). Use the g/ton-mile benefit in place of the (Std – FEL) term.

(c) See § 1037.540 for special testing provisions related to Phase 1 vehicles equipped with hybrid power take-off units.

(d) For Phase 2 and Phase 3 plug-in hybrid electric vehicles and for fuel cells powered by any fuel other than hydrogen, calculate CO₂ credits using an FEL based on emission measurements from powertrain testing. Phase 2 and Phase 3 advanced-technology credits do not apply for hybrid vehicles that have no plug-in capability.

~~(e) You may use an engineering analysis to calculate an improvement factor for fuel cell vehicles based on measured emissions from the fuel cell vehicle. [Reserved]~~

(f) For battery electric vehicles and for ~~fuel cells powered by hydrogen~~ fuel cell electric vehicles, calculate CO₂ credits using an FEL of 0 g/ton-mile. Note that these vehicles are subject to compression-ignition standards for CO₂.

(g) As specified in subpart H of this part, advanced-technology credits generated from Phase 1 vehicles under this section may be used under this part 1037 outside of the averaging set in which they were generated, or they may be used under 40 CFR part 86, subpart S, 86.1819 or 40

CFR part 1036. Advanced-technology credits generated from Phase 2 ~~and Phase 3~~ later vehicles are subject to ~~all~~ the averaging-set restrictions that apply to other emission credits.

(h) You may certify using both provisions of this section and the off-cycle technology provisions of § 1037.610, provided you do not double count emission benefits.

§ 1037.620 Responsibilities for multiple manufacturers.

This section describes certain circumstances in which multiple manufacturers share responsibilities for vehicles they produce together. This section does not limit responsibilities that apply under the Act or these regulations for anyone meeting the definition of “manufacturer” in § 1037.801. Note that the definition of manufacturer is broad and can include persons not commercially considered to be manufacturers.

(a) The following provisions apply when there are multiple persons meeting the definition of manufacturer in § 1037.801:

(1) Each person meeting the definition of manufacturer must comply with the requirements of this part that apply to manufacturers. However, if one person complies with a specific requirement for a given vehicle, then all manufacturers are deemed to have complied with that specific requirement.

(2) We will apply the requirements of subparts C and D of this part to the manufacturer that obtains the certificate of conformity for the vehicle. Other manufacturers are required to comply with the requirements of subparts C and D of this part only when notified by us. In our notification, we will specify a reasonable time period in which you need to comply with the requirements identified in the notice. See § 1037.601 for the applicability of 40 CFR part 1068 to these other manufacturers and remanufacturers.

(b) The provisions of § 1037.621, including delegated assembly, apply for certifying manufacturers that rely on other manufacturers to finish assembly in a certified configuration. The provisions of § 1037.622 generally apply for manufacturers that ship vehicles subject to the requirements of this part to a certifying secondary vehicle manufacturer. The provisions of § 1037.622 also apply to the secondary vehicle manufacturer. If you hold the certificate of conformity for a vehicle only with respect to exhaust or evaporative emissions, and a different company holds the other certificate of conformity for that vehicle, the provisions of § 1037.621 apply with respect to the certified configuration as described in your application for certification, and the provisions of § 1037.622 apply with respect to the certified configuration as described in the other manufacturer’s application for certification.

~~(c) Manufacturers of aerodynamic devices may perform the aerodynamic testing described in § 1037.526 to quantify AC_{a1} values for trailers and submit that data to EPA verification under § 1037.211. Trailer manufacturers may use such verified data to establish input parameters for certifying their trailers. Both device manufacturers and trailer manufacturers are subject to 40 CFR part 1068, including the recall provisions described in 40 CFR part 1068, subpart F.~~

~~(c)~~ Component manufacturers (such as tire manufacturers) providing test data to certifying vehicle manufacturers are responsible as follows for test components and emission test results provided to vehicle manufacturers for the purpose of certification under this part:

(1) Such test results are deemed under § 1037.825 to be submissions to EPA. This means that you may be subject to criminal penalties under 18 U.S.C. 1001 if you knowingly submit false test results to the certifying manufacturer.

(2) You may not cause a vehicle manufacturer to violate the regulations by rendering inaccurate emission test results you provide (or emission test results from testing of test components you provide) to the vehicle manufacturer (see 40 CFR 1068.101(c)).

(3) Your provision of test components and/or emission test results to vehicle manufacturers for the purpose of certifying under this part are deemed to be an agreement to provide components to EPA for confirmatory testing under § 1037.235.

(de) Component manufacturers may contractually agree to process emission warranty claims on behalf of the certifying manufacturer with respect to those components, as follows:

(1) Your fulfillment of the warranty requirements of this part is deemed to fulfill the vehicle manufacturer's warranty obligations under this part with respect to components covered by your warranty.

(2) You may not cause a vehicle manufacturer to violate the regulations by failing to fulfill the emission warranty requirements that you contractually agreed to fulfill (see 40 CFR 1068.101(c)).

(ef) We may require component manufacturers to provide information or take other actions under 42 U.S.C. 7542. For example, we may require component manufacturers to test components they produce.

§ 1037.621 Delegated assembly.

(a) This section describes provisions that allow certificate holders to sell or ship vehicles that are missing certain emission-related components if those components will be installed by a secondary vehicle manufacturer. Paragraph (g) of this section similarly describes how dealers and distributors may modify new vehicles with your advance approval. (Note: See § 1037.622 for provisions related to manufacturers introducing into U.S. commerce partially complete vehicles for which a secondary vehicle manufacturer holds the certificate of conformity.)

(b) You do not need an exemption to ship a vehicle that does not include installation or assembly of certain emission-related components if those components are shipped along with the vehicle. For example, you may generally ship fuel tanks and aerodynamic devices along with vehicles rather than installing them on the vehicle before shipment. We may require you to describe how you plan to use this provision.

(c) You may ask us at the time of certification for an exemption to allow you to ship your vehicles without emission-related components. If we allow this, you must provide emission-related installation instructions as specified in § 1037.130. You must follow delegated-assembly requirements in 40 CFR 1068.261 if you rely on secondary vehicle manufacturers to install certain technologies or components as specified in paragraph (d) of this section. For other technologies or components, we may specify conditions that we determine are needed to ensure that shipping the vehicle without such components will not result in the vehicle being operated outside of its certified configuration; this may include a requirement to comply with the delegated-assembly provisions in paragraph (d) of this section. We may consider your past performance when we specify the conditions that apply.

(d) Delegated-assembly provisions apply as specified in this paragraph (d) if the certifying vehicle manufacturer relies on a secondary vehicle manufacturer to procure and install auxiliary power units, aerodynamic devices, hybrid components (for powertrain or power take-off), or natural gas fuel tanks. These provisions do not apply for other systems or components, such as air conditioning lines and fittings, except as specified in paragraph (c) of this section. Apply the provisions of 40 CFR 1068.261, with the following exceptions and clarifications:

(1) Understand references to “engines” to refer to vehicles.

(2) Understand references to “aftertreatment components” to refer to any relevant emission-related components under this paragraph (d).

(3) Understand “equipment manufacturers” to be secondary vehicle manufacturers.

(4) The provisions of 40 CFR 1068.261(b), (c)(7), (d), and (e) do not apply. Accordingly, the provisions of 40 CFR 1068.261(c) apply regardless of pricing arrangements.

(e) Secondary vehicle manufacturers must follow the engine manufacturer's emission-related installation instructions. Not meeting the manufacturer's emission-related installation instructions is a violation of one or more of the prohibitions of § 1068.101. We may also require secondary vehicle manufacturers to recall defective vehicles under 40 CFR 1068.505 if we determine that their manufacturing practices caused vehicles to not conform to the regulations. Secondary vehicle manufacturers may be required to meet additional requirements if the certifying vehicle manufacturer delegates final assembly of emission controls as described in paragraph (d) of this section.

(f) Except as allowed by § 1037.622, the provisions of this section apply to manufacturers for glider kits they produce. Note that under § 1037.620, glider kit manufacturers are generally presumed to be responsible (in whole or in part) for compliance with respect to vehicles produced from their glider kits, even if a secondary vehicle manufacturer holds the certificate under § 1037.622.

(g) We may allow certifying vehicle manufacturers to authorize dealers or distributors to reconfigure/recalibrate vehicles after the vehicles have been introduced into commerce if they have not yet been delivered to the ultimate purchaser as follows:

(1) This allowance is limited to changes from one certified configuration to another, as noted in the following examples:

(i) If your vehicle family includes certified configurations with different axle ratios, you may authorize changing from one certified axle ratio to another.

(ii) You may authorize adding a certified APU to a tractor.

(2) Your final ABT report must accurately describe the vehicle's certified configuration as delivered to the ultimate purchaser. This means that the allowance no longer applies after you submit the final ABT report.

(3) The vehicle label must accurately reflect the final vehicle configuration.

(4) You must keep records to document modifications under this paragraph (g).

(5) Dealers and distributors must keep a record of your authorizing instructions. Dealers and distributors that fail to follow your instructions or otherwise make unauthorized changes may be committing a tampering violation as described in 40 CFR 1068.105(b).

§ 1037.622 Shipment of partially complete vehicles to secondary vehicle manufacturers.

This section specifies how manufacturers may introduce partially complete vehicles into U.S. commerce (or in the case of certain custom vehicles, introduce complete vehicles into U.S. commerce for modification by a small manufacturer). ~~The provisions of this section are generally not intended for trailers, but they may apply in unusual circumstances, such as when a secondary vehicle manufacturer will modify a trailer in a way that makes it exempt.~~ The provisions of this section are intended to accommodate normal business practices without compromising the effectiveness of certified emission controls. You may not use the provisions of this section to circumvent the intent of this part. For vehicles subject to both exhaust greenhouse gasGHG and evaporative standards, the provisions of this part apply separately for each certificate.

(a) The provisions of this section allow manufacturers to ship partially complete vehicles to secondary vehicle manufacturers or otherwise introduce them into U.S. commerce in the following circumstances:

(1) *Certified vehicles.* Manufacturers may introduce partially complete tractors into U.S. commerce if they are covered by certificates of conformity and are in certified

configurations. See § 1037.621 for vehicles not yet in a certified configuration when introduced into U.S. commerce.

(2) *Uncertified vehicles that will be certified by secondary vehicle manufacturers.*

Manufacturers may introduce into U.S. commerce partially complete vehicles for which they do not hold the required certificate of conformity only as allowed by paragraph (b) of this section; however, the requirements of this section do not apply for tractors or vocational vehicles with a date of manufacture before January 1, 2022, that are produced by a secondary vehicle manufacturer if they are excluded from the standards of this part under § 1037.150(c).

(3) *Exempted vehicles.* Manufacturers may introduce into U.S. commerce partially complete vehicles without a certificate of conformity if the vehicles are exempt under this part or under 40 CFR part 1068. This may involve the secondary vehicle manufacturer qualifying for the exemption.

(4) *Small manufacturers modifying certified tractors.* Small manufacturers that build custom sleeper cabs or natural gas-fueled tractors may modify complete or incomplete vehicles certified as tractors, as specified by paragraph (d) of this section.

(b) The provisions of this paragraph (b) generally apply where the secondary vehicle manufacturer has substantial control over the design and assembly of emission controls. They also apply where a secondary vehicle manufacturer qualifies for a permanent exemption. In unusual circumstances we may allow other secondary vehicle manufacturers to use these provisions. In determining whether a manufacturer has substantial control over the design and assembly of emission controls, we would consider the degree to which the secondary vehicle manufacturer would be able to ensure that the engine and vehicle will conform to the regulations in their final configurations.

(1) A secondary vehicle manufacturer may finish assembly of partially complete vehicles in the following cases:

(i) It obtains a vehicle that is not fully assembled with the intent to manufacture a complete vehicle in a certified or exempted configuration. For example, this would apply where a glider vehicle assembler holds a certificate that allows the assembler to produce certified glider vehicles from glider kits.

(ii) It obtains a vehicle with the intent to modify it to a certified configuration before it reaches the ultimate purchaser. For example, this may apply for converting a gasoline-fueled vehicle to operate on natural gas under the terms of a valid certificate.

(2) Manufacturers may introduce partially complete vehicles into U.S. commerce as described in this paragraph (b) if they have a written request for such vehicles from a secondary vehicle manufacturer that will finish the vehicle assembly and has certified the vehicle (or the vehicle has been exempted or excluded from the requirements of this part). The written request must include a statement that the secondary vehicle manufacturer has a certificate of conformity (or exemption/exclusion) for the vehicle and identify a valid vehicle family name associated with each vehicle model ordered (or the basis for an exemption/exclusion). The original vehicle manufacturer must apply a removable label meeting the requirements of 40 CFR 1068.45(b) that identifies the corporate name of the original manufacturer and states that the vehicle is exempt under the provisions of § 1037.622. The name of the certifying manufacturer must also be on the label or, alternatively, on the bill of lading that accompanies the vehicles during shipment. The original manufacturer may not apply a permanent emission control information label identifying the vehicle's eventual status as a certified vehicle. Note that an exemption

allowing a glider assembler to install an exempt engine does not necessarily exempt the vehicle from the requirements of this part.

(3) If you are the secondary vehicle manufacturer and you will hold the certificate, you must include the following information in your application for certification:

(i) Identify the original manufacturer of the partially complete vehicle or of the complete vehicle you will modify.

(ii) Describe briefly how and where final assembly will be completed. Specify how you have the ability to ensure that the vehicles will conform to the regulations in their final configuration. (Note: This section prohibits using the provisions of this paragraph (b) unless you have substantial control over the design and assembly of emission controls.)

(iii) State unconditionally that you will not distribute the vehicles without conforming to all applicable regulations.

(4) If you are a secondary vehicle manufacturer and you are already a certificate holder for other families, you may receive shipment of partially complete vehicles after you apply for a certificate of conformity but before the certificate's effective date. This exemption allows the original manufacturer to ship vehicles after you have applied for a certificate of conformity. Manufacturers may introduce partially complete vehicles into U.S. commerce as described in this paragraph (b)(4) if they have a written request for such vehicles from a secondary vehicle manufacturer stating that the application for certification has been submitted (instead of the information we specify in paragraph (b)(2) of this section). We may set additional conditions under this paragraph (b)(4) to prevent circumvention of regulatory requirements.

(5) The provisions of this section also apply for shipping partially complete vehicles if the vehicle is covered by a valid exemption and there is no valid family name that could be used to represent the vehicle model. Unless we approve otherwise in advance, you may do this only when shipping engines to secondary vehicle manufacturers that are certificate holders. In this case, the secondary vehicle manufacturer must identify the regulatory cite identifying the applicable exemption instead of a valid family name when ordering engines from the original vehicle manufacturer.

(6) Both original and secondary vehicle manufacturers must keep the records described in this section for at least five years, including the written request for exempted vehicles and the bill of lading for each shipment (if applicable). The written request is deemed to be a submission to EPA.

(7) These provisions are intended only to allow secondary vehicle manufacturers to obtain or transport vehicles in the specific circumstances identified in this section so any exemption under this section expires when the vehicle reaches the point of final assembly identified in paragraph (b)(3)(ii) of this section.

(8) For purposes of this section, an allowance to introduce partially complete vehicles into U.S. commerce includes a conditional allowance to sell, introduce, or deliver such vehicles into commerce in the United States or import them into the United States. It does not include a general allowance to offer such vehicles for sale because this exemption is intended to apply only for cases in which the certificate holder already has an arrangement to purchase the vehicles from the original manufacturer. This exemption does not allow the original manufacturer to subsequently offer the vehicles for sale to a different manufacturer who will hold the certificate unless that second manufacturer has also complied with the requirements of this part. The exemption does not apply for any individual vehicles that are not labeled as specified in this section or which are shipped to someone who is not a certificate holder.

(9) We may suspend, revoke, or void an exemption under this section, as follows:

- (i) We may suspend or revoke your exemption if you fail to meet the requirements of this section. We may suspend or revoke an exemption related to a specific secondary vehicle manufacturer if that manufacturer sells vehicles that are in not in a certified configuration in violation of the regulations. We may disallow this exemption for future shipments to the affected secondary vehicle manufacturer or set additional conditions to ensure that vehicles will be assembled in the certified configuration.
 - (ii) We may void an exemption for all the affected vehicles if you intentionally submit false or incomplete information or fail to keep and provide to EPA the records required by this section.
 - (iii) The exemption is void for a vehicle that is shipped to a company that is not a certificate holder or for a vehicle that is shipped to a secondary vehicle manufacturer that is not in compliance with the requirements of this section.
 - (iv) The secondary vehicle manufacturer may be liable for penalties for causing a prohibited act where the exemption is voided due to actions on the part of the secondary vehicle manufacturer.
- (c) Provide instructions along with partially complete vehicles including all information necessary to ensure that an engine will be installed in its certified configuration.
- (d) Small manufacturers that build custom sleeper cabs or natural gas-fueled tractors may modify complete or incomplete vehicles certified as tractors, subject to the provisions of this paragraph
- (d). Such businesses are secondary vehicle manufacturers.
- (1) Secondary vehicle manufacturers may not modify the vehicle body in front of the b-pillar or increase the effective frontal area of the certified configuration including consideration of the frontal area of the standard trailer. For high-roof custom sleeper tractors, this would generally mean that no part of the added sleeper compartment may extend beyond 102 inches wide or 162 inches high (measured from the ground), which are the dimensions of the standard trailer for high-roof tractors under this part. Note that these dimensions have a tolerance of ± 2 inches.
 - (2) The certifying manufacturer may have responsibilities for the vehicle under this section, as follows:
 - (i) If the vehicle being modified is a complete tractor in a certified configuration, the certifying manufacturer has no additional responsibilities for the vehicle under this section.
 - (ii) If the vehicle being modified is partially complete only because it lacks body components to the rear of the b-pillar (but is otherwise a complete tractor in a certified configuration), the certifying manufacturer has no additional responsibilities for the vehicle under this section.
 - (iii) If the vehicle being modified is an incomplete tractor not in a certified configuration, the certifying manufacturer must comply with the provisions of § 1037.621 for the vehicle.
 - (3) The secondary vehicle manufacturer must add a permanent supplemental label to the vehicle near the original manufacturer's emission control information label. On the label identify your corporate name and include the statement: "THIS TRACTOR WAS MODIFIED UNDER 40 CFR 1037.622."
 - (4) See § 1037.150 for additional interim options that may apply.
 - (5) The provisions of this paragraph (d) may apply separately for vehicle [greenhouse gasGHG](#), evaporative, and refueling emission standards.
 - (6) Modifications under this paragraph (d) do not violate 40 CFR 1068.101(b)(1).

§ 1037.630 Special purpose tractors.

(a) *General provisions.* This section allows a vehicle manufacturer to reclassify certain tractors as vocational tractors. Vocational tractors are treated as vocational vehicles and are exempt from the standards of § 1037.106. Note that references to “tractors” outside of this section mean non-vocational tractors.

(1) This allowance is intended only for vehicles that do not typically operate at highway speeds, or would otherwise not benefit from efficiency improvements designed for line-haul tractors. This allowance is limited to the following vehicle and application types:

(i) Low-roof tractors intended for intra-city pickup and delivery, such as those that deliver bottled beverages to retail stores.

(ii) Tractors intended for off-road operation (including mixed service operation that does not qualify for an exemption under § 1037.631), such as those with reinforced frames and increased ground clearance. This includes drayage tractors.

(iii) Model year 2020 and earlier tractors with a gross combination weight rating (GCWR) at or above 120,000 pounds. Note that Phase 2 ~~and Phase 3~~later tractors meeting the definition of “heavy-haul tractor” in § 1037.801 must be certified to the heavy-haul standards in §§ 1037.106 or § 1037.670.

(2) Where we determine that a manufacturer is not applying this allowance in good faith, we may require the manufacturer to obtain preliminary approval before using this allowance.

(b) *Requirements.* The following requirements apply with respect to tractors reclassified under this section:

(1) The vehicle must fully conform to all requirements applicable to vocational vehicles under this part.

(2) Vehicles reclassified under this section must be certified as a separate vehicle family. However, they remain part of the vocational regulatory subcategory and averaging set that applies for their service class.

(3) You must include the following additional statement on the vehicle’s emission control information label under § 1037.135: “THIS VEHICLE WAS CERTIFIED AS A VOCATIONAL TRACTOR UNDER 40 CFR 1037.630.”

(4) You must keep records for three years to document your basis for believing the vehicles will be used as described in paragraph (a)(1) of this section. Include in your application for certification a brief description of your basis.

(c) *Production limit.* No manufacturer may produce more than 21,000 Phase 1 vehicles under this section in any consecutive three model year period. This means you may not exceed 6,000 in a given model year if the combined total for the previous two years was 15,000. The production limit applies with respect to all Class 7 and Class 8 Phase 1 tractors certified or exempted as vocational tractors. No production limit applies for tractors subject to Phase 2 ~~and Phase 3~~later standards.

(d) *Off-road exemption.* All the provisions of this section apply for vocational tractors exempted under § 1037.631, except as follows:

(1) The vehicles are required to comply with the requirements of § 1037.631 instead of the requirements that would otherwise apply to vocational vehicles. Vehicles complying with the requirements of § 1037.631 and using an engine certified to the standards of 40 CFR part 1036 are deemed to fully conform to all requirements applicable to vocational vehicles under this part.

(2) The vehicles must be labeled as specified under § 1037.631 instead of as specified in paragraph (b)(3) of this section.

§ 1037.631 Exemption for vocational vehicles intended for off-road use.

This section provides an exemption from the greenhouse gas standards of this part for certain vocational vehicles (including certain vocational tractors) that are intended to be used extensively in off-road environments such as forests, oil fields, and construction sites. This section does not exempt engines used in vocational vehicles from the standards of 40 CFR part 86 or part 1036. Note that you may not include these exempted vehicles in any credit calculations under this part.

(a) *Qualifying criteria.* Vocational vehicles intended for off-road use are exempt without request, subject to the provisions of this section, if they are primarily designed to perform work off-road (such as in oil fields, mining, forests, or construction sites), and they meet at least one of the criteria of paragraph (a)(1) of this section and at least one of the criteria of paragraph (a)(2) of this section. See § 1037.105(h) for alternate Phase 2 [and Phase 3](#) standards that apply for vehicles meeting only one of these sets of criteria.

(1) The vehicle must have affixed components designed to work inherently in an off-road environment (such as hazardous material equipment or off-road drill equipment) or be designed to operate at low speeds such that it is unsuitable for normal highway operation.

(2) The vehicle must meet one of the following criteria:

(i) Have an axle that has a gross axle weight rating (GAWR) at or above 29,000 pounds.

(ii) Have a speed attainable in 2.0 miles of not more than 33 mi/hr.

(iii) Have a speed attainable in 2.0 miles of not more than 45 mi/hr, an unloaded vehicle weight that is not less than 95 percent of its gross vehicle weight rating, and no capacity to carry occupants other than the driver and operating crew.

(iv) Have a maximum speed at or below 54 mi/hr. You may consider the vehicle to be appropriately speed-limited if engine speed at 54 mi/hr is at or above 95 percent of the engine's maximum test speed in the highest available gear. You may alternatively limit vehicle speed by programming the engine or vehicle's electronic control module in a way that is tamper-proof.

(b) *Tractors.* The provisions of this section may apply for tractors only if each tractor qualifies as a vocational tractor under § 1037.630.

(c) *Recordkeeping and reporting.* (1) You must keep records to document that your exempted vehicle configurations meet all applicable requirements of this section. Keep these records for at least eight years after you stop producing the exempted vehicle model. We may review these records at any time.

(2) You must also keep records of the individual exempted vehicles you produce, including the vehicle identification number and a description of the vehicle configuration.

(3) Within 90 days after the end of each model year, you must send to the Designated Compliance Officer a report with the following information:

(i) A description of each exempted vehicle configuration, including an explanation of why it qualifies for this exemption.

(ii) The number of vehicles exempted for each vehicle configuration.

(d) *Labeling.* You must include the following additional statement on the vehicle's emission control information label under § 1037.135: "THIS VEHICLE WAS EXEMPTED UNDER 40 CFR 1037.631."

§ 1037.635 Glider kits and glider vehicles.

Except as specified in § 1037.150, the requirements of this section apply beginning January 1, 2017.

(a) Vehicles produced from glider kits and other glider vehicles are subject to the same standards as other new vehicles, including the applicable vehicle standards described in Subpart B of this part. Note that this requirement for the vehicle generally applies even if the engine meets the criteria of paragraph (c)(1) of this section. For engines originally produced before 2017, if you are unable to obtain a fuel map for an engine you may ask to use a default map, consistent with good engineering judgment.

(b) Section 1037.601(a)(1) disallows the introduction into U.S. commerce of a new tractor or vocational vehicle (including a vehicle assembled from a glider kit) unless it has an engine that is certified to the applicable standards in 40 CFR parts 86 and 1036. Except as specified otherwise in this part, the standards apply for engines used in glider vehicles as follows:

(1) The engine must meet the greenhouse gas~~GHG~~ standards of 40 CFR part 1036 that apply for the engine model year corresponding to the vehicle's date of manufacture. For example, for a vehicle with a 2024 date of manufacture, the engine must meet the greenhouse gas~~GHG~~ standards that apply for model year 2024.

(2) The engine must meet the criteria pollutant standards of 40 CFR part 86 or 40 CFR part 1036 that apply for the engine model year corresponding to the vehicle's date of manufacture.

(3) The engine may be from an earlier model year if the standards were identical to the currently applicable engine standards.

(4) Note that alternate standards or requirements may apply under § 1037.150.

(c) The engine standards identified in paragraph (b) of this section do not apply for certain engines when used in glider kits. These engines remain subject to the standards to which they were previously certified.

(1) The allowance in this paragraph (c) applies only for the following engines:

(i) Certified engines still within their original useful life in terms of both miles and years. Glider vehicles produced using engines meeting this criterion are exempt from the requirements of paragraph (a) of this section if the glider vehicle configuration is identical to a configuration previously certified to the requirements of this part 1037 for a model year the same as or later than the model year of the engine.

(ii) Certified engines of any age with less than 100,000 miles of engine operation. This is intended for specialty vehicles (such as fire trucks) that have very low usage rates. These vehicles are exempt from the requirements of paragraph (a) of this section, provided the completed vehicle is returned to the owner of the engine in a configuration equivalent to that of the donor vehicle.

(iii) Certified engines less than three years old with any number of accumulated miles of engine operation. Vehicles using these engines must comply with the requirements of paragraph (a) of this section.

(2) For remanufactured engines, these eligibility criteria apply based on the original date of manufacture rather than the date of remanufacture. For example, an engine originally manufactured in 2003 that is remanufactured in 2012 after 350,000 miles, then accumulates an additional 150,000 miles before being installed in a model year 2020 glider would be considered to be 17 years old and to have accumulated 500,000 miles.

(3) The provisions of this paragraph (c) apply only where you can show that one or more criteria have been met. For example, to apply the criterion of paragraph (c)(1)(i) or (ii), you must be able prove the number of miles the engine has accumulated.

(d) All engines used in glider vehicles (including remanufactured engines) must be in a certified configuration and properly labeled. This requirement applies equally to any engine covered by this section. Depending on the model year of the engine (and other applicable provisions of this section), it may be permissible for the engine to remain in its original certified configuration or another configuration of the same original model year. However, it may be necessary to modify the engine to a newer certified configuration.

(e) The following additional provisions apply:

(1) The Clean Air Act definition of “manufacturer” includes anyone who assembles motor vehicles, including entities that install engines in or otherwise complete assembly of glider kits.

(2) Vehicle manufacturers (including assemblers) producing glider vehicles must comply with the reporting and recordkeeping requirements in § 1037.250.

(3) Manufacturers of glider kits providing glider kits for the purpose of allowing another manufacturer to assemble vehicles under this section are subject to the provisions of §§ 1037.620 through 1037.622, as applicable. For example, introducing an uncertified glider kit into U.S. commerce may subject you to penalties under 40 CFR 1068.101 if the completed glider vehicle does not conform fully with the regulations of the part at any point before being placed into service.

§ 1037.640 Variable vehicle speed limiters.

This section specifies provisions that apply for vehicle speed limiters (VSLs) that you model under § 1037.520. This does not apply for VSLs that you do not model under § 1037.520. ~~(e)~~ This section is written to apply for tractors; however, you may use good engineering judgment to apply equivalent adjustments for Phase 2 ~~and Phase 3~~ later vocational vehicles with vehicle speed limiters.

(a) *General.* The regulations of this part do not constrain how you may design VSLs for your vehicles. For example, you may design your VSL to have a single fixed speed limit or a soft-top speed limit. You may also design your VSL to expire after accumulation of a predetermined number of miles. However, designs with soft tops or expiration features are subject to proration provisions under this section that do not apply to fixed VSLs that do not expire.

(b) *Definitions.* The following definitions apply for purposes of this section:

(1) Default speed limit means the speed limit that normally applies for the vehicle, except as follows:

(i) The default speed limit for adjustable VSLs must represent the speed limit that applies when the VSL is adjusted to its highest setting under paragraph (c) of this section.

(ii) For VSLs with soft tops, the default speed does not include speeds possible only during soft-top operation.

(iii) For expiring VSLs, the default does not include speeds that are possible only after expiration.

(2) Soft-top speed limit means the highest speed limit that applies during soft-top operation.

(3) Maximum soft-top duration means the maximum amount of time that a vehicle could operate above the default speed limit.

(4) Certified VSL means a VSL configuration that applies when a vehicle is new and until it expires.

(5) Expiration point means the mileage at which a vehicle's certified VSL expires (or the point at which tamper protections expire).

(6) Effective speed limit has the meaning given in paragraph (d) of this section.

(c) *Adjustments*. You may design your VSL to be adjustable; however, this may affect the value you use in GEM.

(1) Except as specified in paragraph (c)(2) of this section, any adjustments that can be made to the engine, vehicle, or their controls that change the VSL's actual speed limit are considered to be adjustable operating parameters. Compliance is based on the vehicle being adjusted to the highest speed limit within this range.

(2) The following adjustments are not adjustable parameters:

(i) Adjustments made only to account for changing tire size or final drive ratio.

(ii) Adjustments protected by encrypted controls or passwords.

(iii) Adjustments possible only after the VSL's expiration point.

(d) *Effective speed limit*. (1) For VSLs without soft tops or expiration points that expire before 1,259,000 miles, the effective speed limit is the highest speed limit that results by adjusting the VSL or other vehicle parameters consistent with the provisions of paragraph (c) of this section.

(2) For VSLs with soft tops and/or expiration points, the effective speed limit is calculated as specified in this paragraph (d)(2), which is based on 10 hours of operation per day (394 miles per day for day cabs and 551 miles per day for sleeper cabs). Note that this calculation assumes that a fraction of this operation is speed-limited (3.9 hours and 252 miles for day cabs, and 7.3 hours and 474 miles for sleeper cabs). Use the following equation to calculate the effective speed limit, rounded to the nearest 0.1 mi/hr:

$$\text{Effective speed} = ExF \cdot [STF \cdot STSL + (1-STF) \cdot DSL] + (1-ExF) \cdot 65 \text{ mi/hr}$$

Eq. 1037.640-1

Where:

ExF = expiration point miles/1,259,000 miles.

STF = the maximum number of allowable soft top operation hours per day / 3.9 hours for day cabs (or maximum miles per day / 252), or the maximum number of allowable soft top operation hours per day / 7.3 hours for sleeper cabs (or maximum miles per day / 474).

$STSL$ = the soft-top speed limit.

DSL = the default speed limit.

§ 1037.645 In-use compliance with family emission limits (FELs).

Section 1037.225 describes how to change the FEL for a vehicle family during the model year. This section, which describes how you may ask us to increase a vehicle family's FEL after the end of the model year, is intended to address circumstances in which it is in the public interest to apply a higher in-use FEL based on forfeiting an appropriate number of emission credits. For example, this may be appropriate where we determine that recalling vehicles would not significantly reduce in-use emissions. We will generally not allow this option where we determine the credits being forfeited would likely have expired.

(a) You may ask us to increase a vehicle family's FEL after the end of the model year if you believe some of your in-use vehicles exceed the CO₂ FEL that applied during the model year (or the CO₂ emission standard if the family did not generate or use emission credits). We may consider any available information in making our decision to approve or deny your request.

(b) If we approve your request under this section, you must apply emission credits to cover the increased FEL for all affected vehicles. Apply the emission credits as part of your credit demonstration for the current production year. Include the appropriate calculations in your final report under § 1037.730.

(c) Submit your request to the Designated Compliance Officer. Include the following in your request:

(1) Identify the names of each vehicle family that is the subject of your request. Include separate family names for different model years

(2) Describe why your request does not apply for similar vehicle models or additional model years, as applicable.

(3) Identify the FEL that applied during the model year for each configuration and recommend replacement FELs for in-use vehicles; include a supporting rationale to describe how you determined the recommended replacement FELs.

(4) Describe whether the needed emission credits will come from averaging, banking, or trading.

(d) If we approve your request, we will identify one or more replacement FELs, as follows:

(1) Where your vehicle family includes more than one sub-family with different FELs, we may apply a higher FEL within the family than was applied to the vehicle's configuration in your final ABT report. For example, if your vehicle family included three sub-families, with FELs of 200 g/ton-mile, 210 g/ton-mile, and 220 g/ton-mile, we may apply a 220 g/ton-mile in-use FEL to vehicles that were originally designated as part of the 200 g/ton-mile or 210 g/ton-mile sub-families.

(2) Without regard to the number of sub-families in your certified vehicle family, we may specify one or more new sub-families with higher FELs than you included in your final ABT report. We may apply these higher FELs as in-use FELs for your vehicles. For example, if your vehicle family included three sub-families, with FELs of 200 g/ton-mile, 210 g/ton-mile, and 220 g/ton-mile, we may specify a new 230 g/ton-mile sub-family.

(3) Our selected values for the replacement FEL will reflect our best judgment to accurately reflect the actual in-use performance of your vehicles, consistent with the testing provisions specified in this part.

(4) We may apply the higher FELs to other vehicle families from the same or different model years to the extent they used equivalent emission controls. We may include any appropriate conditions with our approval.

(e) If we order a recall for a vehicle family under 40 CFR 1068.505, we will no longer approve a replacement FEL under this section for any of your vehicles from that vehicle family, or from any other vehicle family that relies on equivalent emission controls.

§ 1037.655 Post-useful life vehicle modifications.

(a) *General.* Vehicle modifications during and after the useful life are presumed to violate 42 U.S.C. 7522(a)(3)(A) if they involve removing or rendering inoperative any emission control device installed to comply with the requirements of this part 1037. This section specifies vehicle modifications that may occur in certain circumstances after a vehicle reaches the end of its regulatory useful life. EPA may require a higher burden of proof with respect to modifications that occur within the useful life period, and the specific examples presented here do not necessarily apply within the useful life. This section also does not apply with respect to engine modifications or recalibrations.

(b) *Allowable modifications.* You may modify a vehicle for the purpose of reducing emissions, provided you have a reasonable technical basis for knowing that such modification will not increase emissions of any other pollutant. “Reasonable technical basis” has the meaning given in 40 CFR 1068.30. This generally requires you to have information that would lead an engineer or other person familiar with engine and vehicle design and function to reasonably believe that the modifications will not increase emissions of any regulated pollutant.

(c) *Examples of allowable modifications.* The following are examples of allowable modifications:

(1) It is generally allowable to remove tractor roof fairings after the end of the vehicle’s useful life if the vehicle will no longer be used primarily to pull box vans.

(2) Other fairings may be removed after the end of the vehicle’s useful life if the vehicle will no longer be used significantly on highways with a vehicle speed of 55 miles per hour or higher.

(d) *Examples of prohibited modifications.* The following are examples of modifications that are not allowable:

(1) No person may disable a vehicle speed limiter prior to its expiration point.

(2) No person may remove aerodynamic fairings from tractors that are used primarily to pull box vans on highways.

§ 1037.660 Idle-reduction technologies.

This section specifies requirements that apply for idle-reduction technologies modeled under § 1037.520. It does not apply for idle-reduction technologies you do not model under § 1037.520.

(a) *Minimum requirements.* Idle-reduction technologies must meet all the following requirements to be modeled under § 1037.520 except as specified in paragraphs (b) and (c) of this section:

(1) *Automatic engine shutdown (AES) systems.* The system must shut down the engine within a threshold inactivity period of 60 seconds or less for vocational vehicles and 300 seconds or less for tractors when all the following conditions are met:

(i) The transmission is set to park, or the transmission is in neutral with the parking brake engaged. This is “parked idle.”

(ii) The operator has not reset the system timer within the specified threshold inactivity period by changing the position of the accelerator, brake, or clutch pedal; or by resetting the system timer with some other mechanism we approve.

(iii) You may identify systems as “tamper-resistant” if you make no provision for vehicle owners, dealers, or other service outlets to adjust the threshold inactivity period.

(iv) For Phase 2 ~~and Phase 3~~ later tractors, you may identify AES systems as “adjustable” if, before delivering to the ultimate purchaser, you enable authorized dealers to modify the vehicle in a way that disables the AES system or makes the threshold inactivity period longer than 300 seconds. However, the vehicle may not be delivered to the ultimate purchaser with the AES system disabled or the threshold inactivity period set longer than 300 seconds. You may allow dealers or repair facilities to make such modifications; this might involve password protection for electronic controls, or special tools that only you provide. Any dealers making any modifications before delivery to the ultimate purchaser must notify you, and you must account for such modifications in your production and ABT reports after the end of the model year. Dealers failing to provide prompt notification are in violation of the tampering prohibition of 40 CFR 1068.101(b)(1). Dealer notifications are deemed to be submissions to EPA. Note that

these adjustments may not be made if the AES system was not “adjustable” when first delivered to the ultimate purchaser.

(v) For vocational vehicles, you may use the provisions of § 1037.610 to apply for an appropriate partial emission reduction for AES systems you identify as “adjustable.”

(2) *Neutral idle.* Phase 2 ~~and later Phase 3~~ vehicles with hydrokinetic torque converters paired with automatic transmissions qualify for neutral-idle credit in GEM modeling if the transmission reduces torque equivalent to shifting into neutral throughout the interval during which the vehicle’s brake pedal is depressed and the vehicle is at a zero-speed condition (beginning within five seconds of the vehicle reaching zero speed with the brake depressed). If a vehicle reduces torque partially but not enough to be equivalent to shifting to neutral, you may use the provisions of § 1037.610(g) to apply for an appropriate partial emission reduction; this may involve A to B testing with the powertrain test procedure in [40 CFR § 1037.1036.5450](#) or the spin-loss portion of the transmission efficiency test in § 1037.565.

(3) *Stop-start.* Phase 2 ~~and later Phase 3~~ vocational vehicles qualify for stop-start reduction in GEM modeling if the engine shuts down no more than 5 seconds after the vehicle’s brake pedal is depressed when the vehicle is at a zero-speed condition.

(b) *Override conditions.* The system may limit activation of the idle-reduction technology while any of the conditions of this paragraph (b) apply. These conditions allow the system to delay engine shutdown, adjust engine restarting, or delay disengaging transmissions, but do not allow for resetting timers. Engines may restart and transmissions may re-engage during override conditions if the vehicle is set up to do this automatically. We may approve additional override criteria as needed to protect the engine and vehicle from damage and to ensure safe vehicle operation.

(1) For AES systems on tractors, the system may delay shutdown—

(i) When an exhaust emission control device is regenerating. The period considered to be regeneration for purposes of this allowance must be consistent with good engineering judgment and may differ in length from the period considered to be regeneration for other purposes. For example, in some cases it may be appropriate to include a cool down period for this purpose but not for infrequent regeneration adjustment factors.

(ii) When the vehicle’s main battery state-of-charge is not sufficient to allow the main engine to be restarted.

(iii) When the vehicle’s transmission, fuel, oil, or engine coolant temperature is too low or too high according to the manufacturer’s specifications for protecting against system damage. This allows the engine to continue operating until it is in a predefined temperature range, within which the shutdown sequence of paragraph (a) of this section would resume.

(iv) When the vehicle’s main engine is operating in power take-off (PTO) mode. For purposes of this paragraph (b), an engine is considered to be in PTO mode when a switch or setting designating PTO mode is enabled.

(v) When external ambient conditions prevent managing cabin temperatures for the driver’s safety.

(vi) When necessary while servicing the vehicle, provided the deactivation of the AES system is accomplished using a diagnostic scan tool. The system must be automatically reactivated when the engine is shut down for more than 60 minutes.

(2) For AES systems on vocational vehicles, the system may limit activation—

(i) When any condition specified in paragraph (b)(1)(i) through (v) of this section applies.

(ii) When the engine compartment is open.

- (3) For neutral idle, the system may delay shifting the transmission to neutral—
 - (i) When the system meets the PTO conditions specified in paragraph (b)(1)(iv) of this section.
 - (ii) When the transmission is in reverse gear.
 - (iii) When the vehicle is ascending or descending a road with grade at or above 6.0 %.
- (4) For stop-start, the system may limit activation—
 - (i) When any condition specified in paragraph (b)(2) or (b)(3)(ii) or (iii) of this section applies.
 - (ii) When air brake pressure is too low according to the manufacturer’s specifications for maintaining vehicle-braking capability.
 - (iii) When an automatic transmission is in “park” or “neutral” and the parking brake is engaged.
 - (iv) When recent vehicle speeds indicate an abnormally high shutdown and restart frequency, such as with congested driving. For example, a vehicle not exceeding 10 mi/hr for the previous 300 seconds or since the most recent engine start would be a proper basis for overriding engine shutdown. You may also design this override to protect against system damage or malfunction of safety systems.
 - (v) When the vehicle detects that a system or component is worn or malfunctioning in a way that could reasonably prevent the engine from restarting, such as low battery voltage.
 - (vi) When the steering angle is at or near the limit of travel.
 - (vii) When flow of diesel exhaust fluid is limited due to freezing.
 - (viii) When a sensor failure could prevent the anti-lock braking system from properly detecting vehicle speed.
 - (ix) When a protection mode designed to prevent component failure is active.
 - (x) When a fault on a system component needed for starting the engine is active.
- (c) *Adjustments to AES systems for Phase 1.* (1) The AES system may include an expiration point (in miles) after which the AES system may be disabled. If your vehicle is equipped with an AES system that expires before 1,259,000 miles, adjust the model input as follows, rounded to the nearest 0.1 g/ton-mile: $\text{AES Input} = 5 \text{ g CO}_2/\text{ton-mile} \times (\text{miles at expiration}/1,259,000 \text{ miles})$.
- (2) For AES systems designed to limit idling to a specific number of hours less than 1,800 hours over any 12-month period, calculate an adjusted AES input using the following equation, rounded to the nearest 0.1 g/ton-mile: $\text{AES Input} = 5 \text{ g CO}_2/\text{ton-mile} \times (1 - (\text{maximum allowable number of idling hours per year}/1,800 \text{ hours}))$. This is an annual allowance that starts when the vehicle is new and resets every 12 months after that. Manufacturers may propose an alternate method based on operating hours or miles instead of years.
- (d) *Adjustable parameters.* Provisions that apply generally with respect to adjustable parameters also apply to the AES system operating parameters, except the following are not considered to be adjustable parameters:
 - (1) Accelerator, brake, and clutch pedals, with respect to resetting the idle timer. Parameters associated with other timer reset mechanisms we approve are also not adjustable parameters.
 - (2) Bypass parameters allowed for vehicle service under paragraph (b)(1)(ii) of this section.
 - (3) Parameters that are adjustable only after the expiration point.
- (e) PM limit for diesel APU. For model year 2020 and earlier tractors with a date of manufacture on or after January 1, 2018, the GEM credit for AES systems with OEM-installed diesel APUs is valid only if the engine is certified under 40 CFR part 1039 with a deteriorated emission level for

particulate matter at or below 0.15 g/kW-hr, or if the engine or APU is certified to the standards specified in § 1037.106(g).

§ 1037.665 Production and in-use tractor testing.

We may require mManufacturers with annual U.S.-directed production volumes of greater than 20,000 tractors ~~must to~~ perform testing as described in this section. Tractors may be new or used.

(a) ~~The following test requirements apply for Test~~ model years 2021 and later tractors as follows:

(1) Each calendar year, we may require you to select for testing three sleeper cabs and two day cabs certified to Phase 1 or Phase 2 ~~or Phase 3~~ standards. If we do not identify certain vehicle configurations for your testing, select models that you project to be among your 12 highest-selling vehicle configurations for the given year.

(2) Set up the tractors on a chassis dynamometer and operate them over all applicable duty cycles from § 1037.510(a)(3). You may use emission-measurement systems meeting the specifications of 40 CFR part 1065, subpart J. Calculate coefficients for the road-load force equation as described in Section 10 of SAE J1263 or Section 11 of SAE J2263 (both incorporated by reference, ~~see in~~ § 1037.810). Use standard payload. Measure emissions of NO_x, PM, CO, NMHC, CO₂, CH₄, and N₂O. Determine emission levels in ~~g/hour for the idle test and~~ g/ton-mile ~~for other duty cycles~~.

(b) Send us an annual report with your test results for each duty cycle and the corresponding GEM results. Send the report by the next October 1 after the year we select the vehicles for testing, or a later date that we approve. We may make your test data publicly available.

(c) We may approve your request to perform alternative testing that will provide equivalent or better information compared to the specified testing. For example, we may allow you to provide CO₂ data from in-use operation or from manufacturer-run on-road testing as long as it allows for reasonable year-to-year comparisons and includes testing from production vehicles. We may also direct you to do less testing than we specify in this section.

(d) ~~Greenhouse gas~~GHG standards do not apply with respect to testing under this section. Note however that NTE standards apply for any qualifying operation that occurs during the testing in the same way that it would during any other in-use testing.

§ 1037.670 Optional CO₂ emission standards for tractors at or above 120,000 pounds

GCWR.

(a) You may certify model year 2026 and earlier tractors at or above 120,000 pounds GCWR to the following CO₂ standards instead of the Phase 2 CO₂ standards of § 1037.106:

TABLE 1 OF PARAGRAPH (a) OF § 1037.670—OPTIONAL ~~PHASE 2~~ CO₂ STANDARDS FOR MODEL YEAR 2026 AND EARLIER TRACTORS ABOVE 120,000 POUNDS GCWR (g/ton-mile)^a

Subcategory	Model Years 2021 - 2023	Model Years 2024 - 2026
Heavy Class 8 Low-Roof Day Cab	53.5	50.8
Heavy Class 8 Low-Roof Sleeper Cab	47.1	44.5
Heavy Class 8 Mid-Roof Day Cab	55.6	52.8
Heavy Class 8 Mid-Roof Sleeper Cab	49.6	46.9
Heavy Class 8 High-Roof Day Cab	54.5	51.4
Heavy Class 8 High-Roof Sleeper Cab	47.1	44.2

^a Note that these standards are not directly comparable to the standards for Heavy-Haul Tractors in § 1037.106 because GEM handles aerodynamic performance differently for the two sets of standards.

(b) Determine subcategories as described in § 1037.230 for tractors that are not heavy-haul tractors. For example, the subcategory for tractors that would otherwise be considered Class 8 low-roof day cabs would be Heavy Class 8 Low-Roof Day Cabs and would be identified as HC8_DC_LR for the GEM run.

(c) Except for the CO₂ standards of § 1037.106, all provisions applicable to tractors under this part continue to apply to tractors certified to the standards of this section. Include the following compliance statement on your label instead of the statement specified in § 1037.135(c)(8): "THIS VEHICLE COMPLIES WITH U.S. EPA REGULATIONS FOR [MODEL YEAR] HEAVY-DUTY VEHICLES UNDER 40 CFR 1037.670."

(d) The optional emission standards in this section are intended primarily for tractors that will be exported; however, you may include any tractors certified under this section in your emission credit calculation under § 1037.705 if they are part of your U.S.-directed production volume.

Subpart H—Averaging, Banking, and Trading for Certification

§ 1037.701 General provisions.

(a) You may average, bank, and trade emission credits for purposes of certification as described in this subpart and in subpart B of this part to show compliance with the standards of §§ 1037.105 ~~through 1037.107 and 1037.106~~. Note that §§ 1037.105(h) ~~and 1037.107 specifies~~ standards involving limited or no use of emission credits under this subpart. Participation in this program is voluntary.

(b) The definitions of subpart I of this part apply to this subpart in addition to the following definitions:

(1) *Actual emission credits* means emission credits you have generated that we have verified by reviewing your final report.

(2) *Averaging set* means a set of vehicles in which emission credits may be exchanged. Note that an averaging set may comprise more than one regulatory subcategory. See § 1037.740.

(3) *Broker* means any entity that facilitates a trade of emission credits between a buyer and seller.

(4) *Buyer* means the entity that receives emission credits as a result of a trade.

(5) *Reserved emission credits* means emission credits you have generated that we have not yet verified by reviewing your final report.

(6) *Seller* means the entity that provides emission credits during a trade.

(7) *Standard* means the emission standard that applies under subpart B of this part for vehicles not participating in the ABT program of this subpart.

- (8) *Trade* means to exchange emission credits, either as a buyer or seller.
- (c) Emission credits may be exchanged only within an averaging set, except as specified in § 1037.740.
- (d) You may not use emission credits generated under this subpart to offset any emissions that exceed an FEL or standard, except as allowed by § 1037.645.
- (e) You may use either of the following approaches to retire or forego emission credits:
- (1) You may trade emission credits generated from any number of your vehicles to the vehicle purchasers or other parties to retire the credits. Identify any such credits in the reports described in § 1037.730. Vehicles must comply with the applicable FELs even if you donate or sell the corresponding emission credits under this paragraph (e). Those credits may no longer be used by anyone to demonstrate compliance with any EPA emission standards.
 - (2) You may certify a family using an FEL below the emission standard as described in this part and choose not to generate emission credits for that family. If you do this, you do not need to calculate emission credits for those families and you do not need to submit or keep the associated records described in this subpart for that family.
- (f) Emission credits may be used in the model year they are generated. Where we allow it, surplus emission credits may be banked for future model years. Surplus emission credits may sometimes be used for past model years, as described in § 1037.745. [You may not apply banked or traded credits in a given model year until you have used all available credits through averaging to resolve credit balances for that model year.](#)
- (g) You may increase or decrease an FEL during the model year by amending your application for certification under § 1037.225. The new FEL may apply only to vehicles you have not already introduced into commerce.
- (h) See § 1037.740 for special credit provisions that apply for credits generated under 40 CFR 86.1819-14-(k)(7), 40 CFR 1036.615, or § 1037.615.
- (i) Unless the regulations explicitly allow it, you may not calculate Phase 1 credits more than once for any emission reduction. For example, if you generate Phase 1 CO₂ emission credits for a given hybrid vehicle under this part, no one may generate CO₂ emission credits for the associated hybrid engine under 40 CFR part 1036. However, Phase 1 credits could be generated for identical engines used in vehicles that did not generate credits under this part.
- (j) You may use emission credits generated under the Phase 1 standards when certifying vehicles to Phase 2 standards. No credit adjustments are required other than corrections for different useful lives.

§ 1037.705 Generating and calculating **CO₂** emission credits.

- (a) The provisions of this section apply separately for calculating **CO₂** emission credits for each pollutant.
- (b) For each participating family or subfamily, calculate positive or negative emission credits relative to the otherwise applicable emission standard. Calculate positive emission credits for a family or subfamily that has an FEL below the standard. Calculate negative emission credits for a family or subfamily that has an FEL above the standard. Sum your positive and negative credits for the model year before rounding. Round the sum of emission credits to the nearest megagram (Mg), using consistent units with the following equation:

$$\text{Emission credits (Mg)} = (\text{Std} - \text{FEL}) \cdot \text{PL} \cdot \text{Volume} \cdot \text{UL} \cdot 10^{-6}$$

Where:

Std = the emission standard associated with the specific regulatory subcategory (g/ton-mile).
[For credits generated on all model year 2027 and later vocational vehicles with tailpipe CO₂](#)

~~emissions deemed to be zero under 40 CFR 1037.150(f), use the emission standard in § 1037.105 that applies for the compression ignition multi-purpose subcategory for the corresponding vehicle weight class.~~

FEL = the family emission limit for the vehicle subfamily (g/ton-mile).

PL = standard payload, in tons.

Volume = U.S.-directed production volume of the vehicle subfamily, subject to the exclusions described in paragraph (c) of this section. For example, if you produce three configurations with the same FEL, the subfamily production volume would be the sum of the production volumes for these three configurations.

UL = useful life of the vehicle, in miles, as described in §§ 1037.105 and 1037.106. ~~Use 250,000 miles for trailers.~~

(c) Compliance with the requirements of this subpart is determined at the end of the model year by calculating emission credits based on actual production volumes, excluding any of the following engines/vehicles: ~~As described in § 1037.730, compliance with the requirements of this subpart is determined at the end of the model year based on actual U.S.-directed production volumes. Keep appropriate records to document these production volumes. Do not include any of the following vehicles to calculate emission credits:~~

- (1) Vehicles that you do not certify to the CO₂ standards of this part because they are permanently exempted under subpart G of this part or under 40 CFR part 1068.
- (2) Exported vehicles even if they are certified under this part and labeled accordingly.
- (3) Vehicles not subject to the requirements of this part, such as those excluded under § 1037.5.
- (4) Any other vehicles, where we indicate elsewhere in this part 1037 that they are not to be included in the calculations of this subpart.

§ 1037.710 Averaging.

(a) Averaging is the exchange of emission credits among your vehicle families. You may average emission credits only within the same averaging set, except as specified in § 1037.740.

(b) You may certify one or more vehicle families (or subfamilies) to an FEL above the applicable standard, subject to any applicable FEL caps and other provisions in subpart B of this part, if you show in your application for certification that your projected balance of all emission-credit transactions in that model year is greater than or equal to zero or that a negative balance is allowed under § 1037.745.

(c) If you certify a vehicle family to an FEL that exceeds the otherwise applicable standard, you must obtain enough emission credits to offset the vehicle family's deficit by the due date for the final report required in § 1037.730. The emission credits used to address the deficit may come from your other vehicle families that generate emission credits in the same model year (or from later model years as specified in § 1037.745), from emission credits you have banked from previous model years, or from emission credits generated in the same or previous model years that you obtained through trading. ~~Note that the option for using banked or traded credits does not apply for trailers.~~

§ 1037.715 Banking.

(a) Banking is the retention of surplus emission credits by the manufacturer generating the emission credits for use in future model years for averaging or trading. ~~Note that § 1037.107 does not allow banking for trailers.~~

- (b) You may designate any emission credits you plan to bank in the reports you submit under § 1037.730 as reserved credits. During the model year and before the due date for the final report, you may designate your reserved emission credits for averaging or trading.
- (c) Reserved credits become actual emission credits when you submit your final report. However, we may revoke these emission credits if we are unable to verify them after reviewing your reports or auditing your records.
- (d) Banked credits retain the designation of the averaging set in which they were generated.

§ 1037.720 Trading.

- (a) Trading is the exchange of emission credits between manufacturers, or the transfer of credits to another party to retire them. You may use traded emission credits for averaging, banking, or further trading transactions. Traded emission credits remain subject to the averaging-set restrictions based on the averaging set in which they were generated. **Note that § 1037.107 does not allow trading for trailers.**
- (b) You may trade actual emission credits as described in this subpart. You may also trade reserved emission credits, but we may revoke these emission credits based on our review of your records or reports or those of the company with which you traded emission credits. You may trade banked credits within an averaging set to any certifying manufacturer.
- (c) If a negative emission credit balance results from a transaction, both the buyer and seller are liable, except in cases we deem to involve fraud. See § 1037.255(e) for cases involving fraud. We may void the certificates of all vehicle families participating in a trade that results in a manufacturer having a negative balance of emission credits. See § 1037.745.

§ 1037.725 Required information for certification.

- (a) You must declare in your application for certification your intent to use the provisions of this subpart for each vehicle family that will be certified using the ABT program. You must also declare the FELs you select for the vehicle family or subfamily for each pollutant for which you are using the ABT program. Your FELs must comply with the specifications of subpart B of this part, including the FEL caps. FELs must be expressed to the same number of decimal places as the applicable standards.
- (b) Include the following in your application for certification:
 - (1) A statement that, to the best of your belief, you will not have a negative balance of emission credits for any averaging set when all emission credits are calculated at the end of the year; or a statement that you will have a negative balance of emission credits for one or more averaging sets but that it is allowed under § 1037.745.
 - (2) Calculations of projected emission credits (positive or negative) based on projected U.S.-directed production volumes. We may require you to include similar calculations from your other vehicle families to project your net credit balances for the model year. If you project negative emission credits for a family or subfamily, state the source of positive emission credits you expect to use to offset the negative emission credits.

§ 1037.730 ABT reports.

- (a) If you certify any vehicle families using the ABT provisions of this subpart, send us a final report by September 30 following the end of the model year.
- (b) Your report must include the following information for each vehicle family participating in the ABT program:

- (1) Vehicle-family and subfamily designations, and averaging set.
 - (2) The regulatory subcategory and emission standards that would otherwise apply to the vehicle family.
 - (3) The FEL for each pollutant. If you change the FEL after the start of production, identify the date that you started using the new FEL and/or give the vehicle identification number for the first vehicle covered by the new FEL. In this case, identify each applicable FEL and calculate the positive or negative emission credits as specified in § 1037.225.
 - (4) The projected and actual ~~U.S.-directed~~ production volumes for the model year for calculating emission credits. If you changed an FEL during the model year, identify the actual ~~U.S.-directed~~ production volume associated with each FEL.
 - (5) Useful life.
 - (6) Calculated positive or negative emission credits for the whole vehicle family. Identify any emission credits that you traded, as described in paragraph (d)(1) of this section.
 - (7) If you have a negative credit balance for the averaging set in the given model year, specify whether the vehicle family (or certain subfamilies with the vehicle family) have a credit deficit for the year. Consider for example, a manufacturer with three vehicle families (“A”, “B”, and “C”) in a given averaging set. If family A generates enough credits to offset the negative credits of family B but not enough to also offset the negative credits of family C (and the manufacturer has no banked credits in the averaging set), the manufacturer may designate families A and B as having no deficit for the model year, provided it designates family C as having a deficit for the model year.
- (c) Your report must include the following additional information:
- (1) Show that your net balance of emission credits from all your participating vehicle families in each averaging set in the applicable model year is not negative, except as allowed under § 1037.745. Your credit tracking must account for the limitation on credit life under § 1037.740(c).
 - (2) State whether you will retain any emission credits for banking. If you choose to retire emission credits that would otherwise be eligible for banking, identify the families that generated the emission credits, including the number of emission credits from each family.
 - (3) State that the report’s contents are accurate.
 - (4) Identify the technologies that make up the certified configuration associated with each vehicle identification number. You may identify this as a range of identification numbers for vehicles involving a single, identical certified configuration.
- (d) If you trade emission credits, you must send us a report within 90 days after the transaction, as follows:
- (1) As the seller, you must include the following information in your report:
 - (i) The corporate names of the buyer and any brokers.
 - (ii) A copy of any contracts related to the trade.
 - (iii) The averaging set corresponding to the vehicle families that generated emission credits for the trade, including the number of emission credits from each averaging set.
 - (2) As the buyer, you must include the following information in your report:
 - (i) The corporate names of the seller and any brokers.
 - (ii) A copy of any contracts related to the trade.
 - (iii) How you intend to use the emission credits, including the number of emission credits you intend to apply for each averaging set.
- (e) Send your reports electronically to the Designated Compliance Officer using an approved information format. If you want to use a different format, send us a written request with justification for a waiver.

(f) Correct errors in your report as follows:

- (1) If you ~~or we determine by September 30 after the end of the model year notify us by the deadline for submitting the final report~~ that errors mistakenly decreased your balance of emission credits, you may correct the errors and recalculate the balance of emission credits. If you notify us that errors mistakenly decreased your balance of emission credits after the deadline for submitting the final report, you may correct the errors and recalculate the balance of emission credits after applying a 10 percent discount to the credit correction, but only if you notify us within 24 months after the deadline for submitting the final report. You may not make these corrections for errors that are determined later than September 30 after the end of the model year. If you report a negative balance of emission credits, we may disallow corrections under this paragraph (f)(1).
- (2) If you or we determine any time that errors mistakenly increased your balance of emission credits, you must correct the errors and recalculate the balance of emission credits.

§ 1037.735 Recordkeeping.

- (a) You must organize and maintain your records as described in this section.
- (b) Keep the records required by this section for at least eight years after the due date for the final report. You may not use emission credits for any vehicles if you do not keep all the records required under this section. You must therefore keep these records to continue to bank valid credits.
- (c) Keep a copy of the reports we require in §§ 1037.725 and 1037.730.
- (d) Keep records of the vehicle identification number for each vehicle you produce. You may identify these numbers as a range. If you change the FEL after the start of production, identify the date you started using each FEL and the range of vehicle identification numbers associated with each FEL. You must also identify the purchaser and destination for each vehicle you produce to the extent this information is available.
- (e) We may require you to keep additional records or to send us relevant information not required by this section in accordance with the Clean Air Act.

§ 1037.740 Restrictions for using emission credits.

The following restrictions apply for using emission credits:

- (a) *Averaging sets.* Except as specified in [§ 1037.105\(h\)](#) and paragraph (b) of this section, emission credits may be exchanged only within an averaging set. The following principal averaging sets apply for vehicles certified to the standards of this part involving emission credits as described in this subpart:
- (1) Light HDV.
 - (2) Medium HDV.
 - (3) Heavy HDV.
 - (4) ~~Long trailers.~~
 - (5) ~~Short trailers.~~
- ~~(6)~~ Note that other separate averaging sets also apply for emission credits not related to this part. For example, vehicles certified to the greenhouse gas standards of 40 CFR [part 86, subpart S, 86.1819](#) comprise a single averaging set. Separate averaging sets also apply for engines under 40 CFR part 1036, including engines used in vehicles subject to this subpart.
- (b) *Credits from hybrid vehicles and other advanced technologies.* The following provisions apply for credits you generate under § 1037.615:

(1) Credits generated from Phase 1 vehicles may be used for any of the averaging sets identified in paragraph (a) of this section; you may also use those credits to demonstrate compliance with the CO₂ emission standards in 40 CFR [part 86, subpart S, 86.1819](#) and 40 CFR part 1036. Similarly, you may use Phase 1 advanced-technology credits generated under 40 CFR 86.1819-14(k)(7) or 40 CFR 1036.615 to demonstrate compliance with the CO₂ standards in this part. The maximum amount of advanced-technology credits generated from Phase 1 vehicles that you may bring into each of the following service class groups is 60,000 Mg per model year:

(i) Spark-ignition HDE, Light HDE, and Light HDV. This group comprises the averaging set listed in paragraph (a)(1) of this section and the averaging set listed in 40 CFR 1036.740(a)(1) and (2).

(ii) Medium HDE and Medium HDV. This group comprises the averaging sets listed in paragraph (a)(2) of this section and 40 CFR 1036.740(a)(3).

(iii) Heavy HDE and Heavy HDV. This group comprises the averaging sets listed in paragraph (a)(3) of this section and 40 CFR 1036.740(a)(4).

(iv) This paragraph (b)(1) does not limit the advanced-technology credits that can be used within a service class group if they were generated in that same service class group.

(2) Credits generated from Phase 2 [and later Phase 3](#) vehicles are subject to ~~all~~ the averaging-set restrictions that apply to other emission credits.

(c) *Credit life.* Banked credits may be used only for five model years after the year in which they are generated. For example, credits you generate in model year 2018 may be used to demonstrate compliance with emission standards only through model year 2023.

(d) *Other restrictions.* Other sections of this part specify additional restrictions for using emission credits under certain special provisions.

§ 1037.745 End-of-year CO₂ credit deficits.

Except as allowed by this section, we may void the certificate of any vehicle family certified to an FEL above the applicable standard for which you do not have sufficient credits by the deadline for submitting the final report.

(a) Your certificate for a vehicle family for which you do not have sufficient CO₂ credits will not be void if you remedy the deficit with surplus credits within three model years ~~(this applies equally for tractors, trailers, and vocational vehicles)~~. For example, if you have a credit deficit of 500 Mg for a vehicle family at the end of model year 2015, you must generate (or otherwise obtain) a surplus of at least 500 Mg in that same averaging set by the end of model year 2018.

(b) You may not bank or trade away CO₂ credits in the averaging set in any model year in which you have a deficit.

(c) You may apply only surplus credits to your deficit. You may not apply credits to a deficit from an earlier model year if they were generated in a model year for which any of your vehicle families for that averaging set had an end-of-year credit deficit.

(d) You must notify us in writing how you plan to eliminate the credit deficit within the specified time frame. If we determine that your plan is unreasonable or unrealistic, we may deny an application for certification for a vehicle family if its FEL would increase your credit deficit. We may determine that your plan is unreasonable or unrealistic based on a consideration of past and projected use of specific technologies, the historical sales mix of your vehicle models, your commitment to limit production of higher-emission vehicles, and expected access to traded credits. We may also consider your plan unreasonable if your credit deficit increases from one

model year to the next. We may require that you send us interim reports describing your progress toward resolving your credit deficit over the course of a model year.

(e) If you do not remedy the deficit with surplus credits within three model years, we may void your certificate for that vehicle family. Note that voiding a certificate applies *ab initio*. Where the net deficit is less than the total amount of negative credits originally generated by the family, we will void the certificate only with respect to the number of vehicles needed to reach the amount of the net deficit. For example, if the original vehicle family generated 500 Mg of negative credits, and the manufacturer's net deficit after three years was 250 Mg, we would void the certificate with respect to half of the vehicles in the family.

(f) For purposes of calculating the statute of limitations, the following actions are all considered to occur at the expiration of the deadline for offsetting a deficit as specified in paragraph (a) of this section:

- (1) Failing to meet the requirements of paragraph (a) of this section.
- (2) Failing to satisfy the conditions upon which a certificate was issued relative to offsetting a deficit.
- (3) Selling, offering for sale, introducing or delivering into U.S. commerce, or importing vehicles that are found not to be covered by a certificate as a result of failing to offset a deficit.

§ 1037.750 What can happen if I do not comply with the provisions of this subpart?

(a) For each vehicle family participating in the ABT program, the certificate of conformity is conditioned upon full compliance with the provisions of this subpart during and after the model year. You are responsible to establish to our satisfaction that you fully comply with applicable requirements. We may void the certificate of conformity for a vehicle family if you fail to comply with any provisions of this subpart.

(b) You may certify your vehicle family or subfamily to an FEL above an applicable standard based on a projection that you will have enough emission credits to offset the deficit for the vehicle family. See § 1037.745 for provisions specifying what happens if you cannot show in your final report that you have enough actual emission credits to offset a deficit for any pollutant in a vehicle family.

(c) We may void the certificate of conformity for a vehicle family if you fail to keep records, send reports, or give us information we request. Note that failing to keep records, send reports, or give us information we request is also a violation of 42 U.S.C. 7522(a)(2).

(d) You may ask for a hearing if we void your certificate under this section (see § 1037.820).

§ 1037.755 Information provided to the Department of Transportation.

After receipt of each manufacturer's final report as specified in § 1037.730 and completion of any verification testing required to validate the manufacturer's submitted final data, we will issue a report to the Department of Transportation with CO₂ emission information and will verify the accuracy of each manufacturer's equivalent fuel consumption data required by NHTSA under 49 CFR 535.8. We will send a report to DOT for each vehicle manufacturer based on each regulatory category and subcategory, including sufficient information for NHTSA to determine fuel consumption and associated credit values. See 49 CFR 535.8 to determine if NHTSA deems submission of this information to EPA to also be a submission to NHTSA.

Subpart I—Definitions and Other Reference Information

§ 1037.801 Definitions.

The following definitions apply to this part. The definitions apply to all subparts unless we note otherwise. All undefined terms have the meaning the Act gives to them. The definitions follow:

Act means the Clean Air Act, as amended, 42 U.S.C. 7401 - 7671q.

Adjustable parameter has the meaning given in 40 CFR 1068.30.

Adjusted Loaded Vehicle Weight means the numerical average of vehicle curb weight and GVWR.

Advanced technology means vehicle technology certified under 40 CFR 86.1819-14(k)(7), 40 CFR 1036.615, or § 1037.615.

Aftertreatment means relating to a catalytic converter, particulate filter, or any other system, component, or technology mounted downstream of the exhaust valve (or exhaust port) whose design function is to decrease emissions in the vehicle exhaust before it is exhausted to the environment. Exhaust gas recirculation (EGR) and turbochargers are not aftertreatment.

Aircraft means any vehicle capable of sustained air travel more than 100 feet off the ground.

Alcohol-fueled vehicle means a vehicle that is designed to run using an alcohol fuel. For purposes of this definition, alcohol fuels do not include fuels with a nominal alcohol content below 25 percent by volume.

Alternative fuel conversion has the meaning given for clean alternative fuel conversion in 40 CFR 85.502.

Ambulance has the meaning given in 40 CFR 86.1803.

Amphibious vehicle means a motor vehicle that is also designed for operation on water. Note that high ground clearance that enables a vehicle to drive through water rather than floating on the water does not make a vehicle amphibious.

A to B testing means testing performed in pairs to allow comparison of two vehicles or other test articles. Back-to-back tests are performed on Article A and Article B, changing only the variable(s) of interest for the two tests.

Automated manual transmission (AMT) means a transmission that operates mechanically similar to a manual transmission, except that an automated clutch actuator controlled by the onboard computer disengages and engages the drivetrain instead of a human driver. An automated manual transmission does not include a torque converter or a clutch pedal controllable by the driver.

Automatic tire inflation system means a pneumatically or electronically activated system installed on a vehicle to maintain tire pressure at a preset level. These systems eliminate the need to manually inflate tires. Note that this is different than a *tire pressure monitoring system*, which we define separately in this section.

Automatic transmission (AT) means a transmission with a torque converter (or equivalent) that uses computerize or other internal controls to shift gears in response to a single driver input for controlling vehicle speed.. Note that automatic manual transmissions are not automatic transmissions because they do not include torque converters.

Auxiliary emission control device means any element of design that senses temperature, motive speed, engine speed (r/min), transmission gear, or any other parameter for the purpose of activating, modulating, delaying, or deactivating the operation of any part of the emission control system.

Auxiliary power unit means a device installed on a vehicle that uses an engine to provide power for purposes other than to (directly or indirectly) propel the vehicle.

Averaging set has the meaning given in § 1037.701.

Axle ratio or Drive axle ratio, k_a , means the dimensionless number representing the angular speed of the transmission output shaft divided by the angular speed of the drive axle.

Basic vehicle frontal area means the area enclosed by the geometric projection of the basic vehicle along the longitudinal axis onto a plane perpendicular to the longitudinal axis of the vehicle, including tires but excluding mirrors and air deflectors. Note that in certain cases, this may refer to the combined area of a tractor and trailer.

Battery electric vehicle means a motor vehicle powered solely by an electric motor where energy for the motor is supplied by one or more batteries that receive power from an external source of electricity. Note that this definition does not include hybrid vehicles or plug-in hybrid electric vehicles.

~~*Box van has the meaning given in the definition for “trailer” in this section.*~~

Bus means a heavy-duty vehicle designed to carry more than 15 passengers. Buses may include coach buses, school buses, and urban transit buses.

Calibration means the set of specifications and tolerances specific to a particular design, version, or application of a component or assembly capable of functionally describing its operation over its working range.

Carryover means relating to certification based on emission data generated from an earlier model year.

Charge-depleting has the meaning given in 40 CFR 1066.1001.

Charge-sustaining has the meaning given in 40 CFR 1066.1001.

Coach bus means a bus designed for inter-city passenger transport. Buses with features to accommodate standing passengers are not coach buses.

Concrete mixer means a heavy-duty vehicle designed to mix and transport concrete in a permanently mounted revolving drum.

Certification means relating to the process of obtaining a certificate of conformity for a vehicle family that complies with the emission standards and requirements in this part.

Certified emission level means the highest deteriorated emission level in a vehicle subfamily for a given pollutant from either transient or steady-state testing.

Class means relating to GVWR classes ~~for vehicles other than trailers~~, as follows:

- (1) *Class 2b* means relating to heavy-duty motor vehicles at or below 10,000 pounds GVWR.
- (2) *Class 3* means relating to heavy-duty motor vehicles above 10,000 pounds GVWR but at or below 14,000 pounds GVWR.
- (3) *Class 4* means relating to heavy-duty motor vehicles above 14,000 pounds GVWR but at or below 16,000 pounds GVWR.
- (4) *Class 5* means relating to heavy-duty motor vehicles above 16,000 pounds GVWR but at or below 19,500 pounds GVWR.
- (5) *Class 6* means relating to heavy-duty motor vehicles above 19,500 pounds GVWR but at or below 26,000 pounds GVWR.
- (6) *Class 7* means relating to heavy-duty motor vehicles above 26,000 pounds GVWR but at or below 33,000 pounds GVWR.
- (7) *Class 8* means relating to heavy-duty motor vehicles above 33,000 pounds GVWR.

Complete vehicle has the meaning given in the definition for *vehicle* in this section.

Compression-ignition has the meaning given in § 1037.101.

~~*Container chassis* means a trailer designed for carrying temporarily mounted shipping containers.~~

Date of manufacture means the date on which the certifying vehicle manufacturer completes its manufacturing operations, except as follows:

- (1) Where the certificate holder is an engine manufacturer that does not manufacture the chassis, the date of manufacture of the vehicle is based on the date assembly of the vehicle is completed.
- (2) We may approve an alternate date of manufacture based on the date on which the certifying (or primary) manufacturer completes assembly at the place of main assembly, consistent with the provisions of § 1037.601 and 49 CFR 567.4.

Day cab means a type of tractor cab that is not a sleeper cab or a heavy-haul tractor cab.

Designated Compliance Officer means one of the following:

- (1) For compression-ignition engines, *Designated Compliance Officer* means Director, Diesel Engine Compliance Center, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; complianceinfo@epa.gov; www.epa.gov/ve-certification.
- (2) For spark-ignition engines, *Designated Compliance Officer* means Director, Gasoline Engine Compliance Center, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; complianceinfo@epa.gov; www.epa.gov/ve-certification.

Deteriorated emission level means the emission level that results from applying the appropriate deterioration factor to the official emission result of the emission-data vehicle. Note that where no deterioration factor applies, references in this part to the *deteriorated emission level* mean the

official emission result.

Deterioration factor means the relationship between the highest emissions during the useful life and emissions at the low-hour test point, expressed in one of the following ways:

- (1) For multiplicative deterioration factors, the ratio of the highest emissions to emissions at the low-hour test point.
- (2) For additive deterioration factors, the difference between the highest emissions and emissions at the low-hour test point.

Diesel exhaust fluid (DEF) means a liquid reducing agent (other than the engine fuel) used in conjunction with selective catalytic reduction to reduce NO_x emissions. *Diesel exhaust fluid* is generally understood to be an aqueous solution of urea conforming to the specifications of ISO 22241.

Drayage tractor means a tractor that is intended for service in a port or intermodal railyard, with multiple design features consistent with that intent, such as a cab with only a single seat, rear cab entry, a raisable fifth wheel, a solid-mounted rear suspension, and a maximum speed at or below 54 mi/hr.

Drive idle means idle operation during which the vehicle operator remains in the vehicle cab, as evidenced by engaging the brake or clutch pedals, or by other indicators we approve.

Driver model means an automated controller that simulates a person driving a vehicle.

Dual-clutch transmission (DCT) means a transmission that operates similar to an automated manual transmission, but with two clutches that allow the transmission to maintain positive torque to the drive axle during a shift.

Dual-fuel means relating to a vehicle or engine designed for operation on two different fuels but not on a continuous mixture of those fuels. For purposes of this part, such a vehicle or engine remains a dual-fuel vehicle or engine even if it is designed for operation on three or more different fuels.

~~*Electric vehicle* means a motor vehicle that does not include an engine, and is powered solely by an external source of electricity and/or solar power. Note that this definition does not include hybrid electric vehicles or fuel cell vehicles that use a chemical fuel such as gasoline, diesel fuel, or hydrogen. Electric vehicles may also be referred to as all electric vehicles to distinguish them from hybrid vehicles.~~

Electronic control module has the meaning given in 40 CFR 1065.1001.

Emergency vehicle means a vehicle that is an ambulance or a fire truck.

Emission control system means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from a vehicle.

Emission-data component means a vehicle component that is tested for certification. This includes vehicle components tested to establish deterioration factors.

Emission-data vehicle means a vehicle (or vehicle component) that is tested for certification.

This includes vehicles tested to establish deterioration factors.

Emission-related component has the meaning given in 40 CFR part 1068, appendix A.

Emission-related maintenance means maintenance that substantially affects emissions or is likely to substantially affect emission deterioration.

Excluded means relating to vehicles that are not subject to some or all of the requirements of this part as follows:

- (1) A vehicle that has been determined not to be a “motor vehicle” is excluded from this part.
- (2) Certain vehicles are excluded from the requirements of this part under § 1037.5.
- (3) Specific regulatory provisions of this part may exclude a vehicle generally subject to this part from one or more specific standards or requirements of this part.

Exempted has the meaning given in 40 CFR 1068.30. Note that exempted vehicles are not considered to be excluded.

Extended idle means tractor idle operation during which the engine is operating to power accessories for a sleeper compartment or other passenger compartment. Although the vehicle is generally parked during extended idle, the term “parked idle” generally refers to something different than extended idle.

Family emission limit (FEL) means an emission level declared by the manufacturer to serve in place of an otherwise applicable emission standard under the ABT program in subpart H of this part. The *family emission limit* must be expressed to the same number of decimal places as the emission standard it replaces. Note that an FEL may apply as a “subfamily” emission limit.

Final drive ratio, k_a , means the dimensionless number representing the angular speed of the transmission input shaft divided by the angular speed of the drive axle when the vehicle is operating in its highest available gear. The *final drive ratio* is the transmission gear ratio (in the highest available gear) multiplied by the drive axle ratio.

Fire truck has the meaning given in 40 CFR 86.1803.

~~*Flatbed trailer* means a trailer designed to accommodate side loading cargo onto a single, continuous load-bearing surface that runs from the rear of the trailer to at least the trailer’s kingpin. This includes trailers that use curtains, straps, or other devices to restrain or protect cargo while underway. It also may include similar trailers that have one or more side walls without completely enclosing the cargo space. For purposes of this definition, disregard any ramps, moveable platforms, or other rear-mounted equipment or devices designed to assist with loading the trailer.~~

Flexible-fuel means relating to an engine designed for operation on any mixture of two or more different fuels.

Fuel cell electric vehicle means a motor vehicle powered solely by an electric motor where energy for the motor is supplied by hydrogen fuel cells. Fuel cell electric vehicles may include energy storage from the fuel cells or from regenerative braking in a battery.

Fuel system means all components involved in transporting, metering, and mixing the fuel from

the fuel tank to the combustion chamber(s), including the fuel tank, fuel pump, fuel filters, fuel lines, carburetor or fuel-injection components, and all fuel-system vents. It also includes components for controlling evaporative and refueling emissions, such as fuel caps, purge valves, and carbon canisters.

Fuel type means a general category of fuels such as diesel fuel or natural gas. There can be multiple grades within a single fuel type, such as high-sulfur or low-sulfur diesel fuel.

Gaseous fuel means a fuel that has a boiling point below 20 °C.

Gear ratio or Transmission gear ratio, k_g , means the dimensionless number representing the angular speed of the transmission's input shaft divided by the angular speed of the transmission's output shaft when the transmission is operating in a specific gear.

Glider kit means either of the following:

- (1) A new vehicle that is incomplete because it lacks an engine, transmission, and/or axle(s).
- (2) Any other new equipment that is substantially similar to a complete motor vehicle and is intended to become a complete motor vehicle with a previously used engine (including a rebuilt or remanufactured engine). For example, incomplete heavy-duty tractor assemblies that are produced on the same assembly lines as complete tractors and that are made available to secondary vehicle manufacturers to complete assembly by installing used/remanufactured engines, transmissions and axles are glider kits.

Glider vehicle means a new motor vehicle produced from a glider kit, or otherwise produced as a new motor vehicle with a with a used/remanufactured engine.

Good engineering judgment has the meaning given in 40 CFR 1068.30. See 40 CFR 1068.5 for the administrative process we use to evaluate good engineering judgment.

Greenhouse gas Emissions Model (GEM) means the GEM simulation tool described in § 1037.520 (incorporated by reference, [see-in](#) § 1037.810). Note that an updated version of GEM applies starting in model year 2021.

Gross axle weight rating (GAWR) means the value specified by the vehicle manufacturer as the maximum weight of a loaded axle or set of axles, consistent with good engineering judgment.

Gross combination weight rating (GCWR) means the value specified by the vehicle manufacturer as the maximum weight of a loaded vehicle and trailer, consistent with good engineering judgment. For example, compliance with SAE J2807 is generally considered to be consistent with good engineering judgment, especially for Class 3 and smaller vehicles.

Gross vehicle weight rating (GVWR) means the value specified by the vehicle manufacturer as the maximum design loaded weight of a single vehicle, consistent with good engineering judgment.

Heavy-duty engine means any engine used for (or for which the engine manufacturer could reasonably expect to be used for) motive power in a heavy-duty vehicle.

Heavy-duty vehicle means any ~~trailer and any other~~ motor vehicle that has a GVWR above 8,500 pounds. An incomplete vehicle is also a heavy-duty vehicle if it has a curb weight above 6,000

pounds or a basic vehicle frontal area greater than 45 square feet.

Heavy-haul tractor means a tractor with GCWR greater than or equal to 120,000 pounds. A heavy-haul tractor is not a vocational tractor in Phase 2 ~~and later Phase 3.~~

High-strength steel has the meaning given in § 1037.520.

~~*Hybrid* has the meaning given in 40 CFR 1036.801. Note that a hybrid vehicle is a vehicle with a hybrid engine or other hybrid powertrain (including a hybrid engine). This includes plug-in hybrid electric vehicles. Hybrid engine or hybrid powertrain means an engine or powertrain that includes energy storage features other than a conventional battery system or conventional flywheel. Supplemental electrical batteries and hydraulic accumulators are examples of hybrid energy storage systems. Note other examples of systems that qualify as hybrid engines or powertrains are systems that recover kinetic energy and use it to power an electric heater in the aftertreatment. Note that certain provisions in this part treat hybrid engines and hybrid powertrains intended for vehicles that include regenerative braking different than those intended for vehicles that do not include regenerative braking.~~

~~*Hybrid vehicle* means a vehicle that includes energy storage features (other than a conventional battery system or conventional flywheel) in addition to an internal combustion engine or other engine using consumable chemical fuel. Supplemental electrical batteries and hydraulic accumulators are examples of hybrid energy storage systems. Note other examples of systems that qualify as hybrid engines or powertrains are systems that recover kinetic energy and use it to power an electric heater in the aftertreatment. Note that certain provisions in this part treat hybrid vehicles that include regenerative braking different than those that do not include regenerative braking.~~

Hydrocarbon (HC) means the hydrocarbon group on which the emission standards are based for each fuel type. For alcohol-fueled vehicles, HC means nonmethane hydrocarbon equivalent (NMHCE) for exhaust emissions and total hydrocarbon equivalent (THCE) for evaporative and emissions. For all other vehicles, HC means nonmethane hydrocarbon (NMHC) for exhaust emissions and total hydrocarbon (THC) for evaporative and refueling emissions.

Identification number means a unique specification (for example, a model number/serial number combination) that allows someone to distinguish a particular vehicle from other similar vehicles.

Idle operation means any operation other than PTO operation during which the vehicle speed is zero. Idle operation may be “Drive idle” or “Parked idle” (as defined in this section).

Incomplete vehicle has the meaning given in the definition of *vehicle* in this section.

Innovative technology means technology certified under § 1037.610 (also described as “off-cycle technology”).

Light-duty truck ~~has the meaning given in 40 CFR 86.1803-01 means any motor vehicle that is not a heavy duty vehicle, but is:~~

~~(1) Designed primarily for purposes of transportation of property or is a derivation of such a vehicle; or~~

~~(2) Designed primarily for transportation of persons and has a capacity of more than 12 persons;~~
~~or~~

~~(3) Available with special features enabling off-street or off-highway operation and use.~~

Light-duty vehicle ~~has the meaning given in 40 CFR 86.1803-01 means a passenger car or passenger car derivative capable of seating 12 or fewer passengers.~~

Low-mileage means relating to a vehicle with stabilized emissions and represents the undeteriorated emission level. This would generally involve approximately 4000 miles of operation.

Low rolling resistance tire means a tire on a vocational vehicle with a TRRL at or below of 7.7 N/kN, a steer tire on a tractor with a TRRL at or below 7.7 N/kN, a drive tire on a tractor with a TRRL at or below 8.1 N/kN, ~~a tire on a non-box trailer with a TRRL at or below of 6.5 N/kN, or a tire on a box van with a TRRL at or below of 6.0 N/kN.~~

Manual transmission (MT) means a transmission that requires the driver to shift the gears and manually engage and disengage the clutch.

Manufacture means the physical and engineering process of designing, constructing, and/or assembling a vehicle.

Manufacturer has the meaning given in section 216(1) of the Act. In general, this term includes any person who manufactures or assembles a vehicle (including ~~a trailer or another an~~ incomplete vehicle) for sale in the United States or otherwise introduces a new motor vehicle into commerce in the United States. This includes importers who import vehicles for resale, entities that manufacture glider kits, and entities that assemble glider vehicles.

Medium-duty passenger vehicle (MDPV) has the meaning given in 40 CFR 86.1803.

Model year means one of the following for compliance with this part. Note that manufacturers may have other model year designations for the same vehicle for compliance with other requirements or for other purposes:

(1) For ~~tractors and vocational~~ vehicles with a date of manufacture on or after January 1, 2021, *model year* means the manufacturer's annual new model production period based on the vehicle's date of manufacture, where the model year is the calendar year corresponding to the date of manufacture, except as follows:

(i) The vehicle's model year may be designated as the year before the calendar year corresponding to the date of manufacture if the engine's model year is also from an earlier year. You may ask us to extend your prior model year certificate to include such vehicles. Note that § 1037.601(a)(2) limits the extent to which vehicle manufacturers may install engines built in earlier calendar years.

(ii) The vehicle's model year may be designated as the year after the calendar year corresponding to the vehicle's date of manufacture. For example, a manufacturer may produce a new vehicle by installing the engine in December 2023 and designating it as a model year 2024 vehicle.

(2) For ~~trailers and for~~ Phase 1 ~~tractors and vocational~~ vehicles with a date of manufacture before January 1, 2021, *model year* means the manufacturer's annual new model production

period, except as restricted under this definition and 40 CFR part 85, subpart X. It must include January 1 of the calendar year for which the model year is named, may not begin before January 2 of the previous calendar year, and it must end by December 31 of the named calendar year. The model year may be set to match the calendar year corresponding to the date of manufacture.

(i) The manufacturer who holds the certificate of conformity for the vehicle must assign the model year based on the date when its manufacturing operations are completed relative to its annual model year period. In unusual circumstances where completion of your assembly is delayed, we may allow you to assign a model year one year earlier, provided it does not affect which regulatory requirements will apply.

(ii) Unless a vehicle is being shipped to a secondary vehicle manufacturer that will hold the certificate of conformity, the model year must be assigned prior to introduction of the vehicle into U.S. commerce. The certifying manufacturer must redesignate the model year if it does not complete its manufacturing operations within the originally identified model year. A vehicle introduced into U.S. commerce without a model year is deemed to have a model year equal to the calendar year of its introduction into U.S. commerce unless the certifying manufacturer assigns a later date.

Motor home has the meaning given in 49 CFR 571.3.

Motor vehicle has the meaning given in 40 CFR 85.1703.

Multi-Purpose means relating to the Multi-Purpose duty cycle as specified in § 1037.510.

Neat has the meaning given in 40 CFR 1065.1001.

Neutral coasting means a vehicle technology that automatically puts the transmission in neutral when the when operator demand is zero while the vehicle has minimal power demand while is in motion, such as driving downhill.

Neutral idle means a vehicle technology that automatically puts the transmission in neutral when the vehicle is stopped, as described in § 1037.660(a).

New motor vehicle has the meaning given in the Act. It generally means a motor vehicle meeting the criteria of either paragraph (1) or (2) of this definition. *New motor vehicles* may be complete or incomplete.

(1) A motor vehicle for which the ultimate purchaser has never received the equitable or legal title is a *new motor vehicle*. This kind of vehicle might commonly be thought of as "brand new" although a *new motor vehicle* may include previously used parts. For example, vehicles commonly known as "glider kits," "glider vehicles," or "gliders" are new motor vehicles. Under this definition, the vehicle is new from the time it is produced until the ultimate purchaser receives the title or places it into service, whichever comes first.

(2) An imported heavy-duty motor vehicle originally produced after the 1969 model year is a *new motor vehicle*.

Noncompliant vehicle means a vehicle that was originally covered by a certificate of conformity, but is not in the certified configuration or otherwise does not comply with the conditions of the certificate.

Nonconforming vehicle means a vehicle not covered by a certificate of conformity that would otherwise be subject to emission standards.

Nonmethane hydrocarbon (NMHC) means the sum of all hydrocarbon species except methane, as measured according to 40 CFR part 1065.

Nonmethane hydrocarbon equivalent (NMHCE) has the meaning given in 40 CFR 1065.1001.

Off-cycle technology means technology certified under § 1037.610 (also described as “innovative technology”).

Official emission result means the measured emission rate for an emission-data vehicle on a given duty cycle before the application of any required deterioration factor, but after the applicability of regeneration adjustment factors.

Owners manual means a document or collection of documents prepared by the vehicle manufacturer for the owners or operators to describe appropriate vehicle maintenance, applicable warranties, and any other information related to operating or keeping the vehicle. The owners manual is typically provided to the ultimate purchaser at the time of sale. The owners manual may be in paper or electronic format.

Oxides of nitrogen has the meaning given in 40 CFR 1065.1001.

Parked idle means idle operation during which the transmission is set to park, or the transmission is in neutral with the parking brake engaged. Although this idle may occur for extended periods, the term “extended idle” refers to tractor operation in which the engine is operating to power accessories for a sleeper compartment or other passenger compartment.

Particulate trap means a filtering device that is designed to physically trap all particulate matter above a certain size.

Percent (%) has the meaning given in 40 CFR 1065.1001. Note that this means percentages identified in this part are assumed to be infinitely precise without regard to the number of significant figures. For example, one percent of 1,493 is 14.93.

Petroleum means gasoline or diesel fuel or other fuels normally derived from crude oil. This does not include methane or liquefied petroleum gas.

Phase 1 means relating to the Phase 1 standards specified in §§ 1037.105 and 1037.106. For example, a vehicle subject to the Phase 1 standards is a Phase 1 vehicle. ~~Note that there are no Phase 1 standards for trailers.~~

Phase 2 means relating to the Phase 2 standards specified in §§ 1037.105 ~~through 1037.107~~ and 1037.106.

Phase 3 means relating to the Phase 3 standards specified in §§ 1037.105 and 1037.106.

Placed into service means put into initial use for its intended purpose, excluding incidental use by the manufacturer or a dealer.

Plug-in hybrid electric vehicle means a hybrid vehicle that has the capability to charge one or more batteries from an external source of electricity while the vehicle is parked.

Power take-off (PTO) means a secondary engine shaft (or equivalent) that provides substantial auxiliary power for purposes unrelated to vehicle propulsion or normal vehicle accessories such as air conditioning, power steering, and basic electrical accessories. A typical PTO uses a secondary shaft on the engine to transmit power to a hydraulic pump that powers auxiliary equipment, such as a boom on a bucket truck. You may ask us to consider other equivalent auxiliary power configurations (such as those with hybrid vehicles) as power take-off systems.

Preliminary approval means approval granted by an authorized EPA representative prior to submission of an application for certification, consistent with the provisions of § 1037.210 ~~or 1037.211~~.

Rechargeable Energy Storage System (RESS) has the meaning given in 40 CFR 1065.1001.

Refuse hauler means a heavy-duty vehicle whose primary purpose is to collect, compact, and transport solid waste, including recycled solid waste.

Regional means relating to the Regional duty cycle as specified in § 1037.510.

Regulatory subcategory has the meaning given in § 1037.230.

Relating to as used in this section means relating to something in a specific, direct manner. This expression is used in this section only to define terms as adjectives and not to broaden the meaning of the terms.

Revoke has the meaning given in 40 CFR 1068.30.

Roof height means the maximum height of a vehicle (rounded to the nearest inch), excluding narrow accessories such as exhaust pipes and antennas, but including any wide accessories such as roof fairings. Measure roof height of the vehicle configured to have its maximum height that will occur during actual use, with properly inflated tires and no driver, passengers, or cargo onboard. *Roof height* may also refer to the following categories:

- (1) *Low-roof* means relating to a vehicle with a roof height of 120 inches or less.
- (2) *Mid-roof* means relating to a vehicle with a roof height of 121 to 147 inches.
- (3) *High-roof* means relating to a vehicle with a roof height of 148 inches or more.

Round has the meaning given in 40 CFR 1065.1001.

Scheduled maintenance means adjusting, repairing, removing, disassembling, cleaning, or replacing components or systems periodically to keep a part or system from failing, malfunctioning, or wearing prematurely. It also may mean actions you expect are necessary to correct an overt indication of failure or malfunction for which periodic maintenance is not appropriate.

School bus has the meaning given in 49 CFR 571.3.

Secondary vehicle manufacturer anyone that produces a vehicle by modifying a complete vehicle or completing the assembly of a partially complete vehicle. For the purpose of this definition,

“modifying” generally does not include making changes that do not remove a vehicle from its original certified configuration. However, custom sleeper modifications and alternative fuel conversions that change actual vehicle aerodynamics are considered to be modifications, even if they are permitted without recertification. This definition applies whether the production involves a complete or partially complete vehicle and whether the vehicle was previously certified to emission standards or not. Manufacturers controlled by the manufacturer of the base vehicle (or by an entity that also controls the manufacturer of the base vehicle) are not secondary vehicle manufacturers; rather, both entities are considered to be one manufacturer for purposes of this part.

Sleeper cab means a type of tractor cab that has a compartment behind the driver’s seat intended to be used by the driver for sleeping, and is not a heavy-haul tractor cab. This includes cabs accessible from the driver’s compartment and those accessible from outside the vehicle.

Small manufacturer means a manufacturer meeting the small business criteria specified in 13 CFR 121.201 for ~~heavy-duty truck manufacturing, vocational vehicles and tractors~~ (NAICS code 336120) ~~or for trailers (NAICS code 336212). Apply the small business criteria for NAICS code 336120 for vocational vehicles and tractors and 336212 for trailers.~~ The employee ~~and revenue~~ limits ~~applies~~ to the total number employees ~~and total revenue together~~ for all affiliated companies (as defined in 40 CFR 1068.30).

Spark-ignition has the meaning given in § 1037.101.

Standard payload means the payload assumed for each vehicle, in tons, for modeling and calculating emission credits, as follows:

- (1) For vocational vehicles:
 - (i) 2.85 tons for Light HDV.
 - (ii) 5.6 tons for Medium HDV.
 - (iii) 7.5 tons for Heavy HDV.
- (2) For tractors:
 - (i) 12.5 tons for Class 7.
 - (ii) 19 tons for Class 8, other than heavy-haul tractors.
 - (iii) 43 tons for heavy-haul tractors.
- ~~(3) For trailers:
 - ~~(i) 10 tons for short box vans.~~
 - ~~(ii) 19 tons for other trailers.~~~~

~~*Standard tractor* has the meaning given in § 1037.501.~~

Standard trailer has the meaning given in § 1037.501.

State of certified energy (SOCE) means a value representing the amount of usable battery energy available at a specific point in time relative to the certified value for a new battery, expressed as a percentage of the certified usable battery energy.

Stop-start means a vehicle technology that automatically turns the engine off when the vehicle is stopped, as described in § 1037.660(a).

Suspend has the meaning given in 40 CFR 1068.30.

~~Tank trailer means a trailer designed to transport liquids or gases.~~

Test sample means the collection of vehicles or components selected from the population of a vehicle family for emission testing. This may include testing for certification, production-line testing, or in-use testing.

Test vehicle means a vehicle in a test sample.

Test weight means the vehicle weight used or represented during testing.

Tire pressure monitoring system (TPMS) is a vehicle system that monitors air pressure in each tire and alerts the operator when tire pressure falls below a specified value.

Tire rolling resistance level (TRRL) means a value with units of N/kN that represents the rolling resistance of a tire configuration. TRRLs are used as modeling inputs under §§ ~~1037.515 and~~ 1037.520. Note that a manufacturer may use the measured value for a tire configuration's coefficient of rolling resistance, or assign some higher value.

~~Tonne means metric ton, which is exactly 1000 kg.~~

~~Ton means a short ton, which is exactly 2000 pounds.~~

Total hydrocarbon has the meaning given in 40 CFR 1065.1001. This generally means the combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon, expressed as a hydrocarbon with an atomic hydrogen-to-carbon ratio of 1.85:1.

Total hydrocarbon equivalent has the meaning given in 40 CFR 1065.1001. This generally means the sum of the carbon mass contributions of non-oxygenated hydrocarbon, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust hydrocarbon from petroleum-fueled vehicles. The atomic hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

Tractor has the meaning given for “truck tractor” in 49 CFR 571.3. This includes most heavy-duty vehicles specifically designed for the primary purpose of pulling trailers, but does not include vehicles designed to carry other loads. For purposes of this definition “other loads” would not include loads carried in the cab, sleeper compartment, or toolboxes. Examples of vehicles that are similar to tractors but that are not *tractors* under this part include dromedary tractors, automobile haulers, straight trucks with trailers hitches, and tow trucks. Note that the provisions of this part that apply for tractors do not apply for tractors that are classified as vocational tractors under § 1037.630.

Trailer means a piece of equipment designed for carrying cargo and for being drawn by a tractor when coupled to the tractor's fifth wheel. ~~These trailers may be known commercially as semi-trailers or truck trailers. This definition excludes equipment that serve similar purposes but are not intended to be pulled by a tractor, whether or not they are known commercially as trailers. Trailers may be divided into different types and categories as described in paragraphs (1) through (4) of this definition. The types of equipment identified in paragraph (5) of this definition are not trailers for purposes of this part.~~

~~(1) Box vans are trailers with enclosed cargo space that is permanently attached to the chassis,~~

~~with fixed sides, nose, and roof. Tank trailers are not box vans.~~

~~(2) Box vans with self-contained HVAC systems are refrigerated vans. Note that this includes systems that provide cooling, heating, or both. All other box vans are dry vans.~~

~~(3) Trailers that are not box vans are non-box trailers. Note that the standards for non-box trailers in this part 1037 apply only to flatbed trailers, tank trailers, and container chassis.~~

~~(4) Box vans with length at or below 50.0 feet are short box vans. Other box vans are long box vans.~~

~~(5) The following types of equipment are not trailers for purposes of this part 1037:~~

~~(i) Containers that are not permanently mounted on chassis.~~

~~(ii) Dollies used to connect tandem trailers.~~

Ultimate purchaser means, with respect to any new vehicle, the first person who in good faith purchases such new vehicle for purposes other than resale.

United States has the meaning given in 40 CFR 1068.30.

Upcoming model year means for a vehicle family the model year after the one currently in production.

Urban means relating to the Urban duty cycle as specified in § 1037.510.

U.S.-directed production volume means the number of vehicle units, subject to the requirements of this part, produced by a manufacturer for which the manufacturer has a reasonable assurance that sale was or will be made to ultimate purchasers in the United States. ~~Note that this includes This does not include vehicles certified to state emission standards that are different than the emission standards in this part.~~

Usable battery energy (UBE) means the energy the battery supplies from the start of the certification test procedure until the applicable break-off criterion. The regulation depends on certified and aged values of UBE to set battery monitoring requirements as described in § 1037.115(f).

Useful life means the period during which a vehicle is required to comply with all applicable emission standards.

Vehicle means equipment intended for use on highways that meets at least one of the criteria of paragraph (1) of this definition, as follows:

(1) The following equipment are vehicles:

(i) A piece of equipment that is intended for self-propelled use on highways becomes a vehicle when it includes at least an engine, a transmission, and a frame. (Note: For purposes of this definition, any electrical, mechanical, and/or hydraulic devices attached to engines for the purpose of powering wheels are considered to be transmissions.)

(ii) A piece of equipment that is intended for self-propelled use on highways becomes a vehicle when it includes a passenger compartment attached to a frame with one or more axles.

~~(iii) Trailers. A trailer becomes a vehicle when it has a frame with one or more axles attached.~~

(2) Vehicles ~~other than trailers~~ may be complete or incomplete vehicles as follows:

(i) A *complete vehicle* is a functioning vehicle that has the primary load carrying device or container (or equivalent equipment) attached when it is first sold as a vehicle.

Examples of equivalent equipment would include fifth wheel trailer hitches, firefighting equipment, and utility booms.

(ii) An *incomplete vehicle* is a vehicle that is not a complete vehicle. Incomplete vehicles may also be cab-complete vehicles. This may include vehicles sold to secondary vehicle manufacturers.

~~(iii) The primary use of the terms “complete vehicle” and “incomplete vehicle” are to distinguish whether a vehicle is complete when it is first sold as a vehicle.~~

~~(iv)~~ You may ask us to allow you to certify a vehicle as incomplete if you manufacture the engines and sell the unassembled chassis components, as long as you do not produce and sell the body components necessary to complete the vehicle.

Vehicle configuration means a unique combination of vehicle hardware and calibration (related to measured or modeled emissions) within a vehicle family. Vehicles with hardware or software differences, but that have no hardware or software differences related to measured or modeled emissions may be included in the same vehicle configuration. Note that vehicles with hardware or software differences related to measured or modeled emissions are considered to be different configurations even if they have the same GEM inputs and FEL. Vehicles within a vehicle configuration differ only with respect to normal production variability or factors unrelated to measured or modeled emissions.

Vehicle family has the meaning given in § 1037.230.

Vehicle service class has the meaning given in § 1037.140. The different vehicle service classes are Light HDV, Medium HDV, and Heavy HDV.

Vehicle subfamily or *subfamily* means a subset of a vehicle family including vehicles subject to the same FEL(s).

Vocational tractor means a vehicle classified as a vocational tractor under § 1037.630.

Vocational vehicle means relating to a vehicle subject to the standards of § 1037.105 (including vocational tractors).

Void has the meaning given in 40 CFR 1068.30.

Volatile liquid fuel means any fuel other than diesel or biodiesel that is a liquid at atmospheric pressure and has a Reid Vapor Pressure higher than 2.0 pounds per square inch.

We (us, our) means the Administrator of the Environmental Protection Agency and any authorized representatives.

§ 1037.805 Symbols, abbreviations, and acronyms.

The procedures in this part generally follow either the International System of Units (SI) or the United States customary units, as detailed in NIST Special Publication 811 (incorporated by reference, [see in](#) § 1037.810). See 40 CFR 1065.20 for specific provisions related to these conventions. This section summarizes the way we use symbols, units of measure, and other abbreviations.

(a) *Symbols for chemical species.* This part uses the following symbols for chemical species and exhaust constituents:

TABLE 1 TO PARAGRAPH (a) OF § 1037.805—SYMBOLS FOR CHEMICAL SPECIES AND EXHAUST CONSTITUENTS

Symbol	Species
C	carbon.
CH ₄	methane.
CO	carbon monoxide.
CO ₂	carbon dioxide.
H ₂ O	water.
HC	hydrocarbon.
NMHC	nonmethane hydrocarbon.
NMHCE	nonmethane hydrocarbon equivalent.
NO	nitric oxide.
NO ₂	nitrogen dioxide.
NO _x	oxides of nitrogen.
N ₂ O	nitrous oxide.
PM	particulate matter.
THC	total hydrocarbon.
THCE	total hydrocarbon equivalent.

(b) *Symbols for quantities.* This part 1037 uses the following symbols and units of measure for various quantities:

TABLE 2 TO PARAGRAPH (b) OF § 1037.805—SYMBOLS FOR QUANTITIES

Symbol	Quantity	Unit	Unit symbol	Unit in terms of SI base units
A	vehicle frictional load	pound force or newton	lbf or N	$\text{kg}\cdot\text{m}\cdot\text{s}^{-2}$.
a	axle position regression coefficient			
α	atomic hydrogen-to-carbon ratio	mole per mole	mol/mol	1.
α	axle position regression coefficient			
α_0	intercept of air speed correction			
α_1	slope of air speed correction			
a_g	acceleration of Earth's gravity	meters per second squared	m/s^2	$\text{m}\cdot\text{s}^{-2}$.
a_0	intercept of least squares regression			
a_1	slope of least squares regression			
B	vehicle load from drag and rolling resistance	pound force per mile per hour or newton second per meter	lbf/(mi/hr) or $\text{N}\cdot\text{s}/\text{m}$	$\text{kg}\cdot\text{s}^{-1}$.
b	axle position regression coefficient			
β	atomic oxygen-to-carbon ratio	mole per mole	mol/mol	1.
β	axle position regression coefficient			
β_0	intercept of air direction correction			
β_1	slope of air direction correction			
C	vehicle-specific aerodynamic effects	pound force per mile per hour squared or newton-second squared per meter squared	lbf/ mph^2 or $\text{N}\cdot\text{s}^2/\text{m}^2$	$\text{kg}\cdot\text{m}^{-1}$.
c	axle position regression coefficient			
c_i	axle test regression coefficients			
C_i	constant			
$\Delta C_d A$	differential drag area	meter squared	m^2	m^2 .
$C_d A$	drag area	meter squared	m^2	m^2 .
C_d	drag coefficient			
CF	correction factor			
C_r	coefficient of rolling resistance	newton per kilonewton	N/kN	10^{-3} .
D	distance	miles or meters	mi or m	m.
e	mass-weighted emission result	grams per ton-mile	$\text{g}/\text{ton}\cdot\text{mi}$	$\text{g}/\text{kg}\cdot\text{km}$.
Eff	efficiency			
F	adjustment factor			
F	force	pound force or newton	lbf or N	$\text{kg}\cdot\text{m}\cdot\text{s}^{-2}$.
f_n	angular speed (shaft)	revolutions per minute	r/min	$\pi\cdot 30\cdot\text{s}^{-1}$.
G	road grade	percent	%	10^{-2} .
g	gravitational acceleration	meters per second squared	m/s^2	$\text{m}\cdot\text{s}^{-2}$.

h	elevation or height	meters	m	m.
i	indexing variable			
k_a	drive axle ratio			1.
k_d	transmission gear ratio			
k_{topgear}	highest available transmission gear			
L	load over axle	pound force or newton	lbf or N	$\text{kg}\cdot\text{m}\cdot\text{s}^{-2}$.
m	mass	pound mass or kilogram	lbm or kg	kg.
M	molar mass	gram per mole	g/mol	$10^{-3}\cdot\text{kg}\cdot\text{mol}^{-1}$.
M	vehicle mass	kilogram	kg	kg.
M_e	vehicle effective mass	kilogram	kg	kg.
M_{rotating}	inertial mass of rotating components	kilogram	kg	kg.
N	total number in series			
n	number of tires			
\dot{n}	amount of substance rate	mole per second	mol/s	$\text{mol}\cdot\text{s}^{-1}$.
P	power	kilowatt	kW	$10^3\cdot\text{m}^2\cdot\text{kg}\cdot\text{s}^{-3}$.
p	pressure	pascal	Pa	$\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-2}$.
ρ	mass density	kilogram per cubic meter	kg/m^3	$\text{kg}\cdot\text{m}^{-3}$.
PL	payload	tons	ton	kg.
ϕ	direction	degrees	$^\circ$	$^\circ$.
ψ	direction	degrees	$^\circ$	$^\circ$.
r	tire radius	meter	m	m.
r^2	coefficient of determination			
$Re^\#$	Reynolds number			
SEE	standard error of the estimate			
σ	standard deviation			
$TRPM$	tire revolutions per mile	revolutions per mile	r/mi	
$TRRL$	tire rolling resistance level	newton per kilonewton	N/kN	10^{-3} .
T	absolute temperature	kelvin	K	K.
T	Celsius temperature	degree Celsius	$^\circ\text{C}$	$\text{K} - 273.15$.
T	torque (moment of force)	newton meter	$\text{N}\cdot\text{m}$	$\text{m}^2\cdot\text{kg}\cdot\text{s}^{-2}$.
t	time	hour or second	hr or s	s.
Δt	time interval, period, 1/frequency	second	s	s.
UF	utility factor			
v	speed	miles per hour or meters per second	mi/hr or m/s	$\text{m}\cdot\text{s}^{-1}$.
w	weighting factor			
w	wind speed	miles per hour	mi/hr	$\text{m}\cdot\text{s}^{-1}$.
W	work	kilowatt-hour	$\text{kW}\cdot\text{hr}$	$3.6\cdot\text{m}^2\cdot\text{kg}\cdot\text{s}^{-1}$.
w_c	carbon mass fraction	gram per gram	g/g	1.
WR	weight reduction	pound mass	lbm	kg.
x	amount of substance mole fraction	mole per mole	mol/mol	1.

(c) *Superscripts*. This part uses the following superscripts for modifying quantity symbols:

TABLE 3 TO PARAGRAPH (C) OF § 1037.805—SUPERSCRIPTS

Superscript	Meaning
overbar (such as \bar{y})	arithmetic mean.
Double overbar (such as $\bar{\bar{y}}$)	arithmetic mean of arithmetic mean.
overdot (such as \dot{y})	quantity per unit time.

(d) *Subscripts*. This part uses the following subscripts for modifying quantity symbols:

TABLE 4 TO PARAGRAPH (d) OF § 1037.805—SUBSCRIPTS

Subscript	Meaning
±6	±6° yaw angle sweep.
A	A speed.
air	air.
aero	aerodynamic.
alt	alternative.
act	actual or measured condition.
air	air.
axle	axle.
B	B speed.
brake	brake.
C	C speed.
Ccombdry	carbon from fuel per mole of dry exhaust.
CD	charge-depleting.
circuit	circuit.
CO2DEF	CO ₂ resulting from diesel exhaust fluid decomposition.
CO2PTO	CO ₂ emissions for PTO cycle.
coastdown	coastdown.
comp	composite.
CS	charge-sustaining.
cycle	test cycle.
drive	drive axle.
drive-idle	idle with the transmission in drive.
driver	driver.
dyno	dynamometer.
effective	effective.
end	end.
eng	engine.
event	event.
fuel	fuel.
full	full.
grade	grade.
H2Oexhaustdry	H ₂ O in exhaust per mole of exhaust.
hi	high.
i	an individual of a series.
idle	idle.
in	inlet.
inc	increment.
lo	low.
loss	loss.
max	maximum.
meas	measured quantity.
med	median.
min	minimum.
moving	moving.
out	outlet.
P	power.
pair	pair of speed segments.
parked-idle	idle with the transmission in park.
partial	partial.
ploss	power loss.
plug-in	plug-in hybrid electric vehicle.
powertrain	powertrain.
PTO	power take-off.
rated	rated speed.

record	record.
ref	reference quantity.
RL	road load.
rotating	rotating.
seg	segment.
speed	speed.
spin	axle spin loss.
start	start.
steer	steer axle.
t	tire.
test	test.
th	theoretical.
total	total.
trac	traction.
trac10	traction force at 10 mi/hr.
trailer	trailer axle.
transient	transient.
TRR	tire rolling resistance.
UF	utility factor.
urea	urea.
veh	vehicle.
w	wind.
wa	wind average.
yaw	yaw angle.
ys	yaw sweep.
zero	zero quantity.

(e) *Other acronyms and abbreviations.* This part uses the following additional abbreviations and acronyms:

TABLE 5 TO PARAGRAPH (e) OF § 1037.805—OTHER ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
ABT	averaging, banking, and trading.
AECD	auxiliary emission control device.
AES	automatic engine shutdown.
APU	auxiliary power unit.
CD	charge-depleting.
CFD	computational fluid dynamics.
CFR	Code of Federal Regulations.
CITT	curb idle transmission torque.
CS	charge-sustaining.
DOT	Department of Transportation.
ECM	electronic control module.
EPA	Environmental Protection Agency.
FE	fuel economy.
FEL	Family Emission Limit.
FTP	Federal Test Procedure.
GAWR	gross axle weight rating.
GCWR	gross combination weight rating.
GEM	greenhouse gas emission model.
GHG	greenhouse gas.
GVWR	gross vehicle weight rating.
Heavy HDE	heavy heavy-duty engine (see 40 CFR 1036.140).
Heavy HDV	heavy heavy-duty vehicle (see § 1037.140).
HVAC	heating, ventilating, and air conditioning.
ISO	International Organization for Standardization.
Light HDE	light heavy-duty engine (see 40 CFR 1036.140).
Light HDV	light heavy-duty vehicle (see § 1037.140).
LLC	Low Load Cycle.
Medium HDE	medium heavy-duty engine (see 40 CFR 1036.140).
Medium HDV	medium heavy-duty vehicle (see § 1037.140).
NARA	National Archives and Records Administration.
NHTSA	National Highway Transportation Safety Administration.
PHEV	plug-in hybrid electric vehicle.
PTO	power take-off.
RESS	rechargeable energy storage system.
SAE	SAE International.
SEE	standard error of the estimate.
SET	Supplemental Emission Test.
SKU	stock-keeping unit.
Spark-ignition HDE	spark-ignition heavy-duty engine (see 40 CFR 1036.140).
TRPM	tire revolutions per mile.
TRRL	tire rolling resistance level.
U.S.C.	United States Code.
VSL	vehicle speed limiter.

(f) *Constants*. This part uses the following constants:

TABLE 6 TO PARAGRAPH (f) OF § 1037.805—CONSTANTS

Symbol	Quantity	Value
g	gravitational constant	9.80665 m·s ⁻² .
R	specific gas constant	287.058 J/(kg·K).

(g) *Prefixes*. This part uses the following prefixes to define a quantity:

TABLE 7 TO PARAGRAPH (g) OF § 1037.805—PREFIXES

Symbol	Quantity	Value
μ	micro	10 ⁻⁶
m	milli	10 ⁻³
c	centi	10 ⁻²
k	kilo	10 ³
M	mega	10 ⁶

§ 1037.810 Incorporation by reference.

Certain material is incorporated by reference into this part with the approval of the Director of the Federal Register under 5 U.S.C. 552(a) and 1 CFR part 51. To enforce any edition other than that specified in this section, EPA must publish a document in the Federal Register and the material must be available to the public. All approved incorporation by reference (IBR) material is available for inspection at EPA and at the National Archives and Records Administration (NARA). Contact EPA at: U.S. EPA, Air and Radiation Docket Center, WJC West Building, Room 3334, 1301 Constitution Ave. NW, Washington, DC 20004; www.epa.gov/dockets; (202) 202-1744. For information on inspecting this material at NARA, visit www.archives.gov/federal-register/cfr/ibr-locations.html or email fr.inspection@nara.gov. The material may be obtained from the following sources:

(a) International Organization for Standardization, Case Postale 56, CH-1211 Geneva 20, Switzerland; (41) 22749 0111; www.iso.org; or central@iso.org.

(1) ISO 28580:2009(E) “Passenger car, truck and bus tyres – Methods of measuring rolling resistance – Single point test and correlation of measurement results”, First Edition, July 1, 2009, (“ISO 28580”); IBR approved for § 1037.520(c).

(2) [Reserved]

(b) National Institute of Standards and Technology (NIST), 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070; (301) 975-6478; www.nist.gov.

(1) NIST Special Publication 811, 2008 Edition, Guide for the Use of the International System of Units (SI), Physics Laboratory, March 2008; IBR approved for § 1037.805.

(2) [Reserved]

(c) SAE International, 400 Commonwealth Dr., Warrendale, PA 15096–0001, (877) 606-7323 (U.S. and Canada) or (724) 776–4970 (outside the U.S. and Canada), www.sae.org.

(1) SAE J1025 AUG2012, Test Procedures for Measuring Truck Tire Revolutions Per Kilometer/Mile, Stabilized August 2012, (“SAE J1025”); IBR approved for § 1037.520(c).

(2) SAE J1252 JUL2012, SAE Wind Tunnel Test Procedure for Trucks and Buses, Revised July 2012, (“SAE J1252”); IBR approved for §§ 1037.525(b) [and \(c\)](#); 1037.530(a).

(3) SAE J1263 MAR2010, Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques, Revised March 2010, (“SAE J1263”); IBR approved for §§ 1037.528 introductory text, (a), (b), (c), (e), and (h); 1037.665(a).

(4) SAE J1594 JUL2010, Vehicle Aerodynamics Terminology, Revised July 2010, (“SAE J1594”); IBR approved for § 1037.530(d).

(5) SAE J2071 REV. JUN94, Aerodynamic Testing of Road Vehicles - Open Throat Wind Tunnel Adjustment, Revised June 1994, (“SAE J2071”); IBR approved for § 1037.530(b).

(6) SAE J2263 MAY2020, (R) Road Load Measurement Using Onboard Anemometry and Coastdown Techniques, Revised May 2020, (“SAE J2263”); IBR approved for §§ 1037.528 introductory text, (a), (b), (d), and (f); 1037.665(a).

(7) SAE J2343 JUL2008, Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles, Revised July 2008, (“SAE J2343”); IBR approved for § 1037.103(e).

(8) SAE J2452 ISSUED JUN1999, Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance, Issued June 1999, (“SAE J2452”); IBR approved for § 1037.528(h).

(9) ~~SAE J2841 MAR2009, Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using 2001 U.S. DOT National Household Travel Survey Data, Issued March 2009, (“SAE J2841”); IBR approved for § 1037.550(a).~~

~~(10) SAE J2966 SEP2013, Guidelines for Aerodynamic Assessment of Medium and Heavy Commercial Ground Vehicles Using Computational Fluid Dynamics, Issued September 2013, (“SAE J2966”); IBR approved for § 1037.532(a).~~

(d) U.S. EPA, Office of Air and Radiation, 2565 Plymouth Road, Ann Arbor, MI 48105; www.epa.gov; complianceinfo@epa.gov.

(1) Greenhouse gas Emissions Model (GEM), Version 2.0.1, September 2012 (“GEM version 2.0.1”); IBR approved for § 1037.520.

(2) Greenhouse gas Emissions Model (GEM) Phase 2, Version 3.0, July 2016 (“GEM Phase 2, Version 3.0”); IBR approved for § 1037.150(~~bbx~~).

(3) Greenhouse gas Emissions Model (GEM) Phase 2, Version 3.5.1, November 2020 (“GEM Phase 2, Version 3.5.1”); IBR approved for § 1037.150(~~bbx~~).

(4) Greenhouse gas Emissions Model (GEM) Phase 2, Version 4.0, April 2022 (“GEM Phase 2, Version 4.0”); IBR approved for §§ 1037.150(~~bbx~~); 1037.520; ~~1037.550(a).~~

(5) GEM’s MATLAB/Simulink Hardware-in-Loop model, Version 3.8, December 2020 (“GEM HIL model 3.8”); IBR approved for § 1037.150(~~bbx~~).

Note 1 to paragraph (d): The computer code for these models is available as noted in the introductory paragraph of this section. A working version of the software is also available for download at www.epa.gov/regulations-emissions-vehicles-and-engines/greenhouse-gas-emissions-model-gem-medium-and-heavy-duty.

~~(e) UN Economic Commission for Europe, Information Service, Palais des Nations, CH-1211 Geneva 10, Switzerland; unece_info@un.org; www.unece.org;~~

~~(1) Addendum 22: United Nations Global Technical Regulation, No. 22, United Nations Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles, Adopted April 14, 2022, (“GTR No. 22”); IBR approved for § 1037.115(f).~~

~~(2) [Reserved]~~

§ 1037.815 Confidential information.

The provisions of 40 CFR 1068.10 and 1068.11 apply for information you submit under this part.

§ 1037.820 Requesting a hearing.

(a) You may request a hearing under certain circumstances, as described elsewhere in this part. To do this, you must file a written request, including a description of your objection and any supporting data, within 30 days after we make a decision.

(b) For a hearing you request under the provisions of this part, we will approve your request if we find that your request raises a substantial factual issue.

(c) If we agree to hold a hearing, we will use the procedures specified in 40 CFR part 1068, subpart G.

§ 1037.825 Reporting and recordkeeping requirements.

(a) This part includes various requirements to submit and record data or other information. Unless we specify otherwise, store required records in any format and on any media and keep

them readily available for eight years after you send an associated application for certification, or eight years after you generate the data if they do not support an application for certification. We may review these records at any time. You must promptly give us organized, written records in English if we ask for them. We may require you to submit written records in an electronic format.

(b) The regulations in § 1037.255 and 40 CFR 1068.25 and 1068.101 describe your obligation to report truthful and complete information. This includes information not related to certification. Failing to properly report information and keep the records we specify violates 40 CFR 1068.101(a)(2), which may involve civil or criminal penalties.

(c) Send all reports and requests for approval to the Designated Compliance Officer (see § 1037.801).

(d) Any written information we require you to send to or receive from another company is deemed to be a required record under this section. Such records are also deemed to be submissions to EPA. Keep these records for eight years unless the regulations specify a different period. We may require you to send us these records whether or not you are a certificate holder.

(e) Under the Paperwork Reduction Act (44 U.S.C. 3501 et seq), the Office of Management and Budget approves the reporting and recordkeeping specified in the applicable regulations. The following items illustrate the kind of reporting and recordkeeping we require for vehicles regulated under this part:

(1) We specify the following requirements related to vehicle certification in this part 1037:

(i) In § 1037.150 we include various reporting and recordkeeping requirements related to interim provisions.

(ii) In subpart C of this part we identify a wide range of information required to certify vehicles.

(iii) In subpart G of this part we identify several reporting and recordkeeping items for making demonstrations and getting approval related to various special compliance provisions.

(iv) In § 1037.725, 1037.730, and 1037.735 we specify certain records related to averaging, banking, and trading.

(2) We specify the following requirements related to testing in 40 CFR part 1066:

(i) In 40 CFR 1066.2 we give an overview of principles for reporting information.

(ii) In 40 CFR 1066.25 we establish basic guidelines for storing test information.

(iii) In 40 CFR 1066.695 we identify the specific information and data items to record when measuring emissions.

(3) We specify the following requirements related to the general compliance provisions in 40 CFR part 1068:

(i) In 40 CFR 1068.5 we establish a process for evaluating good engineering judgment related to testing and certification.

(ii) In 40 CFR 1068.25 we describe general provisions related to sending and keeping information.

(iii) In 40 CFR 1068.27 we require manufacturers to make engines and vehicles available for our testing or inspection if we make such a request.

(iv) In 40 CFR 1068.105 we require vehicle manufacturers to keep certain records related to duplicate labels from engine manufacturers.

(v) In 40 CFR 1068.120 we specify recordkeeping related to rebuilding engines.

(vi) In 40 CFR part 1068, subpart C, we identify several reporting and recordkeeping items for making demonstrations and getting approval related to various exemptions.

- (vii) In 40 CFR part 1068, subpart D, we identify several reporting and recordkeeping items for making demonstrations and getting approval related to importing engines and vehicles.
- (viii) In 40 CFR 1068.450 and 1068.455 we specify certain records related to testing production-line engines and vehicles in a selective enforcement audit.
- (ix) In 40 CFR 1068.501 we specify certain records related to investigating and reporting emission-related defects.
- (x) In 40 CFR 1068.525 and 1068.530 we specify certain records related to recalling nonconforming engines and vehicles.
- (xi) In 40 CFR part 1068, subpart G, we specify certain records for requesting a hearing.

Appendix A to Part 1037 — Heavy-duty Transient Test Cycle

Time (sec)	Speed (mi/hr)						
1	0.00	66	8.84	133	2.50	200	25.91
2	0.00	67	8.35	134	1.94	201	26.26
3	0.00	68	7.81	135	1.56	202	26.38
4	0.00	69	7.22	136	0.95	203	26.26
5	0.00	70	6.65	137	0.42	204	26.49
6	0.00	71	6.13	138	0.00	205	26.76
7	0.41	72	5.75	139	0.00	206	27.07
8	1.18	73	5.61	140	0.00	207	26.64
9	2.26	74	5.65	141	0.00	208	25.99
10	3.19	75	5.80	142	0.00	209	24.77
11	3.97	76	5.95	143	0.00	210	24.04
12	4.66	77	6.09	144	0.00	211	23.39
13	5.32	78	6.21	145	0.00	212	22.73
14	5.94	79	6.31	146	0.00	213	22.16
15	6.48	80	6.34	147	0.00	214	21.66
16	6.91	81	6.47	148	0.00	215	21.39
17	7.28	82	6.65	149	0.00	216	21.43
18	7.64	83	6.88	150	0.00	217	20.67
19	8.02	84	7.04	151	0.00	218	17.98
20	8.36	85	7.05	152	0.00	219	13.15
21	8.60	86	7.01	153	0.00	220	7.71
22	8.74	87	6.90	154	0.00	221	3.30
23	8.82	88	6.88	155	0.00	222	0.88
24	8.82	89	6.89	156	0.00	223	0.00
25	8.76	90	6.96	157	0.00	224	0.00
26	8.66	91	7.04	158	0.00	225	0.00
27	8.58	92	7.17	159	0.00	226	0.00
28	8.52	93	7.29	160	0.00	227	0.00
29	8.46	94	7.39	161	0.00	228	0.00
30	8.38	95	7.48	162	0.00	229	0.00
31	8.31	96	7.57	163	0.00	230	0.00
32	8.21	97	7.61	164	0.00	231	0.00
33	8.11	98	7.59	165	0.00	232	0.00
34	8.00	99	7.53	166	0.00	233	0.00
35	7.94	100	7.46	167	0.00	234	0.00
36	7.94	101	7.40	168	0.00	235	0.00
37	7.80	102	7.39	169	0.00	236	0.00
38	7.43	103	7.38	170	0.00	237	0.00
39	6.79	104	7.37	171	0.00	238	0.00
40	5.81	105	7.37	172	1.11	239	0.00
41	4.65	106	7.39	173	2.65	240	0.00
42	3.03	107	7.42	174	4.45	241	0.00
43	1.88	108	7.43	175	5.68	242	0.00
44	1.15	109	7.40	176	6.75	243	0.00
45	1.14	110	7.39	177	7.59	244	0.00
46	1.12	111	7.42	178	7.75	245	0.00
47	1.11	112	7.50	179	7.63	246	0.00
48	1.19	113	7.57	180	7.67	247	0.00
49	1.57	114	7.60	181	8.70	248	0.00
50	2.31	115	7.60	182	10.20	249	0.00
51	3.37	116	7.61	183	11.92	250	0.00
52	4.51	117	7.64	184	12.84	251	0.00
53	5.56	118	7.68	185	13.27	252	0.00
54	6.41	119	7.74	186	13.38	253	0.00
55	7.09	120	7.82	187	13.61	254	0.00
56	7.59	121	7.90	188	14.15	255	0.00
57	7.99	122	7.96	189	14.84	256	0.00
58	8.32	123	7.99	190	16.49	257	0.00
59	8.64	124	8.02	191	18.33	258	0.00
60	8.91	125	8.01	192	20.36	259	0.50
61	9.13	126	7.87	193	21.47	260	1.57
62	9.29	127	7.59	194	22.35	261	3.07
63	9.40	128	7.20	195	22.96	262	4.57
64	9.39	129	6.52	196	23.46	263	5.65
65	9.20	130	5.53	197	23.92	264	6.95
		131	4.36	198	24.42	265	8.05
		132	3.30	199	24.99	266	9.13
						267	10.05
						268	11.62
						269	12.92
						270	13.84
						271	14.38
						272	15.64
						273	17.14
						274	18.21
						275	18.90
						276	19.44
						277	20.09
						278	21.89
						279	24.15
						280	26.26
						281	26.95
						282	27.03
						283	27.30
						284	28.10
						285	29.44
						286	30.78
						287	32.09
						288	33.24
						289	34.46
						290	35.42
						291	35.88
						292	36.03
						293	35.84
						294	35.65
						295	35.31
						296	35.19
						297	35.12
						298	35.12
						299	35.04
						300	35.08
						301	35.04
						302	35.34
						303	35.50
						304	35.77
						305	35.81
						306	35.92
						307	36.23
						308	36.42
						309	36.65
						310	36.26
						311	36.07
						312	35.84
						313	35.96
						314	36.00
						315	35.57
						316	35.00
						317	34.08
						318	33.39
						319	32.20
						320	30.32
						321	28.48
						322	26.95
						323	26.18
						324	25.38
						325	24.77
						326	23.46
						327	22.39
						328	20.97
						329	20.09
						330	18.90
						331	18.17
						332	16.48
						333	15.07

334	12.23
335	10.08
336	7.71
337	7.32
338	8.63
339	10.77
340	12.65
341	13.88
342	15.03
343	15.64
344	16.99
345	17.98
346	19.13
347	18.67
348	18.25
349	18.17
350	18.40
351	19.63
352	20.32
353	21.43
354	21.47
355	21.97
356	22.27
357	22.69
358	23.15
359	23.69
360	23.96
361	24.27
362	24.34
363	24.50
364	24.42
365	24.38
366	24.31
367	24.23
368	24.69
369	25.11
370	25.53
371	25.38
372	24.58
373	23.77
374	23.54
375	23.50
376	24.15
377	24.30
378	24.15
379	23.19
380	22.50
381	21.93
382	21.85
383	21.55
384	21.89
385	21.97
386	21.97
387	22.01
388	21.85
389	21.62
390	21.62
391	22.01
392	22.81
393	23.54
394	24.38
395	24.80
396	24.61
397	23.12
398	21.62
399	19.90
400	18.86
401	17.79
402	17.25

403	16.91
404	16.75
405	16.75
406	16.87
407	16.37
408	16.37
409	16.49
410	17.21
411	17.41
412	17.37
413	16.87
414	16.72
415	16.22
416	15.76
417	14.72
418	13.69
419	12.00
420	10.43
421	8.71
422	7.44
423	5.71
424	4.22
425	2.30
426	1.00
427	0.00
428	0.61
429	1.19
430	1.61
431	1.53
432	2.34
433	4.29
434	7.25
435	10.20
436	12.46
437	14.53
438	16.22
439	17.87
440	19.74
441	21.01
442	22.23
443	22.62
444	23.61
445	24.88
446	26.15
447	26.99
448	27.56
449	28.18
450	28.94
451	29.83
452	30.78
453	31.82
454	32.78
455	33.24
456	33.47
457	33.31
458	33.08
459	32.78
460	32.39
461	32.13
462	31.82
463	31.55
464	31.25
465	30.94
466	30.71
467	30.56
468	30.79
469	31.13
470	31.55
471	31.51

472	31.47
473	31.44
474	31.51
475	31.59
476	31.67
477	32.01
478	32.63
479	33.39
480	34.31
481	34.81
482	34.20
483	32.39
484	30.29
485	28.56
486	26.45
487	24.79
488	23.12
489	20.73
490	18.33
491	15.72
492	13.11
493	10.47
494	7.82
495	5.70
496	3.57
497	0.92
498	0.00
499	0.00
500	0.00
501	0.00
502	0.00
503	0.00
504	0.00
505	0.00
506	0.00
507	0.00
508	0.00
509	0.00
510	0.00
511	0.00
512	0.00
513	0.00
514	0.00
515	0.00
516	0.00
517	0.00
518	0.00
519	0.00
520	0.00
521	0.00
522	0.50
523	1.50
524	3.00
525	4.50
526	5.80
527	6.52
528	6.75
529	6.44
530	6.17
531	6.33
532	6.71
533	7.40
534	7.67
535	7.33
536	6.71
537	6.41
538	6.60
539	6.56
540	5.94

541	5.45
542	5.87
543	6.71
544	7.56
545	7.59
546	7.63
547	7.67
548	7.67
549	7.48
550	7.29
551	7.29
552	7.40
553	7.48
554	7.52
555	7.52
556	7.48
557	7.44
558	7.28
559	7.21
560	7.09
561	7.06
562	7.29
563	7.75
564	8.55
565	9.09
566	10.04
567	11.12
568	12.46
569	13.00
570	14.26
571	15.37
572	17.02
573	18.17
574	19.21
575	20.17
576	20.66
577	21.12
578	21.43
579	22.66
580	23.92
581	25.42
582	25.53
583	26.68
584	28.14
585	30.06
586	30.94
587	31.63
588	32.36
589	33.24
590	33.66
591	34.12
592	35.92
593	37.72
594	39.26
595	39.45
596	39.83
597	40.18
598	40.48
599	40.75
600	41.02
601	41.36
602	41.79
603	42.40
604	42.82
605	43.05
606	43.09
607	43.24
608	43.59
609	44.01

610	44.35
611	44.55
612	44.82
613	45.05
614	45.31
615	45.58
616	46.00
617	46.31
618	46.54
619	46.61
620	46.92
621	47.19
622	47.46
623	47.54
624	47.54
625	47.54
626	47.50
627	47.50
628	47.50
629	47.31
630	47.04
631	46.77
632	45.54
633	43.24
634	41.52
635	39.79
636	38.07
637	36.34
638	34.04
639	32.45
640	30.86
641	28.83
642	26.45
643	24.27
644	22.04
645	19.82
646	17.04
647	14.26
648	11.52
649	8.78
650	7.17
651	5.56
652	3.72
653	3.38
654	3.11
655	2.58
656	1.66
657	0.67
658	0.00
659	0.00
660	0.00
661	0.00
662	0.00
663	0.00
664	0.00
665	0.00
666	0.00
667	0.00
668	0.00

Appendix B to Part 1037 — Power Take-Off Test Cycle

Cycle Simulation	Mode	Start Time of Mode	Normalized Pressure, Circuit 1 (%)	Normalized Pressure, Circuit 2 (%)
Utility	0	0	0.0	0.0
Utility	1	33	80.5	0.0
Utility	2	40	0.0	0.0
Utility	3	145	83.5	0.0
Utility	4	289	0.0	0.0
Refuse	5	361	0.0	13.0
Refuse	6	363	0.0	38.0
Refuse	7	373	0.0	53.0
Refuse	8	384	0.0	73.0
Refuse	9	388	0.0	0.0
Refuse	10	401	0.0	13.0
Refuse	11	403	0.0	38.0
Refuse	12	413	0.0	53.0
Refuse	13	424	0.0	73.0
Refuse	14	442	11.2	0.0
Refuse	15	468	29.3	0.0
Refuse	16	473	0.0	0.0
Refuse	17	486	11.2	0.0
Refuse	18	512	29.3	0.0
Refuse	19	517	0.0	0.0
Refuse	20	530	12.8	11.1
Refuse	21	532	12.8	38.2
Refuse	22	541	12.8	53.4
Refuse	23	550	12.8	73.5
Refuse	24	553	0.0	0.0
Refuse	25	566	12.8	11.1
Refuse	26	568	12.8	38.2
Refuse	27	577	12.8	53.4
Refuse	28	586	12.8	73.5
Refuse	29	589	0.0	0.0
Refuse	30	600	0.0	0.0

Appendix C to Part 1037 — Emission Control Identifiers

This appendix identifies abbreviations for emission control information labels, as required under § 1037.135.

Vehicle Speed Limiters

- VSL – Vehicle speed limiter
- VSLS – “Soft-top” vehicle speed limiter
- VSLE – Expiring vehicle speed limiter
- VSLD – Vehicle speed limiter with both “soft-top” and expiration

Idle Reduction Technology

- IRT5 – Engine shutoff after 5 minutes or less of idling
- IRTE – Expiring engine shutoff

Tires

- LRRR – Low rolling resistance tires (all, ~~including trailers~~)
- LRRD – Low rolling resistance tires (drive)
- LRRS – Low rolling resistance tires (steer)

Aerodynamic Components

- ATS – Aerodynamic side skirt and/or fuel tank fairing
- ARF – Aerodynamic roof fairing
- ARFR – Adjustable height aerodynamic roof fairing
- TGR – Gap reducing tractor fairing (tractor to trailer gap)
- ~~-TGRT – Gap reducing trailer fairing (tractor to trailer gap)~~
- ~~-TATS – Trailer aerodynamic side skirt~~
- ~~-TARF – Trailer aerodynamic rear fairing~~
- ~~-TAUD – Trailer aerodynamic underbody device~~

Other Components

- ADVH – Vehicle includes advanced hybrid technology components
- ADVO – Vehicle includes other advanced-technology components (i.e., non-hybrid system)
- INV – Vehicle includes innovative (off-cycle) technology components
- ATI – Automatic tire inflation system
- TPMS – Tire pressure monitoring system
- ~~-WRTW – Weight reducing trailer wheels~~
- ~~-WRTC – Weight reducing trailer upper coupler plate~~
- ~~-WRTS – Weight reducing trailer axle sub frames~~
- ~~-WBSW – Wide base single trailer tires with steel wheel~~
- ~~-WBAW – Wide base single trailer tires with aluminum wheel~~
- ~~-WBLW – Wide base single trailer tires with light weight aluminum alloy wheel~~
- ~~-DWSW – Dual wide trailer tires with high strength steel wheel~~
- ~~-DWAW – Dual wide trailer tires with aluminum wheel~~
- ~~-DWLW – Dual wide trailer tires with light weight aluminum alloy wheel~~

Appendix D to Part 1037 — Heavy-duty Grade Profile for Phase 2 and Phase 3 Steady-State Test Cycles

The following table identifies a grade profile for operating vehicles over the highway cruise cycles specified in subpart F of this part. Determine intermediate values by linear interpolation.

Distance (m)	Grade (%)						
0	0	4158	0	9070	-0.69	12602	0.38
402	0	4224	-0.10	9254	-2.13	12708	0
804	0.5	4496	-0.69	9438	-0.69	12752	0
1206	0	4578	-0.97	9498	-0.38	12836	-0.10
1210	0	4664	-1.36	9604	0	12928	-0.17
1222	-0.10	4732	-1.78	9616	0	13150	-0.38
1234	0	4916	-3.23	9664	0.26	13342	-0.58
1244	0	5100	-1.78	9718	0.70	13482	-0.77
1294	0.36	5168	-1.36	9772	0.26	13656	-1.09
1344	0	5254	-0.97	9820	0	13742	-1.29
1354	0	5336	-0.69	9830	0	13866	-1.66
1408	-0.28	5608	-0.10	9898	-0.34	13992	-2.14
1504	-1.04	5674	0	10024	-1.33	14068	-2.57
1600	-0.28	5724	0	10150	-0.34	14140	-3.00
1654	0	5808	0.10	10218	0	14192	-3.27
1666	0	5900	0.17	10228	0	14230	-3.69
1792	0.39	6122	0.38	10316	0.37	14320	-5.01
1860	0.66	6314	0.58	10370	0.70	14410	-3.69
1936	1.15	6454	0.77	10514	1.85	14448	-3.27
2098	2.44	6628	1.09	10658	0.70	14500	-3.00
2260	1.15	6714	1.29	10712	0.37	14572	-2.57
2336	0.66	6838	1.66	10800	0	14648	-2.14
2404	0.39	6964	2.14	10812	0	14774	-1.66
2530	0	7040	2.57	10900	-0.37	14898	-1.29
2548	0	7112	3.00	10954	-0.7	14984	-1.09
2732	-0.46	7164	3.27	11098	-1.85	15158	-0.77
2800	-0.69	7202	3.69	11242	-0.70	15298	-0.58
2880	-1.08	7292	5.01	11296	-0.37	15490	-0.38
2948	-1.53	7382	3.69	11384	0	15712	-0.17
3100	-2.75	7420	3.27	11394	0	15804	-0.10
3252	-1.53	7472	3.00	11462	0.34	15888	0
3320	-1.08	7544	2.57	11588	1.33	15938	0
3400	-0.69	7620	2.14	11714	0.34	16004	0.10
3468	-0.46	7746	1.66	11782	0	16276	0.69
3652	0	7870	1.29	11792	0	16358	0.97
3666	0	7956	1.09	11840	-0.26	16444	1.36
3742	0.35	8130	0.77	11894	-0.70	16512	1.78
3818	0.90	8270	0.58	11948	-0.26	16696	3.23
3904	1.59	8462	0.38	11996	0	16880	1.78
3990	0.90	8684	0.17	12008	0	16948	1.36
4066	0.35	8776	0.10	12114	0.38	17034	0.97
4142	0	8860	0	12174	0.69	17116	0.69
		8904	0	12358	2.13	17388	0.10
		9010	-0.38	12542	0.69	17454	0

Appendix E to Part 1037 — Power Take-Off Utility Factors

Time (min)	Utility Factor Fraction
0	0
10	0.1
20	0.18
30	0.24
40	0.31
50	0.36
60	0.4
70	0.44
80	0.47
90	0.51
100	0.54
110	0.57
120	0.6
130	0.64
140	0.66
150	0.69
160	0.71
170	0.74
180	0.76
190	0.77
200	0.79
210	0.8
220	0.82
230	0.83
240	0.85
250	0.86
260	0.87
270	0.88
280	0.88
290	0.89
300	0.9
310	0.9
320	0.91
330	0.92
340	0.93
350	0.93
360	0.94
370	0.95
380	0.95
390	0.96
420	0.96
430	0.97
460	0.97
470	0.98
520	0.98
530	0.99
580	0.99
590	1

PART 1065—ENGINE-TESTING PROCEDURES

Authority: 42 U.S.C. 7401-7671q.

Subpart A—Applicability and General Provisions

§ 1065.1 Applicability.

- (a) This part describes the procedures that apply to testing we require for the following engines or for vehicles using the following engines:
- (1) Locomotives we regulate under 40 CFR part 1033.
 - (2) Heavy-duty highway engines we regulate under 40 CFR parts 86 and 1036.
 - (3) Nonroad compression-ignition engines we regulate under 40 CFR part 1039 and stationary diesel engines that are certified to the standards in 40 CFR part 1039 as specified in 40 CFR part 60, subpart IIII.
 - (4) Marine compression-ignition engines we regulate under 40 CFR part 1042.
 - (5) Marine spark-ignition engines we regulate under 40 CFR part 1045.
 - (6) Large nonroad spark-ignition engines we regulate under 40 CFR part 1048, and stationary engines that are certified to the standards in 40 CFR part 1048 or as otherwise specified in 40 CFR part 60, subpart JJJJ.
 - (7) Vehicles we regulate under 40 CFR part 1051 (such as snowmobiles and off-highway motorcycles) based on engine testing. See 40 CFR part 1051, subpart F, for standards and procedures that are based on vehicle testing.
 - (8) Small nonroad spark-ignition engines we regulate under 40 CFR part 1054 and stationary engines that are certified to the standards in 40 CFR part 1054 as specified in 40 CFR part 60, subpart JJJJ.
- (b) The procedures of this part may apply to other types of engines, as described in this part and in the standard-setting part.
- (c) The term “you” means anyone performing testing under this part other than EPA.
- (1) This part is addressed primarily to manufacturers of engines, vehicles, equipment, and vessels, but it applies equally to anyone who does testing under this part for such manufacturers.
 - (2) This part applies to any manufacturer or supplier of test equipment, instruments, supplies, or any other goods or services related to the procedures, requirements, recommendations, or options in this part.
- (d) Paragraph (a) of this section identifies the parts of the CFR that define emission standards and other requirements for particular types of engines. In this part, we refer to each of these other parts generically as the “standard-setting part.” For example, 40 CFR part 1051 is always the standard-setting part for snowmobiles. Note that while 40 CFR part 86 is the standard-setting part for heavy-duty highway engines, this refers specifically to 40 CFR part 86, subpart A, and to certain portions of 40 CFR part 86, subpart N, as described in 40 CFR 86.1301.
- (e) Unless we specify otherwise, the terms “procedures” and “test procedures” in this part include all aspects of engine testing, including the equipment specifications, calibrations, calculations, and other protocols and procedural specifications needed to measure emissions.
- (f) For vehicles, equipment, or vessels subject to this part and regulated under vehicle-based, equipment-based, or vessel-based standards, use good engineering judgment to interpret the term “engine” in this part to include vehicles, equipment, or vessels, where appropriate.

(g) For additional information regarding the test procedures in this part, visit our Web site at www.epa.gov, and in particular <https://www.epa.gov/vehicle-and-fuel-emissions-testing/engine-testing-regulations>.

(h) This part describes procedures and specifications for measuring an engine's exhaust emissions. While the measurements are geared toward engine-based measurements (in units of g/kW·hr), many of these provisions apply equally to vehicle-based measurements (in units of g/mile or g/kilometer). 40 CFR part 1066 describes the analogous procedures for vehicle-based emission measurements, and in many cases states that specific provisions of this part 1065 also apply for those vehicle-based measurements. Where material from this part 1065 applies for vehicle-based measurements under 40 CFR part 1066, it is sometimes necessary to include parenthetical statements in this part 1065 to properly cite secondary references that are different for vehicle-based testing. See 40 CFR part 1066 and the standard-setting part for additional information.

(i) The following additional procedures apply as described in subpart L of this part:

- (1) Measuring brake-specific emissions of semi-volatile organic compounds, which are not subject to separate emission standards.
- (2) Identifying the threshold temperature for vanadium sublimation for SCR catalysts.
- (3) Measuring the smoke opacity of engine exhaust.
- (4) Aging aftertreatment devices in support of determining deterioration factors for certified compression-ignition engines.

§ 1065.2 Submitting information to EPA under this part.

(a) You are responsible for statements and information in your applications for certification, requests for approved procedures, selective enforcement audits, laboratory audits, production-line test reports, field test reports, or any other statements you make to us related to this part 1065. If you provide statements or information to someone for submission to EPA, you are responsible for these statements and information as if you had submitted them to EPA yourself.

(b) In the standard-setting part and in 40 CFR 1068.101, we describe your obligation to report truthful and complete information and the consequences of failing to meet this obligation. See also 18 U.S.C. 1001 and 42 U.S.C. 7413(c)(2). This obligation applies whether you submit this information directly to EPA or through someone else.

(c) We may void any certificates or approvals associated with a submission of information if we find that you intentionally submitted false, incomplete, or misleading information. For example, if we find that you intentionally submitted incomplete information to mislead EPA when requesting approval to use alternate test procedures, we may void the certificates for all engine families certified based on emission data collected using the alternate procedures. This paragraph (c) would also apply if you ignore data from incomplete tests or from repeat tests with higher emission results.

(d) We may require an authorized representative of your company to approve and sign the submission, and to certify that all the information submitted is accurate and complete. This includes everyone who submits information, including manufacturers and others.

(e) See 40 CFR 1068.10 for provisions related to confidential information. Note however that under 40 CFR 2.301, emission data are generally not eligible for confidential treatment.

(f) Nothing in this part should be interpreted to limit our ability under Clean Air Act section 208 (42 U.S.C. 7542) to verify that engines conform to the regulations.

§ 1065.5 Overview of this part 1065 and its relationship to the standard-setting part.

(a) This part specifies procedures that apply generally to measuring brake-specific emissions from various categories of engines. See subpart L of this part for measurement procedures for testing related to standards other than brake-specific emission standards. See the standard-setting part for directions in applying specific provisions in this part for a particular type of engine. Before using this part’s procedures, read the standard-setting part to answer at least the following questions:

- (1) What duty cycles must I use for laboratory testing?
- (2) Should I warm up the test engine before measuring emissions, or do I need to measure cold-start emissions during a warm-up segment of the duty cycle?
- (3) Which exhaust constituents do I need to measure? Measure all exhaust constituents that are subject to emission standards, any other exhaust constituents needed for calculating emission rates, and any additional exhaust constituents as specified in the standard-setting part. Alternatively, you may omit the measurement of N₂O and CH₄ for an engine, provided it is not subject to an N₂O or CH₄ emission standard. If you omit the measurement of N₂O and CH₄, you must provide other information and/or data that will give us a reasonable basis for estimating the engine’s emission rates.
- (4) Do any unique specifications apply for test fuels?
- (5) What maintenance steps may I take before or between tests on an emission-data engine?
- (6) Do any unique requirements apply to stabilizing emission levels on a new engine?
- (7) Do any unique requirements apply to test limits, such as ambient temperatures or pressures?
- (8) Is field testing required or allowed, and are there different emission standards or procedures that apply to field testing?
- (9) Are there any emission standards specified at particular engine-operating conditions or ambient conditions?
- (10) Do any unique requirements apply for durability testing?

(b) The testing specifications in the standard-setting part may differ from the specifications in this part. In cases where it is not possible to comply with both the standard-setting part and this part, you must comply with the specifications in the standard-setting part. The standard-setting part may also allow you to deviate from the procedures of this part for other reasons.

(c) The following table shows how this part divides testing specifications into subparts:

TABLE 1 OF § 1065.5—DESCRIPTION OF PART 1065 SUBPARTS

This subpart	Describes these specifications or procedures
Subpart A	Applicability and general provisions.
Subpart B	Equipment for testing.
Subpart C	Measurement instruments for testing.
Subpart D	Calibration and performance verifications for measurement systems.
Subpart E	How to prepare engines for testing, including service accumulation.
Subpart F	How to run an emission test over a predetermined duty cycle.
Subpart G	Test procedure calculations.
Subpart H	Fuels, engine fluids, analytical gases, and other calibration standards.
Subpart I	Special procedures related to oxygenated fuels.
Subpart J	How to test with portable emission measurement systems (PEMS).
Subpart L	How to test for unregulated and special pollutants and to perform additional measurements related to certification.

§ 1065.10 Other procedures.

(a) *Your testing.* The procedures in this part apply for all testing you do to show compliance with emission standards, with certain exceptions noted in this section. In some other sections in this part, we allow you to use other procedures (such as less precise or less accurate procedures) if they do not affect your ability to show that your engines comply with the applicable emission standards. This generally requires emission levels to be far enough below the applicable emission standards so that any errors caused by greater imprecision or inaccuracy do not affect your ability to state unconditionally that the engines meet all applicable emission standards.

(b) *Our testing.* These procedures generally apply for testing that we do to determine if your engines comply with applicable emission standards. We may perform other testing as allowed by the Act.

(c) *Exceptions.* We may allow or require you to use procedures other than those specified in this part in the following cases, which may apply to laboratory testing, field testing, or both. We intend to publicly announce when we allow or require such exceptions. All of the test procedures noted here as exceptions to the specified procedures are considered generically as "other procedures." Note that the terms "special procedures" and "alternate procedures" have specific meanings; "special procedures" are those allowed by § 1065.10(c)(2) and "alternate procedures" are those allowed by § 1065.10(c)(7).

(1) The objective of the procedures in this part is to produce emission measurements equivalent to those that would result from measuring emissions during in-use operation using the same engine configuration as installed in a vehicle, equipment, or vessel. However, in unusual circumstances where these procedures may result in measurements that do not represent in-use operation, you must notify us if good engineering judgment indicates that the specified procedures cause unrepresentative emission measurements for your engines. Note that you need not notify us of unrepresentative aspects of the test procedure if measured emissions are equivalent to in-use emissions. This provision does not obligate you to pursue new information regarding the different ways your engine might operate in use, nor does it obligate you to collect any other in-use information to verify whether or not these test procedures are representative of your engine's in-use operation. If you notify us of unrepresentative procedures under this paragraph (c)(1), we will cooperate with you to establish whether and how the procedures should be appropriately changed to result in more representative measurements. While the provisions of this paragraph (c)(1) allow us to be responsive to issues as they arise, we would generally work toward making these testing changes generally applicable through rulemaking. We will allow reasonable lead time for compliance with any resulting change in procedures. We will consider the following factors in determining the importance of pursuing changes to the procedures:

- (i) Whether supplemental emission standards or other requirements in the standard-setting part address the type of operation of concern or otherwise prevent inappropriate design strategies.
- (ii) Whether the unrepresentative aspect of the procedures affects your ability to show compliance with the applicable emission standards.
- (iii) The extent to which the established procedures require the use of emission-control technologies or strategies that are expected to ensure a comparable degree of emission control under the in-use operation that differs from the specified procedures.

(2) You may request to use special procedures if your engine cannot be tested using the specified procedures. For example, this may apply if your engine cannot operate on the specified duty cycle. In this case, tell us in writing why you cannot satisfactorily test your engine using this part's procedures and ask to use a different approach. We will approve your

request if we determine that it would produce emission measurements that represent in-use operation and we determine that it can be used to show compliance with the requirements of the standard-setting part. Where we approve special procedures that differ substantially from the specified procedures, we may preclude you from participating in averaging, banking, and trading with the affected engine families.

(3) In a given model year, you may use procedures required for later model year engines without request. If you upgrade your testing facility in stages, you may rely on a combination of procedures for current and later model year engines as long as you can ensure, using good engineering judgment, that the combination you use for testing does not affect your ability to show compliance with the applicable emission standards.

(4) In a given model year, you may ask to use procedures allowed for earlier model year engines. We will approve this only if you show us that using the procedures allowed for earlier model years does not affect your ability to show compliance with the applicable emission standards.

(5) You may ask to use emission data collected using other procedures, such as those of the California Air Resources Board or the International Organization for Standardization. We will approve this only if you show us that using these other procedures does not affect your ability to show compliance with the applicable emission standards.

(6) During the 12 months following the effective date of any change in the provisions of this part 1065 (and 40 CFR part 1066 for vehicle testing), you may use data collected using procedures specified in the previously applicable version of this part 1065 (and 40 CFR part 1066 for vehicle testing). This also applies for changes to test procedures specified in the standard-setting part to the extent that these changes are not related to new emission standards. This paragraph (c)(6) does not restrict the use of carryover certification data otherwise allowed by the standard-setting part.

(7) You may request to use alternate procedures that are equivalent to the specified procedures, or procedures that are more accurate or more precise than the specified procedures. We may perform tests with your engines using either the approved alternate procedures or the specified procedures. The following provisions apply to requests for alternate procedures:

(i) Applications. Follow the instructions in § 1065.12.

(ii) Submission. Submit requests in writing to the EPA Program Officer.

(iii) Notification. We may approve your request by telling you directly, or we may issue guidance announcing our approval of a specific alternate procedure, which would make additional requests for approval unnecessary.

(d) *Advance approval.* If we require you to request approval to use other procedures under paragraph (c) of this section, you may not use them until we approve your request.

§ 1065.12 Approval of alternate procedures.

(a) To get approval for an alternate procedure under § 1065.10(c), send the EPA Program Officer an initial written request describing the alternate procedure and why you believe it is equivalent to the specified procedure. Anyone may request alternate procedure approval. This means that an individual engine manufacturer may request to use an alternate procedure. This also means that an instrument manufacturer may request to have an instrument, equipment, or procedure approved as an alternate procedure to those specified in this part. We may approve your request based on this information alone, whether or not it includes all the information specified in this section. Where we determine that your original submission does not include enough information for us to determine that the alternate procedure is equivalent to the specified procedure, we may

ask you to submit supplemental information showing that your alternate procedure is consistently and reliably at least as accurate and repeatable as the specified procedure.

(b) We may make our approval under this section conditional upon meeting other requirements or specifications. We may limit our approval, for example, to certain time frames, specific duty cycles, or specific emission standards. Based upon any supplemental information we receive after our initial approval, we may amend a previously approved alternate procedure to extend, limit, or discontinue its use. We intend to publicly announce alternate procedures that we approve.

(c) Although we will make every effort to approve only alternate procedures that completely meet our requirements, we may revoke our approval of an alternate procedure if new information shows that it is significantly not equivalent to the specified procedure. If we do this, we will grant time to switch to testing using an allowed procedure, considering the following factors:

(1) The cost, difficulty, and availability to switch to a procedure that we allow.

(2) The degree to which the alternate procedure affects your ability to show that your engines comply with all applicable emission standards.

(3) Any relevant factors considered in our initial approval.

(d) If we do not approve your proposed alternate procedure based on the information in your initial request, we may ask you to send additional information to fully evaluate your request. While we consider the information specified in this paragraph (d) and the statistical criteria of paragraph (e) of this section to be sufficient to demonstrate equivalence, it may not be necessary to include all the information or meet the specified statistical criteria. For example, systems that do not meet the statistical criteria in paragraph (e) of this section because they have a small bias toward high emission results could be approved since they would not adversely affect your ability to demonstrate compliance with applicable standards.

(1) *Theoretical basis.* Give a brief technical description explaining why you believe the proposed alternate procedure should result in emission measurements equivalent to those using the specified procedure. You may include equations, figures, and references. You should consider the full range of parameters that may affect equivalence. For example, for a request to use a different NO_x measurement procedure, you should theoretically relate the alternate detection principle to the specified detection principle over the expected concentration ranges for NO, NO₂, and interference [gases/species](#). For a request to use a different PM measurement procedure, you should explain the principles by which the alternate procedure quantifies particulate mass similarly to the specified procedures.

(2) *Technical description.* Describe briefly any hardware or software needed to perform the alternate procedure. You may include dimensioned drawings, flowcharts, schematics, and component specifications. Explain any necessary calculations or other data manipulation.

(3) *Procedure execution.* Describe briefly how to perform the alternate procedure and recommend a level of training an operator should have to achieve acceptable results.

Summarize the installation, calibration, operation, and maintenance procedures in a step-by-step format. Describe how any calibration is performed using NIST-traceable standards or other similar standards we approve. Calibration must be specified by using known quantities and must not be specified as a comparison with other allowed procedures.

(4) *Data-collection techniques.* Compare measured emission results using the proposed alternate procedure and the specified procedure, as follows:

(i) Both procedures must be calibrated independently to NIST-traceable standards or to other similar standards we approve.

(ii) Include measured emission results from all applicable duty cycles. Measured emission results should show that the test engine meets all applicable emission standards according to specified procedures.

(iii) Use statistical methods to evaluate the emission measurements, such as those described in paragraph (e) of this section.

(e) Absent any other directions from us, use a t -test and an F -test calculated according to § 1065.602 to evaluate whether your proposed alternate procedure is equivalent to the specified procedure. We may give you specific directions regarding methods for statistical analysis, or we may approve other methods that you propose. Such alternate methods may be more or less stringent than those specified in this paragraph (e). In determining the appropriate statistical criteria, we will consider the repeatability of measurements made with the reference procedure. For example, less stringent statistical criteria may be appropriate for measuring emission levels being so low that they adversely affect the repeatability of reference measurements. We recommend that you consult a statistician if you are unfamiliar with these statistical tests.

Perform the tests as follows:

(1) Repeat measurements for all applicable duty cycles at least seven times for each procedure. You may use laboratory duty cycles to evaluate field-testing procedures. Be sure to include all available results to evaluate the precision and accuracy of the proposed alternate procedure, as described in § 1065.2.

(2) Demonstrate the accuracy of the proposed alternate procedure by showing that it passes a two-sided t -test. Use an unpaired t -test, unless you show that a paired t -test is appropriate under both of the following provisions:

(i) For paired data, the population of the paired differences from which you sampled paired differences must be independent. That is, the probability of any given value of one paired difference is unchanged by knowledge of the value of another paired difference. For example, your paired data would violate this requirement if your series of paired differences showed a distinct increase or decrease that was dependent on the time at which they were sampled.

(ii) For paired data, the population of paired differences from which you sampled the paired differences must have a normal (i.e., Gaussian) distribution. If the population of paired difference is not normally distributed, consult a statistician for a more appropriate statistical test, which may include transforming the data with a mathematical function or using some kind of non-parametric test.

(3) Show that t is less than the critical t value, t_{crit} , tabulated in § 1065.602, for the following confidence intervals:

(i) 90 % for a proposed alternate procedure for laboratory testing.

(ii) 95 % for a proposed alternate procedure for field testing.

(4) Demonstrate the precision of the proposed alternate procedure by showing that it passes an F -test. Use a set of at least seven samples from the reference procedure and a set of at least seven samples from the alternate procedure to perform an F -test. The sets must meet the following requirements:

(i) Within each set, the values must be independent. That is, the probability of any given value in a set must be unchanged by knowledge of another value in that set. For example, your data would violate this requirement if a set showed a distinct increase or decrease that was dependent upon the time at which they were sampled.

(ii) For each set, the population of values from which you sampled must have a normal (i.e., Gaussian) distribution. If the population of values is not normally distributed, consult a statistician for a more appropriate statistical test, which may include transforming the data with a mathematical function or using some kind of non-parametric test.

(iii) The two sets must be independent of each other. That is, the probability of any given value in one set must be unchanged by knowledge of another value in the other set. For

example, your data would violate this requirement if one value in a set showed a distinct increase or decrease that was dependent upon a value in the other set. Note that a trend of emission changes from an engine would not violate this requirement.

(iv) If you collect paired data for the paired t -test in paragraph (e)(2) in this section, use caution when selecting sets from paired data for the F -test. If you do this, select sets that do not mask the precision of the measurement procedure. We recommend selecting such sets only from data collected using the same engine, measurement instruments, and test cycle.

(5) Show that F is less than the critical F value, F_{crit} , tabulated in § 1065.602. If you have several F -test results from several sets of data, show that the mean F -test value is less than the mean critical F value for all the sets. Evaluate F_{crit} , based on the following confidence intervals:

(i) 90 % for a proposed alternate procedure for laboratory testing.

(ii) 95 % for a proposed alternate procedure for field testing.

§ 1065.15 Overview of procedures for laboratory and field testing.

This section outlines the procedures to test engines that are subject to emission standards.

(a) In the standard-setting part, we set brake-specific emission standards in g/(kW·hr) (or g/(hp·hr)), for the following constituents:

(1) Total oxides of nitrogen, NO_x.

(2) Hydrocarbon, HC, which may be expressed in the following ways:

(i) Total hydrocarbon, THC.

(ii) Nonmethane hydrocarbon, NMHC, which results from subtracting methane, CH₄, from THC.

(iii) Nonmethane-nonethane hydrocarbon, NMNEHC, which results from subtracting methane, CH₄, and ethane, C₂H₆, from THC.

(iv) Total hydrocarbon-equivalent, THCE, which results from adjusting THC mathematically to be equivalent on a carbon-mass basis.

(v) Nonmethane hydrocarbon-equivalent, NMHCE, which results from adjusting NMHC mathematically to be equivalent on a carbon-mass basis.

(3) Particulate matter, PM.

(4) Carbon monoxide, CO.

(5) Carbon dioxide, CO₂.

(6) Methane, CH₄.

(7) Nitrous oxide, N₂O.

(b) Note that some engines are not subject to standards for all the emission constituents identified in paragraph (a) of this section. Note also that the standard-setting part may include standards for pollutants not listed in paragraph (a) of this section.

(c) We generally set brake-specific emission standards over test intervals and/or duty cycles, as follows:

(1) *Engine operation.* Testing may involve measuring emissions and work in a laboratory-type environment or in the field, as described in paragraph (f) of this section. For most laboratory testing, the engine is operated over one or more duty cycles specified in the standard-setting part. However, laboratory testing may also include non-duty cycle testing (such as simulation of field testing in a laboratory). For field testing, the engine is operated under normal in-use operation. The standard-setting part specifies how test intervals are defined for field testing. Refer to the definitions of “duty cycle” and “test interval” in § 1065.1001. Note that a single duty cycle may have multiple test intervals and require

weighting of results from multiple test intervals to calculate a composite brake-specific emissions value to compare to the standard.

(2) *Constituent determination.* Determine the total mass of each constituent over a test interval by selecting from the following methods:

(i) *Continuous sampling.* In continuous sampling, measure the constituent's concentration continuously from raw or dilute exhaust. Multiply this concentration by the continuous (raw or dilute) flow rate at the emission sampling location to determine the constituent's flow rate. Sum the constituent's flow rate continuously over the test interval. This sum is the total mass of the emitted constituent.

(ii) *Batch sampling.* In batch sampling, continuously extract and store a sample of raw or dilute exhaust for later measurement. Extract a sample proportional to the raw or dilute exhaust flow rate. You may extract and store a proportional sample of exhaust in an appropriate container, such as a bag, and then measure NO_x, HC, CO, CO₂, CH₄, N₂O, and CH₂O concentrations in the container after the test interval. You may deposit PM from proportionally extracted exhaust onto an appropriate substrate, such as a filter. In this case, divide the PM by the amount of filtered exhaust to calculate the PM concentration. Multiply batch sampled concentrations by the total (raw or dilute) flow from which it was extracted during the test interval. This product is the total mass of the emitted constituent.

(iii) *Combined sampling.* You may use continuous and batch sampling simultaneously during a test interval, as follows:

(A) You may use continuous sampling for some constituents and batch sampling for others.

(B) You may use continuous and batch sampling for a single constituent, with one being a redundant measurement. See § 1065.201 for more information on redundant measurements.

(3) *Work determination.* Determine work over a test interval by one of the following methods:

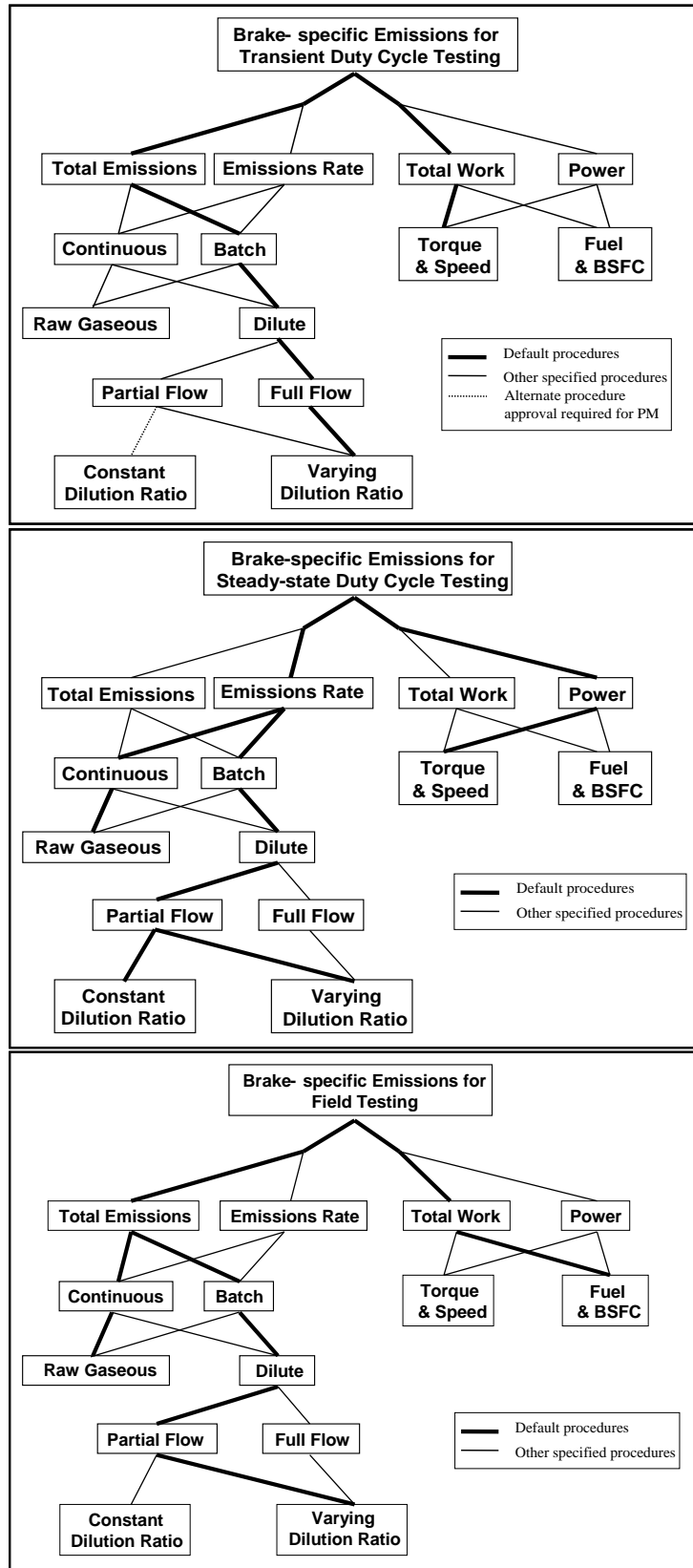
(i) *Speed and torque.* Synchronously multiply speed and brake torque to calculate instantaneous values for engine brake power. Sum engine brake power over a test interval to determine total work.

(ii) *Fuel consumed and brake-specific fuel consumption.* Directly measure fuel consumed or calculate it with chemical balances of the fuel, intake air, and exhaust. To calculate fuel consumed by a chemical balance, you must also measure either intake-air flow rate or exhaust flow rate. Divide the fuel consumed during a test interval by the brake-specific fuel consumption to determine work over the test interval. For laboratory testing, calculate the brake-specific fuel consumption using fuel consumed and speed and torque over a test interval. For field testing, refer to the standard-setting part and § 1065.915 for selecting an appropriate value for brake-specific fuel consumption.

(d) Refer to § 1065.650 for calculations to determine brake-specific emissions.

(e) The following figure illustrates the allowed measurement configurations described in this part 1065:

FIGURE 1 OF § 1065.15—DEFAULT TEST PROCEDURES AND OTHER SPECIFIED PROCEDURES.



- (f) This part 1065 describes how to test engines in a laboratory-type environment or in the field.
- (1) This affects test intervals and duty cycles as follows:
 - (i) For laboratory testing, you generally determine brake-specific emissions for duty-cycle testing by using an engine dynamometer in a laboratory or other environment. This typically consists of one or more test intervals, each defined by a duty cycle, which is a sequence of modes, speeds, and/or torques (or powers) that an engine must follow. If the standard-setting part allows it, you may also simulate field testing with an engine dynamometer in a laboratory or other environment.
 - (ii) Field testing consists of normal in-use engine operation while an engine is installed in a vehicle, equipment, or vessel rather than following a specific engine duty cycle. The standard-setting part specifies how test intervals are defined for field testing.
 - (2) The type of testing may also affect what test equipment may be used. You may use “lab-grade” test equipment for any testing. The term “lab-grade” refers to equipment that fully conforms to the applicable specifications of this part. For some testing you may alternatively use “field-grade” equipment. The term “field-grade” refers to equipment that fully conforms to the applicable specifications of subpart J of this part, but does not fully conform to other specifications of this part. You may use “field-grade” equipment for field testing. We also specify in this part and in the standard-setting parts certain cases in which you may use “field-grade” equipment for testing in a laboratory-type environment. (Note: Although “field-grade” equipment is generally more portable than “lab-grade” test equipment, portability is not relevant to whether equipment is considered to be “field-grade” or “lab-grade”.)

§ 1065.20 Units of measure and overview of calculations.

- (a) *System of units.* The procedures in this part generally follow the International System of Units (SI), as detailed in NIST Special Publication 811, which we incorporate by reference in § 1065.1010. The following exceptions apply:
- (1) We designate angular speed, f_n , of an engine’s crankshaft in revolutions per minute (r/min), rather than the SI unit of radians per second (rad/s). This is based on the commonplace use of r/min in many engine dynamometer laboratories.
 - (2) We designate brake-specific emissions in grams per kilowatt-hour (g/(kW·hr)), rather than the SI unit of grams per megajoule (g/MJ). In addition, we use the symbol *hr* to identify hour, rather than the SI convention of using *h*. This is based on the fact that engines are generally subject to emission standards expressed in g/kW·hr. If we specify engine standards in grams per horsepower·hour (g/(hp·hr)) in the standard-setting part, convert units as specified in paragraph (d) of this section.
 - (3) We generally designate temperatures in units of degrees Celsius (°C) unless a calculation requires an absolute temperature. In that case, we designate temperatures in units of Kelvin (K). For conversion purposes throughout this part, 0 °C equals 273.15 K. Unless specified otherwise, always use absolute temperature values for multiplying or dividing by temperature.
- (b) *Concentrations.* This part does not rely on amounts expressed in parts per million. Rather, we express such amounts in the following SI units:
- (1) For ideal gases, $\mu\text{mol/mol}$, formerly ppm (volume).
 - (2) For all substances, cm^3/m^3 , formerly ppm (volume).
 - (3) For all substances, mg/kg, formerly ppm (mass).
- (c) *Absolute pressure.* Measure absolute pressure directly or calculate it as the sum of atmospheric pressure plus a differential pressure that is referenced to atmospheric pressure. Always use absolute pressure values for multiplying or dividing by pressure.

- (d) *Units conversion.* Use the following conventions to convert units:
- (1) Testing. You may record values and perform calculations with other units. For testing with equipment that involves other units, use the conversion factors from NIST Special Publication 811, as described in paragraph (a) of this section.
 - (2) Humidity. In this part, we identify humidity levels by specifying dewpoint, which is the temperature at which pure water begins to condense out of air. Use humidity conversions as described in § 1065.645.
 - (3) Emission standards. If your standard is in g/(hp·hr) units, convert kW to hp before any rounding by using the conversion factor of 1 hp (550 ft·lbf/s) = 0.7456999 kW. Round the final value for comparison to the applicable standard.
- (e) *Rounding.* You are required to round certain final values, such as emission values. You may round intermediate values when transferring data as long as you maintain at least six significant digits (which requires more than six decimal places for values less than 0.1), or all significant digits if fewer than six digits are available. Unless the standard-setting part specifies otherwise, do not round other intermediate values. Round values to the number of significant digits necessary to match the number of decimal places of the applicable standard or specification as described in this paragraph (e). Note that specifications expressed as percentages have infinite precision (as described in paragraph (e)(7) of this section). Use the following rounding convention, which is consistent with ASTM E29 and NIST SP 811:
- (1) If the first (left-most) digit to be removed is less than five, remove all the appropriate digits without changing the digits that remain. For example, 3.141593 rounded to the second decimal place is 3.14.
 - (2) If the first digit to be removed is greater than five, remove all the appropriate digits and increase the lowest-value remaining digit by one. For example, 3.141593 rounded to the fourth decimal place is 3.1416.
 - (3) If the first digit to be removed is five with at least one additional non-zero digit following the five, remove all the appropriate digits and increase the lowest-value remaining digit by one. For example, 3.141593 rounded to the third decimal place is 3.142.
 - (4) If the first digit to be removed is five with no additional non-zero digits following the five, remove all the appropriate digits, increase the lowest-value remaining digit by one if it is odd and leave it unchanged if it is even. For example, 1.75 and 1.750 rounded to the first decimal place are 1.8; while 1.85 and 1.850 rounded to the first decimal place are also 1.8. Note that this rounding procedure will always result in an even number for the lowest-value digit.
 - (5) This paragraph (e)(5) applies if the regulation specifies rounding to an increment other than decimal places or powers of ten (to the nearest 0.01, 0.1, 1, 10, 100, etc.). To round numbers for these special cases, divide the quantity by the specified rounding increment. Round the result to the nearest whole number as described in paragraphs (e)(1) through (4) of this section. Multiply the rounded number by the specified rounding increment. This value is the desired result. For example, to round 0.90 to the nearest 0.2, divide 0.90 by 0.2 to get a result of 4.5, which rounds to 4. Multiplying 4 by 0.2 gives 0.8, which is the result of rounding 0.90 to the nearest 0.2.
- (6) The following tables further illustrate the rounding procedures specified in this paragraph (e):

Quantity	Rounding Increment			
	10	1	0.1	0.01
3.141593	0	3	3.1	3.14
123,456.789	123,460	123,457	123,456.8	123,456.79
5.500	10	6	5.5	5.50
4.500	0	4	4.5	4.50

Quantity	Rounding Increment			
	25	3	0.5	0.02
229.267	225	228	229.5	229.26
62.500	50	63	62.5	62.50
87.500	100	87	87.5	87.50
7.500	0	6	7.5	7.50

(7) This paragraph (e)(7) applies where we specify a limit or tolerance as some percentage of another value (such as $\pm 2\%$ of a maximum concentration). You may show compliance with such specifications either by applying the percentage to the total value to calculate an absolute limit, or by converting the absolute value to a percentage by dividing it by the total value.

(i) Do not round either value (the absolute limit or the calculated percentage), except as specified in paragraph (e)(7)(ii) of this section. For example, assume we specify that an analyzer must have a repeatability of $\pm 1\%$ of the maximum concentration or better, the maximum concentration is 1059 ppm, and you determine repeatability to be ± 6.3 ppm. In this example, you could calculate an absolute limit of ± 10.59 ppm ($1059 \text{ ppm} \times 0.01$) or calculate that the 6.3 ppm repeatability is equivalent to a repeatability of 0.5949008498584 %.

(ii) Prior to July 1, 2013, you may treat tolerances (and equivalent specifications) specified in percentages as having fixed rather than infinite precision. For example, 2 % would be equivalent to 1.51 % to 2.50 % and 2.0 % would be equivalent to 1.951 % to 2.050 %. Note that this allowance applies whether or not the percentage is explicitly specified as a percentage of another value.

(8) You may use measurement devices that incorporate internal rounding, consistent with the provisions of this paragraph (e)(8). You may use devices that use any rounding convention if they report six or more significant digits. You may use devices that report fewer than six digits, consistent with good engineering judgment and the accuracy, repeatability, and noise specifications of this part. Note that this provision does not necessarily require you to perform engineering analysis or keep records.

(f) *Interpretation of ranges.* Interpret a range as a tolerance unless we explicitly identify it as an accuracy, repeatability, linearity, or noise specification. See § 1065.1001 for the definition of tolerance. In this part, we specify two types of ranges:

(1) Whenever we specify a range by a single value and corresponding limit values above and below that value (such as $X \pm Y$), target the associated control point to that single value (X). Examples of this type of range include “ $\pm 10\%$ of maximum pressure”, or “(30 \pm 10) kPa”. In these examples, you would target the maximum pressure or 30 kPa, respectively.

(2) Whenever we specify a range by the interval between two values, you may target any associated control point to any value within that range. An example of this type of range is “(40 to 50) kPa”.

(g) *Scaling of specifications with respect to an applicable standard.* Because this part 1065 is applicable to a wide range of engines and emission standards, some of the specifications in this part are scaled with respect to an engine’s applicable standard or maximum power. This ensures

that the specification will be adequate to determine compliance, but not overly burdensome by requiring unnecessarily high-precision equipment. Many of these specifications are given with respect to a “flow-weighted mean” that is expected at the standard or during testing. Flow-weighted mean is the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products (dry-to-wet corrected, if applicable) of each recorded concentration times its respective exhaust flow rate, divided by the sum of the recorded flow rates. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration, because the CVS system itself flow-weights the bag concentration. Refer to § 1065.602 for information needed to estimate and calculate flow-weighted means. Wherever a specification is scaled to a value based upon an applicable standard, interpret the standard to be the family emission limit if the engine is certified under an emission credit program in the standard-setting part.

§ 1065.25 Recordkeeping.

- (a) The procedures in this part include various requirements to record data or other information. Refer to the standard-setting part and § 1065.695 regarding specific recordkeeping requirements.
- (b) You must promptly send us organized, written records in English if we ask for them. We may review them at any time.
- (c) We may waive specific reporting or recordkeeping requirements we determine to be unnecessary for the purposes of this part and the standard-setting part. Note that while we will generally keep the records required by this part, we are not obligated to keep records we determine to be unnecessary for us to keep. For example, while we require you to keep records for invalid tests so that we may verify that your invalidation was appropriate, it is not necessary for us to keep records for our own invalid tests.

Subpart B—Equipment Specifications

§ 1065.101 Overview.

- (a) This subpart specifies equipment, other than measurement instruments, related to emission testing. The provisions of this subpart apply for all engine dynamometer testing where engine speeds and loads are controlled to follow a prescribed duty cycle. See subpart J of this part to determine which of the provisions of this subpart apply for field testing. This equipment includes three broad categories—dynamometers, engine fluid systems (such as fuel and intake-air systems), and emission-sampling hardware.
- (b) Other related subparts in this part identify measurement instruments (subpart C), describe how to evaluate the performance of these instruments (subpart D), and specify engine fluids and analytical gases (subpart H).
- (c) Subpart J of this part describes additional equipment that is specific to field testing.
- (d) Figures 1 and 2 of this section illustrate some of the possible configurations of laboratory equipment. These figures are schematics only; we do not require exact conformance to them. Figure 1 of this section illustrates the equipment specified in this subpart and gives some references to sections in this subpart. Figure 2 of this section illustrates some of the possible configurations of a full-flow dilution, constant-volume sampling (CVS) system. Not all possible CVS configurations are shown.
- (e) Dynamometer testing involves engine operation over speeds and loads that are controlled to a prescribed duty cycle. Field testing involves measuring emissions over normal in-use operation

of a vehicle or piece of equipment. Field testing does not involve operating an engine over a prescribed duty cycle.

FIGURE 1 OF § 1065.101—ENGINE DYNAMOMETER LABORATORY EQUIPMENT.

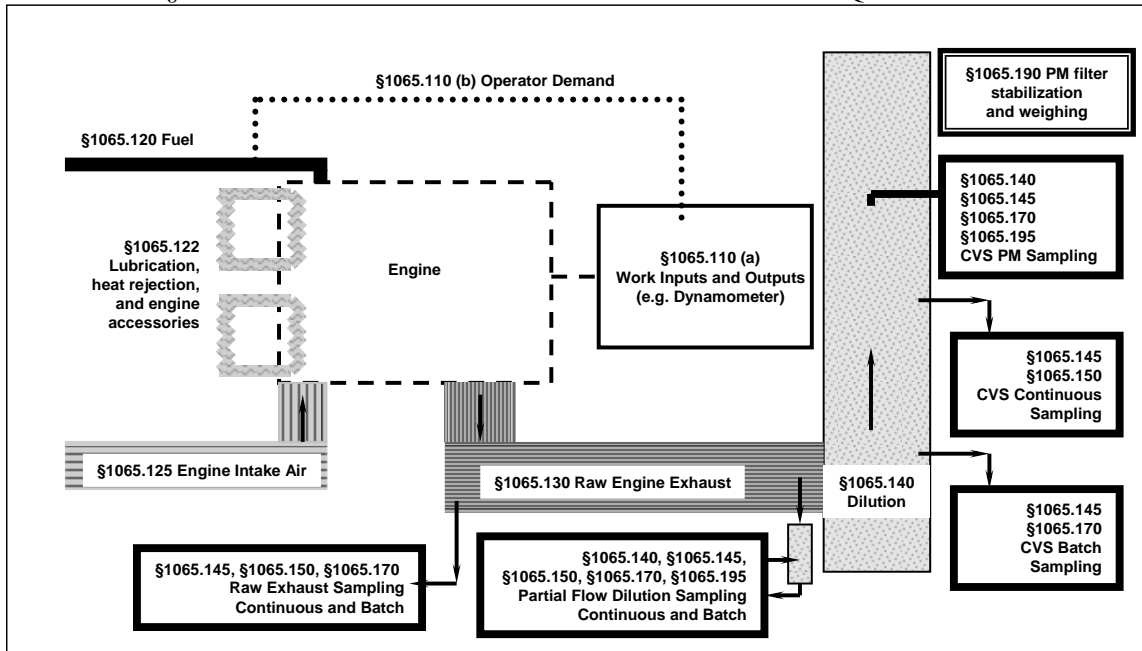
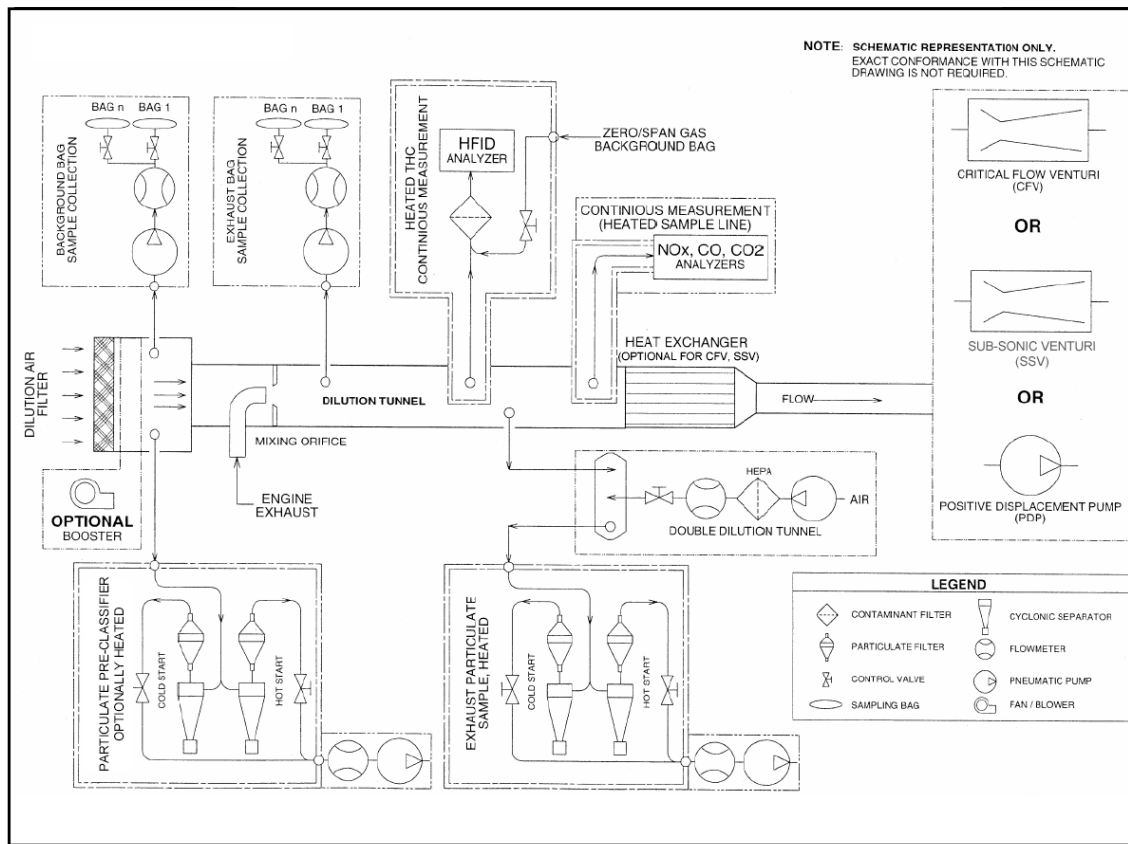


FIGURE 2 OF § 1065.101—EXAMPLES OF SOME FULL-FLOW DILUTION SAMPLING CONFIGURATIONS.



§ 1065.110 Work inputs and outputs, accessory work, and operator demand.

(a) *Work.* Use good engineering judgment to simulate all engine work inputs and outputs as they typically would operate in use. Account for work inputs and outputs during an emission test by measuring them; or, if they are small, you may show by engineering analysis that disregarding them does not affect your ability to determine the net work output by more than $\pm 0.5\%$ of the net expected work output over the test interval. Use equipment to simulate the specific types of work, as follows:

(1) *Shaft work.* Use an engine dynamometer that is able to meet the cycle-validation criteria in § 1065.514 over each applicable duty cycle.

(i) You may use eddy-current and water-brake dynamometers for any testing that does not involve engine motoring, which is identified by negative torque commands in a reference duty cycle. See the standard setting part for reference duty cycles that are applicable to your engine.

(ii) You may use alternating-current or direct-current motoring dynamometers for any type of testing.

(iii) You may use one or more dynamometers.

(iv) You may use any device that is already installed on a vehicle, equipment, or vessel to absorb work from the engine's output shaft(s). Examples of these types of devices include a vessel's propeller and a locomotive's generator.

(2) *Electrical work.* Use one or more of the following to simulate electrical work:

(i) Use storage batteries or capacitors that are of the type and capacity installed in use.

- (ii) Use motors, generators, and alternators that are of the type and capacity installed in use.
- (iii) Use a resistor load bank to simulate electrical loads.
- (3) *Pump, compressor, and turbine work.* Use pumps, compressors, and turbines that are of the type and capacity installed in use. Use working fluids that are of the same type and thermodynamic state as normal in-use operation.
- (b) *Laboratory work inputs.* You may supply any laboratory inputs of work to the engine. For example, you may supply electrical work to the engine to operate a fuel system, and as another example you may supply compressor work to the engine to actuate pneumatic valves. We may ask you to show by engineering analysis your accounting of laboratory work inputs to meet the criterion in paragraph (a) of this section.
- (c) *Engine accessories.* You must either install or account for the work of engine accessories required to fuel, lubricate, or heat the engine, circulate coolant to the engine, or to operate aftertreatment devices. Operate the engine with these accessories installed or accounted for during all testing operations, including mapping. If these accessories are not powered by the engine during a test, account for the work required to perform these functions from the total work used in brake-specific emission calculations. For air-cooled engines only, subtract externally powered fan work from total work. We may ask you to show by engineering analysis your accounting of engine accessories to meet the criterion in paragraph (a) of this section.
- (d) *Engine starter.* You may install a production-type starter.
- (e) *Operator demand for shaft work.* Operator demand is defined in § 1065.1001. Command the operator demand and the dynamometer(s) to follow a prescribed duty cycle with set points for engine speed and torque as specified in § 1065.512. Refer to the standard-setting part to determine the specifications for your duty cycle(s). Use a mechanical or electronic input to control operator demand such that the engine is able to meet the validation criteria in § 1065.514 over each applicable duty cycle. Record feedback values for engine speed and torque as specified in § 1065.512. Using good engineering judgment, you may improve control of operator demand by altering on-engine speed and torque controls. However, if these changes result in unrepresentative testing, you must notify us and recommend other test procedures under § 1065.10(c)(1).
- (f) *Other engine inputs.* If your electronic control module requires specific input signals that are not available during dynamometer testing, such as vehicle speed or transmission signals, you may simulate the signals using good engineering judgment. Keep records that describe what signals you simulate and explain why these signals are necessary for representative testing.

§ 1065.120 Fuel properties and fuel temperature and pressure.

- (a) Use fuels as specified in the standard-setting part, or as specified in subpart H of this part if fuels are not specified in the standard-setting part.
- (b) If the engine manufacturer specifies fuel temperature and pressure tolerances and the location where they are to be measured, then measure the fuel temperature and pressure at the specified location to show that you are within these tolerances throughout testing.
- (c) If the engine manufacturer does not specify fuel temperature and pressure tolerances, use good engineering judgment to set and control fuel temperature and pressure in a way that represents typical in-use fuel temperatures and pressures.

§ 1065.122 Engine cooling and lubrication.

(a) *Engine cooling.* Cool the engine during testing so its intake-air, oil, coolant, block, and head temperatures are within their expected ranges for normal operation. You may use auxiliary coolers and fans.

(1) For air-cooled engines only, if you use auxiliary fans you must account for work input to the fan(s) according to § 1065.110.

(2) See § 1065.125 for more information related to intake-air cooling.

(3) See § 1065.127 for more information related to exhaust gas recirculation cooling.

(4) Measure temperatures at the manufacturer-specified locations. If the manufacturer does not specify temperature measurement locations, then use good engineering judgment to monitor intake-air, oil, coolant, block, and head temperatures to ensure that they are in their expected ranges for normal operation.

(b) *Forced cooldown.* You may install a forced cooldown system for an engine and an exhaust aftertreatment device according to § 1065.530(a)(1).

(c) *Lubricating oil.* Use lubricating oils specified in § 1065.740. For two-stroke engines that involve a specified mixture of fuel and lubricating oil, mix the lubricating oil with the fuel according to the manufacturer's specifications.

(d) *Coolant.* For liquid-cooled engines, use coolant as specified in § 1065.745.

§ 1065.125 Engine intake air.

(a) Use the intake-air system installed on the engine or one that represents a typical in-use configuration. This includes the charge-air cooling and exhaust gas recirculation systems.

(b) Measure temperature, humidity, and atmospheric pressure near the entrance of the furthest upstream engine or in-use intake system component. This would generally be near the engine's air filter, or near the inlet to the in-use air intake system for engines that have no air filter. For engines with multiple intakes, make measurements near the entrance of each intake.

(1) *Pressure.* You may use a single shared atmospheric pressure meter as long as your laboratory equipment for handling intake air maintains ambient pressure at all intakes within ± 1 kPa of the shared atmospheric pressure. For engines with multiple intakes with separate atmospheric pressure measurements at each intake, use an average value for verifying compliance to § 1065.520(b)(2).

(2) *Humidity.* You may use a single shared humidity measurement for intake air as long as your equipment for handling intake air maintains dewpoint at all intakes to within ± 0.5 °C of the shared humidity measurement. For engines with multiple intakes with separate humidity measurements at each intake, use a flow-weighted average humidity for NO_x corrections. If individual flows of each intake are not measured, use good engineering judgment to estimate a flow-weighted average humidity.

(3) *Temperature.* Good engineering judgment may require that you shield the temperature sensors or move them upstream of an elbow in the laboratory intake system to prevent measurement errors due to radiant heating from hot engine surfaces or in-use intake system components. You must limit the distance between the temperature sensor and the entrance to the furthest upstream engine or in-use intake system component to no more than 12 times the outer hydraulic diameter of the entrance to the furthest upstream engine or in-use intake system component. However, you may exceed this limit if you use good engineering judgment to show that the temperature at the furthest upstream engine or in-use intake system component meets the specification in paragraph (c) of this section. For engines with multiple intakes, use a flow-weighted average value to verify compliance with the specification in

paragraph (c) of this section. If individual flows of each intake are not measured, you may use good engineering judgment to estimate a flow-weighted average temperature. You may also verify that each individual intake complies with the specification in paragraph (c) of this section.

- (c) Maintain the temperature of intake air to (25 ± 5) °C, except as follows:
 - (1) Follow the standard-setting part if it specifies different temperatures.
 - (2) For engines above 560 kW, you may use 35 °C as the upper bound of the tolerance. However, your system must be capable of controlling the temperature to the 25 °C setpoint for any steady-state operation at >30 % of maximum engine power.
 - (3) You may ask us to allow you to apply a different setpoint for intake air temperature if it is necessary to remain consistent with the provisions of § 1065.10(c)(1) for testing during which ambient temperature will be outside this range.
- (d) Use an intake-air restriction that represents production engines. Make sure the intake-air restriction is between the manufacturer's specified maximum for a clean filter and the manufacturer's specified maximum allowed. Measure the static differential pressure of the restriction at the location and at the speed and torque set points specified by the manufacturer. If the manufacturer does not specify a location, measure this pressure upstream of any turbocharger or exhaust gas recirculation system connection to the intake air system. If the manufacturer does not specify speed and torque points, measure this pressure while the engine outputs maximum power. As the manufacturer, you are liable for emission compliance for all values up to the maximum restriction you specify for a particular engine.
- (e) This paragraph (e) includes provisions for simulating charge-air cooling in the laboratory. This approach is described in paragraph (e)(1) of this section. Limits on using this approach are described in paragraphs (e)(2) and (3) of this section.
 - (1) Use a charge-air cooling system with a total intake-air capacity that represents production engines' in-use installation. Design any laboratory charge-air cooling system to minimize accumulation of condensate. Drain any accumulated condensate. Before starting a duty cycle (or preconditioning for a duty cycle), completely close all drains that would normally be closed during in-use operation. Keep those drains closed during the emission test. Maintain coolant conditions as follows:
 - (i) Maintain a coolant temperature of at least 20 °C at the inlet to the charge-air cooler throughout testing. We recommend maintaining a coolant temperature of 25 ± 5 °C at the inlet of the charge-air cooler.
 - (ii) At the engine conditions specified by the manufacturer, set the coolant flow rate to achieve an air temperature within ± 5 °C of the value specified by the manufacturer after the charge-air cooler's outlet. Measure the air-outlet temperature at the location specified by the manufacturer. Use this coolant flow rate set point throughout testing. If the engine manufacturer does not specify engine conditions or the corresponding charge-air cooler air outlet temperature, set the coolant flow rate at maximum engine power to achieve a charge-air cooler air outlet temperature that represents in-use operation.
 - (iii) If the engine manufacturer specifies pressure-drop limits across the charge-air cooling system, ensure that the pressure drop across the charge-air cooling system at engine conditions specified by the manufacturer is within the manufacturer's specified limit(s). Measure the pressure drop at the manufacturer's specified locations.
 - (2) Using a constant flow rate as described in paragraph (e)(1) of this section may result in unrepresentative overcooling of the intake air. The provisions of this paragraph (e)(2) apply instead of the provisions of § 1065.10(c)(1) for this simulation. Our allowance to cool intake air as specified in this paragraph (e) does not affect your liability for field testing or for laboratory testing that is done in a way that better represents in-use operation. Where we

determine that this allowance adversely affects your ability to demonstrate that your engines would comply with emission standards under in-use conditions, we may require you to use more sophisticated setpoints and controls of charge-air pressure drop, coolant temperature, and flow rate to achieve more representative results.

(3) This approach does not apply for field testing. You may not correct measured emission levels from field testing to account for any differences caused by the simulated cooling in the laboratory.

§ 1065.127 Exhaust gas recirculation.

Use the exhaust gas recirculation (EGR) system installed with the engine or one that represents a typical in-use configuration. This includes any applicable EGR cooling devices.

§ 1065.130 Engine exhaust.

(a) *General.* Use the exhaust system installed with the engine or one that represents a typical in-use configuration. This includes any applicable aftertreatment devices. We refer to exhaust piping as an exhaust stack; this is equivalent to a tailpipe for vehicle configurations.

(b) *Aftertreatment configuration.* If you do not use the exhaust system installed with the engine, configure any aftertreatment devices as follows:

(1) Position any aftertreatment device so its distance from the nearest exhaust manifold flange or turbocharger outlet is within the range specified by the engine manufacturer in the application for certification. If this distance is not specified, position aftertreatment devices to represent typical in-use vehicle configurations.

(2) You may use exhaust tubing that is not from the in-use exhaust system upstream of any aftertreatment device that is of diameter(s) typical of in-use configurations. If you use exhaust tubing that is not from the in-use exhaust system upstream of any aftertreatment device, position each aftertreatment device according to paragraph (b)(1) of this section.

(c) *Sampling system connections.* Connect an engine's exhaust system to any raw sampling location or dilution stage, as follows:

(1) Minimize laboratory exhaust tubing lengths and use a total length of laboratory tubing of no more than 10 m or 50 outside diameters, whichever is greater. The start of laboratory exhaust tubing should be specified as the exit of the exhaust manifold, turbocharger outlet, last aftertreatment device, or the in-use exhaust system, whichever is furthest downstream. The end of laboratory exhaust tubing should be specified as the sample point, or first point of dilution. If laboratory exhaust tubing consists of several different outside tubing diameters, count the number of diameters of length of each individual diameter, then sum all the diameters to determine the total length of exhaust tubing in diameters. Use the mean outside diameter of any converging or diverging sections of tubing. Use outside hydraulic diameters of any noncircular sections. For multiple stack configurations where all the exhaust stacks are combined, the start of the laboratory exhaust tubing may be taken at the last joint of where all the stacks are combined.

(2) You may install short sections of flexible laboratory exhaust tubing at any location in the engine or laboratory exhaust systems. You may use up to a combined total of 2 m or 10 outside diameters of flexible exhaust tubing.

(3) Insulate any laboratory exhaust tubing downstream of the first 25 outside diameters of length.

(4) Use laboratory exhaust tubing materials that are smooth-walled, electrically conductive, and not reactive with exhaust constituents. Stainless steel is an acceptable material.

(5) We recommend that you use laboratory exhaust tubing that has either a wall thickness of less than 2 mm or is air gap-insulated to minimize temperature differences between the wall and the exhaust.

(6) We recommend that you connect multiple exhaust stacks from a single engine into one stack upstream of any emission sampling. For raw or dilute partial-flow emission sampling, to ensure mixing of the multiple exhaust streams before emission sampling, we recommend a minimum Reynolds number, $Re^{\#}$, of 4000 for the combined exhaust stream, where $Re^{\#}$ is based on the inside diameter of the combined flow at the first sampling point. You may configure the exhaust system with turbulence generators, such as orifice plates or fins, to achieve good mixing; inclusion of turbulence generators may be required for $Re^{\#}$ less than 4000 to ensure mixing. $Re^{\#}$ is defined in § 1065.640. For dilute full-flow (CVS) emission sampling, you may configure the exhaust system without regard to mixing in the laboratory section of the raw exhaust. For example you may size the laboratory section to reduce its pressure drop even if the $Re^{\#}$ in the laboratory section of the raw exhaust is less than 4000.

(d) *In-line instruments.* You may insert instruments into the laboratory exhaust tubing, such as an in-line smoke meter. If you do this, you may leave a length of up to 5 outside diameters of laboratory exhaust tubing uninsulated on each side of each instrument, but you must leave a length of no more than 25 outside diameters of laboratory exhaust tubing uninsulated in total, including any lengths adjacent to in-line instruments.

(e) *Leaks.* Minimize leaks sufficiently to ensure your ability to demonstrate compliance with the applicable standards in this chapter. We recommend performing carbon balance error verification as described in § 1065.543 to verify exhaust system integrity.

(f) *Grounding.* Electrically ground the entire exhaust system.

(g) *Forced cooldown.* You may install a forced cooldown system for an exhaust aftertreatment device according to § 1065.530(a)(1)(i).

(h) *Exhaust restriction.* As the manufacturer, you are liable for emission compliance for all values up to the maximum restriction(s) you specify for a particular engine. Measure and set exhaust restriction(s) at the location(s) and at the engine speed and torque values specified by the manufacturer. Also, for variable-restriction aftertreatment devices, measure and set exhaust restriction(s) at the aftertreatment condition (degreening/aging and regeneration/loading level) specified by the manufacturer. If the manufacturer does not specify a location, measure this pressure downstream of any turbocharger. If the manufacturer does not specify speed and torque points, measure pressure while the engine produces maximum power. Use an exhaust-restriction setpoint that represents a typical in-use value, if available. If a typical in-use value for exhaust restriction is not available, set the exhaust restriction at (80 to 100) % of the maximum exhaust restriction specified by the manufacturer, or if the maximum is 5 kPa or less, the set point must be no less than 1.0 kPa from the maximum. For example, if the maximum back pressure is 4.5 kPa, do not use an exhaust restriction set point that is less than 3.5 kPa.

(i) *Open crankcase emissions.* If the standard-setting part requires measuring open crankcase emissions, you may either measure open crankcase emissions separately using a method that we approve in advance, or route open crankcase emissions directly into the exhaust system for emission measurement. If the engine is not already configured to route open crankcase emissions for emission measurement, route open crankcase emissions as follows:

(1) Use laboratory tubing materials that are smooth-walled, electrically conductive, and not reactive with crankcase emissions. Stainless steel is an acceptable material. Minimize tube lengths. We also recommend using heated or thin-walled or air gap-insulated tubing to minimize temperature differences between the wall and the crankcase emission constituents.

(2) Minimize the number of bends in the laboratory crankcase tubing and maximize the radius of any unavoidable bend.

- (3) Use laboratory crankcase exhaust tubing that meets the engine manufacturer's specifications for crankcase back pressure.
- (4) Connect the crankcase exhaust tubing into the raw exhaust downstream of any aftertreatment system, downstream of any installed exhaust restriction, and sufficiently upstream of any sample probes to ensure complete mixing with the engine's exhaust before sampling. Extend the crankcase exhaust tube into the free stream of exhaust to avoid boundary-layer effects and to promote mixing. You may orient the crankcase exhaust tube's outlet in any direction relative to the raw exhaust flow.

§ 1065.140 Dilution for gaseous and PM constituents.

(a) *General.* You may dilute exhaust with ambient air, purified air, or nitrogen. References in this part to "dilution air" may include any of these. For gaseous emission measurement, the dilution air must be at least 15 °C. Note that the composition of the dilution air affects some gaseous emission measurement instruments' response to emissions. We recommend diluting exhaust at a location as close as possible to the location where ambient air dilution would occur in use. Dilution may occur in a single stage or in multiple stages. For dilution in multiple stages, the first stage is considered primary dilution and later stages are considered secondary dilution.

(b) *Dilution-air conditions and background concentrations.* Before dilution air is mixed with exhaust, you may precondition it by increasing or decreasing its temperature or humidity. You may also remove constituents to reduce their background concentrations. The following provisions apply to removing constituents or accounting for background concentrations:

- (1) You may measure constituent concentrations in the dilution air and compensate for background effects on test results. See § 1065.650 for calculations that compensate for background concentrations (40 CFR 1066.610 for vehicle testing).

- (2) Measure these background concentrations the same way you measure diluted exhaust constituents, or measure them in a way that does not affect your ability to demonstrate compliance with the applicable standards in this chapter. For example, you may use the following simplifications for background sampling:

- (i) You may disregard any proportional sampling requirements.
- (ii) You may use unheated gaseous sampling systems.
- (iii) You may use unheated PM sampling systems.
- (iv) You may use continuous sampling if you use batch sampling for diluted emissions.
- (v) You may use batch sampling if you use continuous sampling for diluted emissions.

- (3) For removing background PM, we recommend that you filter all dilution air, including primary full-flow dilution air, with high-efficiency particulate air (HEPA) filters that have an initial minimum collection efficiency specification of 99.97 % (see § 1065.1001 for procedures related to HEPA-filtration efficiencies). Ensure that HEPA filters are installed properly so that background PM does not leak past the HEPA filters. If you choose to correct for background PM without using HEPA filtration, demonstrate that the background PM in the dilution air contributes less than 50 % to the net PM collected on the sample filter. You may correct net PM without restriction if you use HEPA filtration.

(c) *Full-flow dilution; constant-volume sampling (CVS).* You may dilute the full flow of raw exhaust in a dilution tunnel that maintains a nominally constant volume flow rate, molar flow rate or mass flow rate of diluted exhaust, as follows:

- (1) *Construction.* Use a tunnel with inside surfaces of 300 series stainless steel. Electrically ground the entire dilution tunnel. We recommend a thin-walled and insulated dilution tunnel to minimize temperature differences between the wall and the exhaust gases. You may not use any flexible tubing in the dilution tunnel upstream of the PM sample probe. You may use

nonconductive flexible tubing downstream of the PM sample probe and upstream of the CVS flow meter; use good engineering judgment to select a tubing material that is not prone to leaks, and configure the tubing to ensure smooth flow at the CVS flow meter.

(2) *Pressure control.* Maintain static pressure at the location where raw exhaust is introduced into the tunnel within ± 1.2 kPa of atmospheric pressure. You may use a booster blower to control this pressure. If you test using more careful pressure control and you show by engineering analysis or by test data that you require this level of control to demonstrate compliance at the applicable standards in this chapter, we will maintain the same level of static pressure control when we test.

(3) *Mixing.* Introduce raw exhaust into the tunnel by directing it downstream along the centerline of the tunnel. If you dilute directly from the exhaust stack, the end of the exhaust stack is considered to be the start of the dilution tunnel. You may introduce a fraction of dilution air radially from the tunnel's inner surface to minimize exhaust interaction with the tunnel walls. You may configure the system with turbulence generators such as orifice plates or fins to achieve good mixing. We recommend a minimum Reynolds number, $Re^{\#}$, of 4000 for the diluted exhaust stream, where $Re^{\#}$ is based on the inside diameter of the dilution tunnel. $Re^{\#}$ is defined in § 1065.640.

(4) *Flow measurement preconditioning.* You may condition the diluted exhaust before measuring its flow rate, as long as this conditioning takes place downstream of any heated HC or PM sample probes, as follows:

- (i) You may use flow straighteners, pulsation dampeners, or both of these.
- (ii) You may use a filter.
- (iii) You may use a heat exchanger to control the temperature upstream of any flow meter, but you must take steps to prevent aqueous condensation as described in paragraph (c)(6) of this section.

(5) *Flow measurement.* Section 1065.240 describes measurement instruments for diluted exhaust flow.

(6) *Aqueous condensation.* You must address aqueous condensation in the CVS as described in this paragraph (c)(6). You may meet these requirements by preventing or limiting aqueous condensation in the CVS from the exhaust inlet to the last emission sample probe. See paragraph (c)(6)(2)(B) of this section for provisions related to the CVS between the last emission sample probe and the CVS flow meter. You may heat and/or insulate the dilution tunnel walls, as well as the bulk stream tubing downstream of the tunnel to prevent or limit aqueous condensation. Where we allow aqueous condensation to occur, use good engineering judgment to ensure that the condensation does not affect your ability to demonstrate that your engines comply with the applicable standards in this chapter (see § 1065.10(a)).

- (i) *Preventing aqueous condensation.* To prevent condensation, you must keep the temperature of internal surfaces, excluding any sample probes, above the dewpoint of the dilute exhaust passing through the CVS tunnel. Use good engineering judgment to monitor temperatures in the CVS. For the purposes of this paragraph (c)(6), assume that aqueous condensation is pure water condensate only, even though the definition of "aqueous condensation" in § 1065.1001 includes condensation of any constituents that contain water. No specific verification check is required under this paragraph (c)(6)(i), but we may ask you to show how you comply with this requirement. You may use engineering analysis, CVS tunnel design, alarm systems, measurements of wall temperatures, and calculation of water dewpoint to demonstrate compliance with this requirement. For optional CVS heat exchangers, you may use the lowest water temperature at the inlet(s) and outlet(s) to determine the minimum internal surface temperature.

(ii) *Limiting aqueous condensation.* This paragraph (c)(6)(ii) specifies limits of allowable condensation and requires you to verify that the amount of condensation that occurs during each test interval does not exceed the specified limits.

(A) Use chemical balance equations in § 1065.655 to calculate the mole fraction of water in the dilute exhaust continuously during testing. Alternatively, you may continuously measure the mole fraction of water in the dilute exhaust prior to any condensation during testing. Use good engineering judgment to select, calibrate and verify water analyzers/detectors. The linearity verification requirements of § 1065.307 do not apply to water analyzers/detectors used to correct for the water content in exhaust samples.

(B) Use good engineering judgment to select and monitor locations on the CVS tunnel walls prior to the last emission sample probe. If you are also verifying limited condensation from the last emission sample probe to the CVS flow meter, use good engineering judgment to select and monitor locations on the CVS tunnel walls, optional CVS heat exchanger, and CVS flow meter. For optional CVS heat exchangers, you may use the lowest water temperature at the inlet(s) and outlet(s) to determine the minimum internal surface temperature. Identify the minimum surface temperature on a continuous basis.

(C) Identify the maximum potential mole fraction of dilute exhaust lost on a continuous basis during the entire test interval. This value must be less than or equal to 0.02. Calculate on a continuous basis the mole fraction of water that would be in equilibrium with liquid water at the measured minimum surface temperature. Subtract this mole fraction from the mole fraction of water that would be in the exhaust without condensation (either measured or from the chemical balance), and set any negative values to zero. This difference is the potential mole fraction of the dilute exhaust that would be lost due to water condensation on a continuous basis.

(D) Integrate the product of the molar flow rate of the dilute exhaust and the potential mole fraction of dilute exhaust lost, and divide by the totalized dilute exhaust molar flow over the test interval. This is the potential mole fraction of the dilute exhaust that would be lost due to water condensation over the entire test interval. Note that this assumes no re-evaporation. This value must be less than or equal to 0.005.

(7) *Flow compensation.* Maintain nominally constant molar, volumetric or mass flow of diluted exhaust. You may maintain nominally constant flow by either maintaining the temperature and pressure at the flow meter or by directly controlling the flow of diluted exhaust. You may also directly control the flow of proportional samplers to maintain proportional sampling. For an individual test, verify proportional sampling as described in § 1065.545.

(d) *Partial-flow dilution (PFD).* You may dilute a partial flow of raw or previously diluted exhaust before measuring emissions. Section 1065.240 describes PFD-related flow measurement instruments. PFD may consist of constant or varying dilution ratios as described in paragraphs (d)(2) and (3) of this section. An example of a constant dilution ratio PFD is a “secondary dilution PM” measurement system.

(1) *Applicability.* (i) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous PM emission sampling over any transient duty cycle, any steady-state duty cycle, or any ramped-modal cycle.

(ii) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous gaseous emission sampling over any transient duty cycle, any steady-state duty cycle, or any ramped-modal cycle.

- (iii) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous field-testing.
 - (iv) You may use PFD to extract a proportional diluted exhaust sample from a CVS for any batch or continuous emission sampling.
 - (v) You may use PFD to extract a constant raw or diluted exhaust sample for any continuous emission sampling.
 - (vi) You may use PFD to extract a constant raw or diluted exhaust sample for any steady-state emission sampling.
- (2) *Constant dilution-ratio PFD.* Do one of the following for constant dilution-ratio PFD:
- (i) Dilute an already proportional flow. For example, you may do this as a way of performing secondary dilution from a CVS tunnel to achieve overall dilution ratio for PM sampling.
 - (ii) Continuously measure constituent concentrations. For example, you might dilute to precondition a sample of raw exhaust to control its temperature, humidity, or constituent concentrations upstream of continuous analyzers. In this case, you must take into account the dilution ratio before multiplying the continuous concentration by the sampled exhaust flow rate.
 - (iii) Extract a proportional sample from a separate constant dilution ratio PFD system. For example, you might use a variable-flow pump to proportionally fill a gaseous storage medium such as a bag from a PFD system. In this case, the proportional sampling must meet the same specifications as varying dilution ratio PFD in paragraph (d)(3) of this section.
 - (iv) For each mode of a discrete-mode test (such as a locomotive notch setting or a specific setting for speed and torque), use a constant dilution ratio for any PM sampling. You must change the overall PM sampling system dilution ratio between modes so that the dilution ratio on the mode with the highest exhaust flow rate meets § 1065.140(e)(2) and the dilution ratios on all other modes is higher than this (minimum) dilution ratio by the ratio of the maximum exhaust flow rate to the exhaust flow rate of the corresponding other mode. This is the same dilution ratio requirement for RMC or field transient testing. You must account for this change in dilution ratio in your emission calculations.
- (3) *Varying dilution-ratio PFD.* All the following provisions apply for varying dilution-ratio PFD:
- (i) Use a control system with sensors and actuators that can maintain proportional sampling over intervals as short as 200 ms (i.e., 5 Hz control).
 - (ii) For control input, you may use any sensor output from one or more measurements; for example, intake-air flow, fuel flow, exhaust flow, engine speed, and intake manifold temperature and pressure.
 - (iii) Account for any emission transit time in the PFD system, as necessary.
 - (iv) You may use preprogrammed data if they have been determined for the specific test site, duty cycle, and test engine from which you dilute emissions.
 - (v) We recommend that you run practice cycles to meet the verification criteria in § 1065.545. Note that you must verify every emission test by meeting the verification criteria with the data from that specific test. Data from previously verified practice cycles or other tests may not be used to verify a different emission test.
 - (vi) You may not use a PFD system that requires preparatory tuning or calibration with a CVS or with the emission results from a CVS. Rather, you must be able to independently calibrate the PFD.

(e) *Dilution air temperature, dilution ratio, residence time, and temperature control of PM samples.* Dilute PM samples at least once upstream of transfer lines. You may dilute PM samples

upstream of a transfer line using full-flow dilution, or partial-flow dilution immediately downstream of a PM probe. In the case of partial-flow dilution, you may have up to 26 cm of insulated length between the end of the probe and the dilution stage, but we recommend that the length be as short as practical. The intent of these specifications is to minimize heat transfer to or from the emission sample before the final stage of dilution, other than the heat you may need to add to prevent aqueous condensation. This is accomplished by initially cooling the sample through dilution. Configure dilution systems as follows:

- (1) Set the dilution air temperature to (25 ± 5) °C. Use good engineering judgment to select a location to measure this temperature that is as close as practical upstream of the point where dilution air mixes with raw exhaust.
- (2) For any PM dilution system (i.e., CVS or PFD), add dilution air to the raw exhaust such that the minimum overall ratio of diluted exhaust to raw exhaust is within the range of (5:1 to 7:1) and is at least 2:1 for any primary dilution stage. Base this minimum value on the maximum engine exhaust flow rate during a given duty cycle for discrete-mode testing and on the maximum engine exhaust flow rate during a given test interval for other testing. Either measure the maximum exhaust flow during a practice run of the test interval or estimate it based on good engineering judgment (for example, you might rely on manufacturer-published literature).
- (3) Configure any PM dilution system to have an overall residence time of (1.0 to 5.5) s, as measured from the location of initial dilution air introduction to the location where PM is collected on the sample media. Also configure the system to have a residence time of at least 0.50 s, as measured from the location of final dilution air introduction to the location where PM is collected on the sample media. When determining residence times within sampling system volumes, use an assumed flow temperature of 25 °C and pressure of 101.325 kPa.
- (4) Control sample temperature to a (47 ± 5) °C tolerance, as measured anywhere within 20 cm upstream or downstream of the PM storage media (such as a filter). You may instead measure sample temperature up to 30 cm upstream of the filter or other PM storage media if it is housed within a chamber with temperature controlled to stay within the specified temperature range. Measure sample temperature with a bare-wire junction thermocouple with wires that are (0.500 ± 0.025) mm diameter, or with another suitable instrument that has equivalent performance.

§ 1065.145 Gaseous and PM probes, transfer lines, and sampling system components.

- (a) *Continuous and batch sampling.* Determine the total mass of each constituent with continuous or batch sampling. Both types of sampling systems have probes, transfer lines, and other sampling system components that are described in this section.
- (b) *Options for engines with multiple exhaust stacks.* Measure emissions from a test engine as described in this paragraph (b) if it has multiple exhaust stacks. You may choose to use different measurement procedures for different pollutants under this paragraph (b) for a given test. For purposes of this part 1065, the test engine includes all the devices related to converting the chemical energy in the fuel to the engine's mechanical output energy. This may or may not involve vehicle- or equipment-based devices. For example, all of an engine's cylinders are considered to be part of the test engine even if the exhaust is divided into separate exhaust stacks. As another example, all the cylinders of a diesel-electric locomotive are considered to be part of the test engine even if they transmit power through separate output shafts, such as might occur with multiple engine-generator sets working in tandem. Use one of the following procedures to measure emissions with multiple exhaust stacks:

(1) Route the exhaust flow from the multiple stacks into a single flow as described in § 1065.130(c)(6). Sample and measure emissions after the exhaust streams are mixed. Calculate the emissions as a single sample from the entire engine. We recommend this as the preferred option, since it requires only a single measurement and calculation of the exhaust molar flow for the entire engine.

(2) Sample and measure emissions from each stack and calculate emissions separately for each stack. Add the mass (or mass rate) emissions from each stack to calculate the emissions from the entire engine. Testing under this paragraph (b)(2) requires measuring or calculating the exhaust molar flow for each stack separately. If the exhaust molar flow in each stack cannot be calculated from intake air flow(s), fuel flow(s), and measured gaseous emissions, and it is impractical to measure the exhaust molar flows directly, you may alternatively proportion the engine's calculated total exhaust molar flow rate (where the flow is calculated using intake air mass flow(s), fuel mass flow(s), and emissions concentrations) based on exhaust molar flow measurements in each stack using a less accurate, non-traceable method. For example, you may use a total pressure probe and static pressure measurement in each stack.

(3) Sample and measure emissions from one stack and repeat the duty cycle as needed to collect emissions from each stack separately. Calculate the emissions from each stack and add the separate measurements to calculate the mass (or mass rate) emissions from the entire engine. Testing under this paragraph (b)(3) requires measuring or calculating the exhaust molar flow for each stack separately. You may alternatively proportion the engine's calculated total exhaust molar flow rate based on calculation and measurement limitations as described in paragraph (b)(2) of this section. Use the average of the engine's total power or work values from the multiple test runs to calculate brake-specific emissions. Divide the total mass (or mass rate) of each emission by the average power (or work). You may alternatively use the engine power or work associated with the corresponding stack during each test run if these values can be determined for each stack separately.

(4) Sample and measure emissions from each stack separately and calculate emissions for the entire engine based on the stack with the highest concentration. Testing under this paragraph (b)(4) requires only a single exhaust flow measurement or calculation for the entire engine. You may determine which stack has the highest concentration by performing multiple test runs, reviewing the results of earlier tests, or using good engineering judgment. Note that the highest concentration of different pollutants may occur in different stacks. Note also that the stack with the highest concentration of a pollutant during a test interval for field testing may be a different stack than the one you identified based on average concentrations over a duty cycle.

(5) Sample emissions from each stack separately and combine the wet sample streams from each stack proportionally to the exhaust molar flows in each stack. Measure the emission concentrations and calculate the emissions for the entire engine based on these weighted concentrations. Testing under this paragraph (b)(5) requires measuring or calculating the exhaust molar flow for each stack separately during the test run to proportion the sample streams from each stack. If it is impractical to measure the exhaust molar flows directly, you may alternatively proportion the wet sample streams based on less accurate, non-traceable flow methods. For example, you may use a total pressure probe and static pressure measurement in each stack. The following restrictions apply for testing under this paragraph (b)(5):

- (i) You must use an accurate, traceable measurement or calculation of the engine's total exhaust molar flow rate for calculating the mass of emissions from the entire engine.

(ii) You may dry the single, combined, proportional sample stream; you may not dry the sample streams from each stack separately.

(iii) You must measure and proportion the sample flows from each stack with active flow controls. For PM sampling, you must measure and proportion the diluted sample flows from each stack with active flow controls that use only smooth walls with no sudden change in cross-sectional area. For example, you may control the dilute exhaust PM sample flows using electrically conductive vinyl tubing and a control device that pinches the tube over a long enough transition length so no flow separation occurs.

(iv) For PM sampling, the transfer lines from each stack must be joined so the angle of the joining flows is 12.5° or less. Note that the exhaust manifold must meet the same specifications as the transfer line according to paragraph (d) of this section.

(6) Sample emissions from each stack separately and combine the wet sample streams from each stack equally. Measure the emission concentrations and calculate the emissions for the entire engine based on these measured concentrations. Testing under this paragraph (b)(6) assumes that the raw-exhaust and sample flows are the same for each stack. The following restrictions apply for testing under this paragraph (b)(6):

(i) You must measure and demonstrate that the sample flow from each stack is within 5 % of the value from the stack with the highest sample flow. You may alternatively ensure that the stacks have equal flow rates without measuring sample flows by designing a passive sampling system that meets the following requirements:

(A) The probes and transfer line branches must be symmetrical, have equal lengths and diameters, have the same number of bends, and have no filters.

(B) If probes are designed such that they are sensitive to stack velocity, the stack velocity must be similar at each probe. For example, a static pressure probe used for gaseous sampling is not sensitive to stack velocity.

(C) The stack static pressure must be the same at each probe. You can meet this requirement by placing probes at the end of stacks that are vented to atmosphere.

(D) For PM sampling, the transfer lines from each stack must be joined so the angle of the joining flows is 12.5° or less. Note that the exhaust manifold must meet the same specifications as the transfer line according to paragraph (d) of this section.

(ii) You may use the procedure in this paragraph (b)(6) only if you perform an analysis showing that the resulting error due to imbalanced stack flows and concentrations is either at or below 2 %. You may alternatively show that the resulting error does not impact your ability to demonstrate compliance with applicable standards. For example, you may use less accurate, non-traceable measurements of emission concentrations and molar flow in each stack and demonstrate that the imbalances in flows and concentrations cause 2 % or less error.

(iii) For a two-stack engine, you may use the procedure in this paragraph (b)(6) only if you can show that the stack with the higher flow has the lower average concentration for each pollutant over the duty cycle.

(iv) You must use an accurate, traceable measurement or calculation of the engine's total exhaust molar flow rate for calculating the mass of emissions from the entire engine.

(v) You may dry the single, equally combined, sample stream; you may not dry the sample streams from each stack separately.

(vi) You may determine your exhaust flow rates with a chemical balance of exhaust gas concentrations and either intake air flow or fuel flow.

(c) *Gaseous and PM sample probes.* A probe is the first fitting in a sampling system. It protrudes into a raw or diluted exhaust stream to extract a sample, such that its inside and outside surfaces

are in contact with the exhaust. A sample is transported out of a probe into a transfer line, as described in paragraph (d) of this section. The following provisions apply to sample probes:

(1) *Probe design and construction.* Use sample probes with inside surfaces of 300 series stainless steel or, for raw exhaust sampling, use any nonreactive material capable of withstanding raw exhaust temperatures. Locate sample probes where constituents are mixed to their mean sample concentration. Take into account the mixing of any crankcase emissions that may be routed into the raw exhaust. Locate each probe to minimize interference with the flow to other probes. We recommend that all probes remain free from influences of boundary layers, wakes, and eddies—especially near the outlet of a raw-exhaust stack where unintended dilution might occur. Make sure that purging or back-flushing of a probe does not influence another probe during testing. You may use a single probe to extract a sample of more than one constituent as long as the probe meets all the specifications for each constituent.

(2) *Gaseous sample probes.* Use either single-port or multi-port probes for sampling gaseous emissions. You may orient these probes in any direction relative to the raw or diluted exhaust flow. For some probes, you must control sample temperatures, as follows:

(i) For probes that extract NO_x from diluted exhaust, control the probe's wall temperature to prevent aqueous condensation.

(ii) For probes that extract hydrocarbons for THC or NMHC analysis from the diluted exhaust of compression-ignition engines, two-stroke spark-ignition engines, or four-stroke spark-ignition engines at or below 19 kW, we recommend heating the probe to minimize hydrocarbon contamination consistent with good engineering judgment. If you routinely fail the contamination check in the 1065.520 pretest check, we recommend heating the probe section to approximately 190 °C to minimize contamination.

(3) *PM sample probes.* Use PM probes with a single opening at the end. Orient PM probes to face directly upstream. If you shield a PM probe's opening with a PM pre-classifier such as a hat, you may not use the preclassifier we specify in paragraph (f)(1) of this section. We recommend sizing the inside diameter of PM probes to approximate isokinetic sampling at the expected mean flow rate.

(d) *Transfer lines.* You may use transfer lines to transport an extracted sample from a probe to an analyzer, storage medium, or dilution system, noting certain restrictions for PM sampling in § 1065.140(e). Minimize the length of all transfer lines by locating analyzers, storage media, and dilution systems as close to probes as practical. We recommend that you minimize the number of bends in transfer lines and that you maximize the radius of any unavoidable bend. Avoid using 90° elbows, tees, and cross-fittings in transfer lines. Where such connections and fittings are necessary, take steps, using good engineering judgment, to ensure that you meet the temperature tolerances in this paragraph (d). This may involve measuring temperature at various locations within transfer lines and fittings. You may use a single transfer line to transport a sample of more than one constituent, as long as the transfer line meets all the specifications for each constituent. The following construction and temperature tolerances apply to transfer lines:

(1) *Gaseous samples.* Use transfer lines with inside surfaces of 300 series stainless steel, PTFE, Viton™, or any other material that you demonstrate has better properties for emission sampling. For raw exhaust sampling, use a non-reactive material capable of withstanding raw exhaust temperatures. You may use in-line filters if they do not react with exhaust constituents and if the filter and its housing meet the same temperature requirements as the transfer lines, as follows:

(i) For NO_x transfer lines upstream of either an NO_2 -to- NO converter that meets the specifications of § 1065.378 or a chiller that meets the specifications of § 1065.376, maintain a sample temperature that prevents aqueous condensation.

(ii) For THC transfer lines for testing compression-ignition engines, two-stroke spark-ignition engines, or four-stroke spark-ignition engines at or below 19 kW, maintain a wall temperature

tolerance throughout the entire line of (191 ± 11) °C. If you sample from raw exhaust, you may connect an unheated, insulated transfer line directly to a probe. Design the length and insulation of the transfer line to cool the highest expected raw exhaust temperature to no lower than 191 °C, as measured at the transfer line's outlet. For dilute sampling, you may use a transition zone between the probe and transfer line of up to 92 cm to allow your wall temperature to transition to (191 ± 11) °C.

(2) *PM samples.* We recommend heated transfer lines or a heated enclosure to minimize temperature differences between transfer lines and exhaust constituents. Use transfer lines that are inert with respect to PM and are electrically conductive on the inside surfaces. We recommend using PM transfer lines made of 300 series stainless steel. Electrically ground the inside surface of PM transfer lines.

(e) *Optional sample-conditioning components for gaseous sampling.* You may use the following sample-conditioning components to prepare gaseous samples for analysis, as long as you do not install or use them in a way that adversely affects your ability to show that your engines comply with all applicable gaseous emission standards.

(1) *NO₂-to-NO converter.* You may use an NO₂-to-NO converter that meets the converter conversion verification specified in § 1065.378 at any point upstream of a NO_x analyzer, sample bag, or other storage medium.

(2) *Sample dryer.* You may use either type of sample dryer described in this paragraph (e)(2) to decrease the effects of water on gaseous emission measurements. You may not use a chemical dryer, or use dryers upstream of PM sample filters.

(i) *Osmotic-membrane.* You may use an osmotic-membrane dryer upstream of any gaseous analyzer or storage medium, as long as it meets the temperature specifications in paragraph (d)(1) of this section. Because osmotic-membrane dryers may deteriorate after prolonged exposure to certain exhaust constituents, consult with the membrane manufacturer regarding your application before incorporating an osmotic-membrane dryer. Monitor the dewpoint, T_{dew} , and absolute pressure, p_{total} , downstream of an osmotic-membrane dryer. You may use continuously recorded values of T_{dew} and p_{total} in the amount of water calculations specified in § 1065.645. For our testing we may use average temperature and pressure values over the test interval or a nominal pressure value that we estimate as the dryer's average pressure expected during testing as constant values in the amount of water calculations specified in § 1065.645. For your testing, you may use the maximum temperature or minimum pressure values observed during a test interval or duty cycle or the high alarm temperature setpoint or low alarm pressure setpoint as constant values in the calculations specified in § 1065.645. For your testing, you may also use a nominal p_{total} , which you may estimate as the dryer's lowest absolute pressure expected during testing.

(ii) *Thermal chiller.* You may use a thermal chiller upstream of some gas analyzers and storage media. You may not use a thermal chiller upstream of a THC measurement system for compression-ignition engines, two-stroke spark-ignition engines, or four-stroke spark-ignition engines at or below 19 kW. If you use a thermal chiller upstream of an NO₂-to-NO converter or in a sampling system without an NO₂-to-NO converter, the chiller must meet the NO₂ loss-performance check specified in § 1065.376. Monitor the dewpoint, T_{dew} , and absolute pressure, p_{total} , downstream of a thermal chiller. You may use continuously recorded values of T_{dew} and p_{total} in the amount of water calculations specified in § 1065.645. If it is valid to assume the degree of saturation in the thermal chiller, you may calculate T_{dew} based on the known chiller performance and continuous monitoring of chiller temperature, T_{chiller} . If it is valid to assume a constant temperature offset between T_{chiller} and T_{dew} , due to a known and fixed amount of sample reheat between the chiller outlet and the temperature measurement location, you may factor in this assumed temperature offset value into emission calculations. If we ask for it, you must show

by engineering analysis or by data the validity of any assumptions allowed by this paragraph (e)(2)(ii). For our testing we may use average temperature and pressure values over the test interval or a nominal pressure value that we estimate as the dryer's average pressure expected during testing as constant values in the calculations specified in § 1065.645. For your testing you may use the maximum temperature and minimum pressure values observed during a test interval or duty cycle or the high alarm temperature setpoint and the low alarm pressure setpoint as constant values in the amount of water calculations specified in § 1065.645. For your testing you may also use a nominal p_{total} , which you may estimate as the dryer's lowest absolute pressure expected during testing.

(3) *Sample pumps*. You may use sample pumps upstream of an analyzer or storage medium for any gas. Use sample pumps with inside surfaces of 300 series stainless steel, PTFE, or any other material that you demonstrate has better properties for emission sampling. For some sample pumps, you must control temperatures, as follows:

(i) If you use a NO_x sample pump upstream of either an NO_2 -to- NO converter that meets § 1065.378 or a chiller that meets § 1065.376, design the sampling system to prevent aqueous condensation.

(ii) For testing compression-ignition engines, two-stroke spark-ignition engines, or four-stroke spark-ignition engines at or below 19 kW, if you use a THC sample pump upstream of a THC analyzer or storage medium, its inner surfaces must be heated to a tolerance of $(191 \pm 11) ^\circ C$.

(4) *Ammonia Scrubber*. You may use ammonia scrubbers for any or all gaseous sampling systems to prevent interference with NH_3 , poisoning of the NO_2 -to- NO converter, and deposits in the sampling system or analyzers. Follow the ammonia scrubber manufacturer's recommendations or use good engineering judgment in applying ammonia scrubbers.

(f) *Optional sample-conditioning components for PM sampling*. You may use the following sample-conditioning components to prepare PM samples for analysis, as long as you do not install or use them in a way that adversely affects your ability to show that your engines comply with the applicable PM emission standards. You may condition PM samples to minimize positive and negative biases to PM results, as follows:

(1) *PM preclassifier*. You may use a PM preclassifier to remove large-diameter particles. The PM preclassifier may be either an inertial impactor or a cyclonic separator. It must be constructed of 300 series stainless steel. The preclassifier must be rated to remove at least 50 % of PM at an aerodynamic diameter of $10 \mu m$ and no more than 1 % of PM at an aerodynamic diameter of $1 \mu m$ over the range of flow rates for which you use it. Follow the preclassifier manufacturer's instructions for any periodic servicing that may be necessary to prevent a buildup of PM. Install the preclassifier in the dilution system downstream of the last dilution stage. Configure the preclassifier outlet with a means of bypassing any PM sample media so the preclassifier flow may be stabilized before starting a test. Locate PM sample media within 75 cm downstream of the preclassifier's exit. You may not use this preclassifier if you use a PM probe that already has a preclassifier. For example, if you use a hat-shaped preclassifier that is located immediately upstream of the probe in such a way that it forces the sample flow to change direction before entering the probe, you may not use any other preclassifier in your PM sampling system.

(2) *Other components*. You may request to use other PM conditioning components upstream of a PM preclassifier, such as components that condition humidity or remove gaseous-phase hydrocarbons from the diluted exhaust stream. You may use such components only if we approve them under § 1065.10.

§ 1065.150 Continuous sampling.

You may use continuous sampling techniques for measurements that involve raw or dilute sampling. Make sure continuous sampling systems meet the specifications in § 1065.145. Make sure continuous analyzers meet the specifications in subparts C and D of this part.

§ 1065.170 Batch sampling for gaseous and PM constituents.

Batch sampling involves collecting and storing emissions for later analysis. Examples of batch sampling include collecting and storing gaseous emissions in a bag or collecting and storing PM on a filter. You may use batch sampling to store emissions that have been diluted at least once in some way, such as with CVS, PFD, or BMD. You may use batch sampling to store undiluted emissions. You may stop emission sampling anytime the engine is turned off, consistent with good engineering judgment. This is intended to allow for higher concentrations of dilute exhaust gases and more accurate measurements. Account for exhaust transport delay in the sampling system and integrate over the actual sampling duration when determining n_{dexh} . Use good engineering judgment to add dilution air to fill bags up to minimum read volumes, as needed.

(a) *Sampling methods.* If you extract from a constant-volume flow rate, sample at a constant-volume flow rate as follows:

(1) Verify proportional sampling after an emission test as described in § 1065.545. You must exclude from the proportional sampling verification any portion of the test where you are not sampling emissions because the engine is turned off and the batch samplers are not sampling, accounting for exhaust transport delay in the sampling system. Use good engineering judgment to select storage media that will not significantly change measured emission levels (either up or down). For example, do not use sample bags for storing emissions if the bags are permeable with respect to emissions or if they off gas emissions to the extent that it affects your ability to demonstrate compliance with the applicable gaseous emission standards in this chapter. As another example, do not use PM filters that irreversibly absorb or adsorb gases to the extent that it affects your ability to demonstrate compliance with the applicable PM emission standards in this chapter.

(2) You must follow the requirements in § 1065.140(e)(2) related to PM dilution ratios. For each filter, if you expect the net PM mass on the filter to exceed 400 µg, assuming a 38 mm diameter filter stain area, you may take the following actions in sequence:

(i) For discrete-mode testing only, you may reduce sample time as needed to target a filter loading of 400 µg, but not below the minimum sample time specified in the standard-setting part.

(ii) Reduce filter face velocity as needed to target a filter loading of 400 µg, down to 50 cm/s or less.

(iii) Increase overall dilution ratio above the values specified in § 1065.140(e)(2) to target a filter loading of 400 µg.

(b) *Gaseous sample storage media.* Store gas volumes in sufficiently clean containers that minimally off-gas or allow permeation of gases. Use good engineering judgment to determine acceptable thresholds of storage media cleanliness and permeation. To clean a container, you may repeatedly purge and evacuate a container and you may heat it. Use a flexible container (such as a bag) within a temperature-controlled environment, or use a temperature controlled rigid container that is initially evacuated or has a volume that can be displaced, such as a piston and cylinder arrangement. Use containers meeting the specifications in the Table 1 of this section, noting that you may request to use other container materials under § 1065.10. Sample temperatures must stay within the following ranges for each container material:

- (1) Up to 40 °C for Tedlar™ and Kynar™.
- (2) (191 ±11) °C for Teflon™ and 300 series stainless steel used with measuring THC or NMHC from compression-ignition engines, two-stroke spark-ignition engines, and four-stroke spark-ignition engines at or below 19 kW. For all other engines and pollutants, these materials may be used for sample temperatures up to 202 °C.

TABLE 1 OF § 1065.170– CONTAINER MATERIALS FOR GASEOUS BATCH SAMPLING

Emissions	Engine type	
	Compression-ignition Two-stroke spark-ignition Four-stroke spark-ignition at or below 19 kW	All other engines
CO, CO ₂ , O ₂ , CH ₄ , C ₂ H ₆ , C ₃ H ₈ , NO, NO ₂ , N ₂ O	Tedlar™, Kynar™, Teflon™, or 300 series stainless steel	Tedlar™, Kynar™, Teflon™, or 300 series stainless steel
THC, NMHC	Teflon™ or 300 series stainless steel	Tedlar™, Kynar™, Teflon™, or 300 series stainless steel

(c) *PM sample media.* Apply the following methods for sampling particulate emissions:

(1) If you use filter-based sampling media to extract and store PM for measurement, your procedure must meet the following specifications:

- (i) If you expect that a filter’s total surface concentration of PM will exceed 400 µg, assuming a 38 mm diameter filter stain area, for a given test interval, you may use filter media with a minimum initial collection efficiency of 98 %; otherwise you must use a filter media with a minimum initial collection efficiency of 99.7 %. Collection efficiency must be measured as described in [ASTM D2986](#) (incorporated by reference, [see in § 1065.1010](#)), though you may rely on the sample-media manufacturer’s measurements reflected in their product ratings to show that you meet this requirement.
- (ii) The filter must be circular, with an overall diameter of (46.50 ±0.60) mm and an exposed diameter of at least 38 mm. See the cassette specifications in paragraph (c)(1)(vii) of this section.
- (iii) We highly recommend that you use a pure PTFE filter material that does not have any flow-through support bonded to the back and has an overall thickness of (40 ±20) µm. An inert polymer ring may be bonded to the periphery of the filter material for support and for sealing between the filter cassette parts. We consider Polymethylpentene (PMP) and PTFE inert materials for a support ring, but other inert materials may be used. See the cassette specifications in paragraph (c)(1)(vii) of this section. We allow the use of PTFE-coated glass fiber filter material, as long as this filter media selection does not affect your ability to demonstrate compliance with the applicable standards in this chapter, which we base on a pure PTFE filter material. Note that we will use pure PTFE filter material for compliance testing, and we may require you to use pure PTFE filter material for any compliance testing we require, such as for selective enforcement audits.
- (iv) You may request to use other filter materials or sizes under the provisions of § 1065.10.
- (v) To minimize turbulent deposition and to deposit PM evenly on a filter, use a filter holder with a 12.5° (from center) divergent cone angle to transition from the transfer-line inside diameter to the exposed diameter of the filter face. Use 300 series stainless steel for this transition.
- (vi) Maintain a filter face velocity near 100 cm/s with less than 5 % of the recorded flow values exceeding 100 cm/s, unless you expect the net PM mass on the filter to exceed 400 µg, assuming a 38 mm diameter filter stain area. Measure face velocity as the volumetric flow rate of the sample at the pressure upstream of the filter and temperature of the filter

face as measured in § 1065.140(e), divided by the filter's exposed area. You may use the exhaust stack or CVS tunnel pressure for the upstream pressure if the pressure drop through the PM sampler up to the filter is less than 2 kPa.

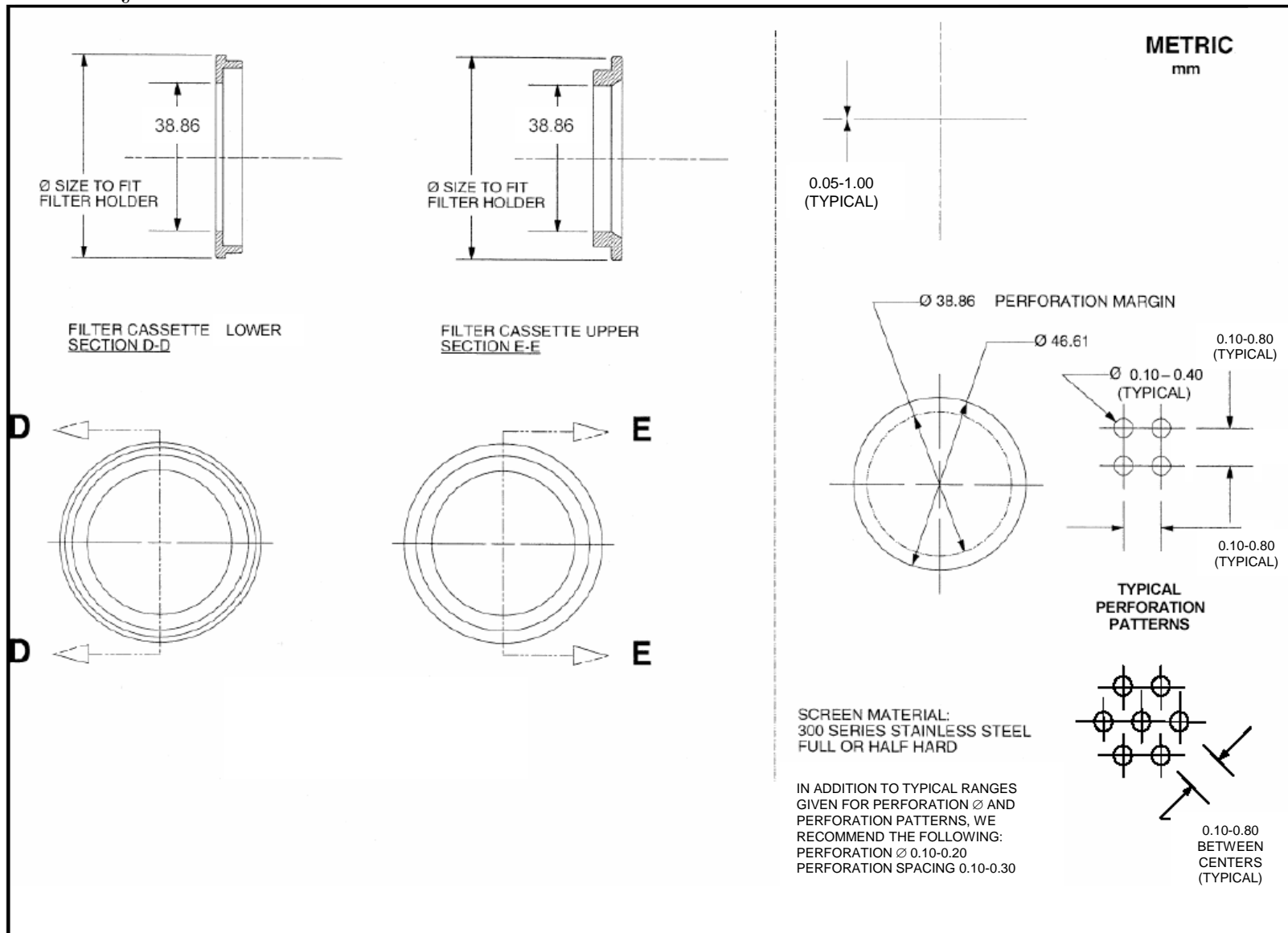
(vii) Use a clean cassette designed to the specifications of Figure 1 of § 1065.170. In auto changer configurations, you may use cassettes of similar design. Cassettes must be made of one of the following materials: Delrin™, 300 series stainless steel, polycarbonate, acrylonitrile-butadiene-styrene (ABS) resin, or conductive polypropylene. We recommend that you keep filter cassettes clean by periodically washing or wiping them with a compatible solvent applied using a lint-free cloth. Depending upon your cassette material, ethanol (C₂H₅OH) might be an acceptable solvent. Your cleaning frequency will depend on your engine's PM and HC emissions.

(viii) If you keep the cassette in the filter holder after sampling, prevent flow through the filter until either the holder or cassette is removed from the PM sampler. If you remove the cassettes from filter holders after sampling, transfer the cassette to an individual container that is covered or sealed to prevent communication of semi-volatile matter from one filter to another. If you remove the filter holder, cap the inlet and outlet. Keep them covered or sealed until they return to the stabilization or weighing environments.

(ix) The filters should not be handled outside of the PM stabilization and weighing environments and should be loaded into cassettes, filter holders, or auto changer apparatus before removal from these environments.

(2) You may use other PM sample media that we approve under § 1065.10, including non-filtering techniques. For example, you might deposit PM on an inert substrate that collects PM using electrostatic, thermophoresis, inertia, diffusion, or some other deposition mechanism, as approved.

FIGURE 1 OF § 1065.170—PM FILTER CASSETTE SPECIFICATIONS.



§ 1065.190 PM-stabilization and weighing environments for gravimetric analysis.

- (a) This section describes the two environments required to stabilize and weigh PM for gravimetric analysis: the PM stabilization environment, where filters are stored before weighing; and the weighing environment, where the balance is located. The two environments may share a common space. These volumes may be one or more rooms, or they may be much smaller, such as a glove box or an automated weighing system consisting of one or more countertop-sized environments.
- (b) We recommend that you keep both the stabilization and the weighing environments free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could contaminate PM samples. We recommend that these environments conform with an “as-built” Class Six clean room specification according to ISO 14644-1 (incorporated by reference, [see-in](#) § 1065.1010); however, we also recommend that you deviate from ISO 14644-1 as necessary to minimize air motion that might affect weighing. We recommend maximum air-supply and air-return velocities of 0.05 m/s in the weighing environment.
- (c) Verify the cleanliness of the PM-stabilization environment using reference filters, as described in § 1065.390(d).
- (d) Maintain the following ambient conditions within the two environments during all stabilization and weighing:
- (1) *Ambient temperature and tolerances.* Maintain the weighing environment at a tolerance of (22 ± 1) °C. If the two environments share a common space, maintain both environments at a tolerance of (22 ± 1) °C. If they are separate, maintain the stabilization environment at a tolerance of (22 ± 3) °C.
 - (2) *Dewpoint.* Maintain a dewpoint of 9.5 °C in both environments. This dewpoint will control the amount of water associated with sulfuric acid (H₂SO₄) PM, such that 1.2216 grams of water will be associated with each gram of H₂SO₄.
 - (3) *Dewpoint tolerances.* If the expected fraction of sulfuric acid in PM is unknown, we recommend controlling dewpoint at within ± 1 °C tolerance. This would limit any dewpoint-related change in PM to less than ± 2 %, even for PM that is 50 % sulfuric acid. If you know your expected fraction of sulfuric acid in PM, we recommend that you select an appropriate dewpoint tolerance for showing compliance with emission standards using the following table as a guide:

TABLE 1 OF § 1065.190—DEWPOINT TOLERANCE AS A FUNCTION OF % PM CHANGE AND % SULFURIC ACID PM

Expected sulfuric acid fraction of PM	± 0.5 % PM mass change	± 1 % PM mass change	± 2 % PM mass change
5 %	± 3 °C	± 6 °C	± 12 °C
50 %	± 0.3 °C	± 0.6 °C	± 1.2 °C
100 %	± 0.15 °C	± 0.3 °C	± 0.6 °C

- (e) Verify the following ambient conditions using measurement instruments that meet the specifications in subpart C of this part:
- (1) Continuously measure dewpoint and ambient temperature. Use these values to determine if the stabilization and weighing environments have remained within the tolerances specified

in paragraph (d) of this section for at least 60 min before weighing sample media (e.g., filters). We recommend that you use an interlock that automatically prevents the balance from reporting values if either of the environments have not been within the applicable tolerances for the past 60 min.

(2) Continuously measure atmospheric pressure within the weighing environment. An acceptable alternative is to use a barometer that measures atmospheric pressure outside the weighing environment, as long as you can ensure that atmospheric pressure at the balance is always within ± 100 Pa of that outside environment during weighing operations. Record atmospheric pressure as you weigh filters, and use these pressure values to perform the buoyancy correction in § 1065.690.

(f) We recommend that you install a balance as follows:

(1) Install the balance on a vibration-isolation platform to isolate it from external noise and vibration.

(2) Shield the balance from convective airflow with a static-dissipating draft shield that is electrically grounded.

(3) Follow the balance manufacturer's specifications for all preventive maintenance.

(4) Operate the balance manually or as part of an automated weighing system.

(g) Minimize static electric charge in the balance environment, as follows:

(1) Electrically ground the balance.

(2) Use 300 series stainless steel tweezers if PM sample media (e.g., filters) must be handled manually.

(3) Ground tweezers with a grounding strap, or provide a grounding strap for the operator such that the grounding strap shares a common ground with the balance. Make sure grounding straps have an appropriate resistor to protect operators from accidental shock.

(4) Provide a static-electricity neutralizer that is electrically grounded in common with the balance to remove static charge from PM sample media (e.g., filters), as follows:

(i) You may use radioactive neutralizers such as a Polonium (^{210}Po) source. Replace radioactive sources at the intervals recommended by the neutralizer manufacturer.

(ii) You may use other neutralizers, such as corona-discharge ionizers. If you use a corona-discharge ionizer, we recommend that you monitor it for neutral net charge according to the ionizer manufacturer's recommendations.

§ 1065.195 PM-stabilization environment for in-situ analyzers.

(a) This section describes the environment required to determine PM in-situ. For in-situ analyzers, such as an inertial balance, this is the environment within a PM sampling system that surrounds the PM sample media (e.g., filters). This is typically a very small volume.

(b) Maintain the environment free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could contaminate PM samples. Filter all air used for stabilization with HEPA filters. Ensure that HEPA filters are installed properly so that background PM does not leak past the HEPA filters.

(c) Maintain the following thermodynamic conditions within the environment before measuring PM:

(1) *Ambient temperature.* Select a nominal ambient temperature, T_{amb} , between (42 and 52) °C. Maintain the ambient temperature within ± 1.0 °C of the selected nominal value.

(2) *Dewpoint*. Select a dewpoint, T_{dew} , that corresponds to T_{amb} such that $T_{\text{dew}} = (0.95 \cdot T_{\text{amb}} - 11.40)$ °C. The resulting dewpoint will control the amount of water associated with sulfuric acid (H_2SO_4) PM, such that 1.1368 grams of water will be associated with each gram of H_2SO_4 . For example, if you select a nominal ambient temperature of 47 °C, set a dewpoint of 33.3 °C.

(3) *Dewpoint tolerance*. If the expected fraction of sulfuric acid in PM is unknown, we recommend controlling dewpoint within ± 1.0 °C. This would limit any dewpoint-related change in PM to less than ± 2 %, even for PM that is 50 % sulfuric acid. If you know your expected fraction of sulfuric acid in PM, we recommend that you select an appropriate dewpoint tolerance for showing compliance with emission standards using Table 1 of § 1065.190 as a guide:

(4) *Absolute pressure*. Use good engineering judgment to maintain a tolerance of absolute pressure if your PM measurement instrument requires it.

(d) Continuously measure dewpoint, temperature, and pressure using measurement instruments that meet the PM-stabilization environment specifications in subpart C of this part. Use these values to determine if the in-situ stabilization environment is within the tolerances specified in paragraph (c) of this section. Do not use any PM quantities that are recorded when any of these parameters exceed the applicable tolerances.

(e) If you use an inertial PM balance, we recommend that you install it as follows:

(1) Isolate the balance from any external noise and vibration that is within a frequency range that could affect the balance.

(2) Follow the balance manufacturer's specifications.

(f) If static electricity affects an inertial balance, you may use a static neutralizer, as follows:

(1) You may use a radioactive neutralizer such as a Polonium (^{210}Po) source or a Krypton (^{85}Kr) source. Replace radioactive sources at the intervals recommended by the neutralizer manufacturer.

(2) You may use other neutralizers, such as a corona-discharge ionizer. If you use a corona-discharge ionizer, we recommend that you monitor it for neutral net charge according to the ionizer manufacturer's recommendations.

Subpart C—Measurement Instruments

§ 1065.201 Overview and general provisions.

(a) *Scope*. This subpart specifies measurement instruments and associated system requirements related to emission testing in a laboratory or similar environment and in the field. This includes laboratory instruments and portable emission measurement systems (PEMS) for measuring engine parameters, ambient conditions, flow-related parameters, and emission concentrations.

(b) *Instrument types*. You may use any of the specified instruments as described in this subpart to perform emission tests. If you want to use one of these instruments in a way that is not specified in this subpart, or if you want to use a different instrument, you must first get us to approve your alternate procedure under § 1065.10. Where we specify more than one instrument for a particular measurement, we may identify which instrument serves as the reference for comparing with an alternate procedure. You may generally use instruments with compensation algorithms that are functions of other gaseous measurements and the known or assumed fuel properties for the test

fuel. The target value for any compensation algorithm is 0 % (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

(c) *Measurement systems.* Assemble a system of measurement instruments that allows you to show that your engines comply with the applicable emission standards, using good engineering judgment. When selecting instruments, consider how conditions such as vibration, temperature, pressure, humidity, viscosity, specific heat, and exhaust composition (including trace concentrations) may affect instrument compatibility and performance.

(d) *Redundant systems.* For all measurement instruments described in this subpart, you may use data from multiple instruments to calculate test results for a single test. If you use redundant systems, use good engineering judgment to use multiple measured values in calculations or to disregard individual measurements. Note that you must keep your results from all measurements. This requirement applies whether or not you actually use the measurements in your calculations.

(e) *Range.* You may use an instrument's response above 100 % of its operating range if this does not affect your ability to show that your engines comply with the applicable emission standards. Note that we require additional testing and reporting if an analyzer responds above 100 % of its range. Auto-ranging analyzers do not require additional testing or reporting.

(f) *Related subparts for laboratory testing.* Subpart D of this part describes how to evaluate the performance of the measurement instruments in this subpart. In general, if an instrument is specified in a specific section of this subpart, its calibration and verifications are typically specified in a similarly numbered section in subpart D of this part. For example, § 1065.290 gives instrument specifications for PM balances and § 1065.390 describes the corresponding calibrations and verifications. Note that some instruments also have other requirements in other sections of subpart D of this part. Subpart B of this part identifies specifications for other types of equipment, and subpart H of this part specifies engine fluids and analytical gases.

(g) *Field testing and testing with PEMS.* Subpart J of this part describes how to use these and other measurement instruments for field testing and other PEMS testing.

(h) *Recommended practices.* This subpart identifies a variety of recommended but not required practices for proper measurements. We believe in most cases it is necessary to follow these recommended practices for accurate and repeatable measurements. However, we do not specifically require you to follow these recommended practices to perform a valid test, as long as you meet the required calibrations and verifications of measurement systems specified in subpart D of this part. Similarly, we are not required to follow all recommended practices, as long as we meet the required calibrations and verifications. Our decision to follow or not follow a given recommendation when we perform a test does not depend on whether you followed it during your testing.

§ 1065.202 Data updating, recording, and control.

Your test system must be able to update data, record data and control systems related to operator demand, the dynamometer, sampling equipment, and measurement instruments. Set up the measurement and recording equipment to avoid aliasing by ensuring that the sampling frequency is at least double that of the signal you are measuring, consistent with good engineering judgment; this may require increasing the sampling rate or filtering the signal. Use data acquisition and control systems that can record at the specified minimum frequencies, as follows:

TABLE 1 OF § 1065.202—DATA RECORDING AND CONTROL MINIMUM FREQUENCIES

Applicable Test Protocol Section	Measured Values	Minimum Command and Control Frequency ^a	Minimum Recording Frequency ^{b,c}
§ 1065.510	Speed and torque during an engine step-map	1 Hz	1 mean value per step
§ 1065.510	Speed and torque during an engine sweep-map	5 Hz	1 Hz means
§ 1065.514 § 1065.530	Transient duty cycle reference and feedback speeds and torques	5 Hz	1 Hz means
§ 1065.514 § 1065.530	Steady-state and ramped-modal duty cycle reference and feedback speeds and torques	1 Hz	1 Hz
§ 1065.520 § 1065.530 § 1065.550	Continuous concentrations of raw or dilute analyzers	—	1 Hz
§ 1065.520 § 1065.530 § 1065.550	Batch concentrations of raw or dilute analyzers	—	1 mean value per test interval
§ 1065.530 § 1065.545	Diluted exhaust flow rate from a CVS with a heat exchanger upstream of the flow measurement	—	1 Hz
§ 1065.530 § 1065.545	Diluted exhaust flow rate from a CVS without a heat exchanger upstream of the flow measurement	5 Hz	1 Hz means
§ 1065.530 § 1065.545	Intake-air or raw-exhaust flow rate	—	1 Hz means
§ 1065.530 § 1065.545	Dilution air flow if actively controlled (for example, a partial-flow PM sampling system) ^d	5 Hz	1 Hz means
§ 1065.530 § 1065.545	Sample flow from a CVS that has a heat exchanger	1 Hz	1 Hz
§ 1065.530 § 1065.545	Sample flow from a CVS that does not have a heat exchanger	5 Hz	1 Hz means

^aThe specifications for minimum command and control frequency do not apply for CFVs that are not using active control.

^b1 Hz means are data reported from the instrument at a higher frequency, but recorded as a series of 1 s mean values at a rate of 1 Hz.

^cFor CFVs in a CVS, the minimum recording frequency is 1 Hz. The minimum recording frequency does not apply for CFVs used to control sampling from a CVS utilizing CFVs.

^dDilution air flow specifications do not apply for CVS dilution air.

§ 1065.205 Performance specifications for measurement instruments.

Your test system as a whole must meet all the calibrations, verifications, and test-validation criteria specified elsewhere in this part for laboratory testing or field testing, as applicable. We recommend that your instruments meet the specifications in this section for all ranges you use for testing. We also recommend that you keep any documentation you receive from instrument manufacturers showing that your instruments meet the specifications in the following table:

TABLE 1 OF § 1065.205—RECOMMENDED PERFORMANCE SPECIFICATIONS FOR MEASUREMENT INSTRUMENTS

Measurement Instrument	Measured quantity symbol	Complete System Rise time (t_{10-90}) and Fall time (t_{90-10}) ^a	Recording update frequency	Accuracy ^b	Repeatability ^b	Noise ^b
Engine speed transducer	f_n	1 s	1 Hz means	2 % of pt. or 0.5 % of max.	1 % of pt. or 0.25 % of max.	0.05 % of max
Engine torque transducer	T	1 s	1 Hz means	2 % of pt. or 1 % of max.	1 % of pt. or 0.5 % of max	0.05 % of max.
Electrical work (active-power meter)	W	1 s	1 Hz means	2 % of pt. or 0.5 % of max.	1 % of pt. or 0.25 % of max.	0.05 % of max
General pressure transducer (not a part of another instrument)	p	5 s	1 Hz	2 % of pt. or 1 % of max.	1 % of pt. or 0.5 % of max.	0.1 % of max
Atmospheric pressure meter for PM-stabilization and balance environments	p_{atmos}	50 s	5 times per hour	50 Pa	25 Pa	5 Pa
General purpose atmospheric pressure meter	p_{atmos}	50 s	5 times per hour	250 Pa	100Pa	50 Pa
Temperature sensor for PM-stabilization and balance environments	T	50 s	0.1 Hz	0.25 K	0.1 K	0.1 K
Other temperature sensor (not a part of another instrument)	T	10 s	0.5 Hz	0.4 % of pt. K or 0.2 % of max. K	0.2 % of pt. K or 0.1 % of max. K	0.1 % of max.
Dewpoint sensor for intake air, PM-stabilization and balance environments	T_{dew}	50 s	0.1 Hz	0.25 K	0.1 K	0.02 K
Other dewpoint sensor	T_{dew}	50 s	0.1 Hz	1 K	0.5 K	0.1 K
Fuel mass flow rate meter ^c	\dot{m}	5 s	1 Hz	2 % of pt. or 1.5 % of max.	1 % of pt. or 0.75 % of max.	0.5 % of max.
DEF mass flow rate meter ^c	\dot{m}	5 s	1 Hz	5 % of pt. or 4 % of max.	2.5 % of pt. or 2 % of max.	1.25 % of max.
Fuel mass scale ^d	m	5 s	1 Hz	0.36 % · m_{max} + 0.25 % · pt.	1.13 % · m_{max}	4.4 % · m_{max}
DEF mass scale ^d	m	5 s	1 Hz	0.36 % · m_{max} + 0.25 % · pt.	1.13 % · m_{max}	4.4 % · m_{max}
Total diluted exhaust meter (CVS) ^c (With heat exchanger before meter)	\dot{n}	1 s (5 s)	1 Hz means (1 Hz)	2 % of pt. or 1.5 % of max.	1 % of pt. or 0.75 % of max.	1 % of max.
Dilution air, inlet air, exhaust, and sample flow meters ^c	\dot{n}	1 s	1 Hz means of 5 Hz samples	2.5 % of pt. or 1.5 % of max.	1.25 % of pt. or 0.75 % of max.	1 % of max.
Continuous gas analyzer	x	5 s	1 Hz	2 % of pt. or 2 % of meas.	1 % of pt. or 1 % of meas.	1 % of max.
Batch gas analyzer	x	—	—	2 % of pt. or 2 % of meas.	1 % of pt. or 1 % of meas.	1 % of max.
Gravimetric PM balance	m_{PM}	—	—	See § 1065.790	0.5 µg	—
Inertial PM balance	m_{PM}	5 s	1 Hz	2 % of pt. or 2 % of meas.	1 % of pt. or 1 % of meas.	0.2 % of max.

^aThe performance specifications identified in the table apply separately for rise time and fall time.

^bAccuracy, repeatability, and noise are all determined with the same collected data, as described in § 1065.305, and based on absolute values. “pt.” refers to the overall flow-weighted mean value expected at the standard; “max.” refers to the peak value expected at the standard over any test interval, not the maximum of the instrument’s range; “meas” refers to the actual flow-weighted mean measured over any test interval.

^cThe procedure for accuracy, repeatability, and noise measurement described in § 1065.305 may be modified for flow meters to allow noise to be measured at the lowest calibrated value instead of zero flow rate.

^dBase performance specifications for mass scales on differential mass over the test interval as described in § 1065.307(e)(9).

MEASUREMENT OF ENGINE PARAMETERS AND AMBIENT CONDITIONS

§ 1065.210 Work input and output sensors.

(a) *Application.* Use instruments as specified in this section to measure work inputs and outputs during engine operation. We recommend that you use sensors, transducers, and meters that meet the specifications in ~~Table 1 of~~ § 1065.205. Note that your overall systems for measuring work inputs and outputs must meet the linearity verifications in § 1065.307. In all cases, ensure that you are able to accurately demonstrate compliance with the applicable standards in this chapter. The following additional provisions apply related to work inputs and outputs:

(1) We recommend that you measure work inputs and outputs where they cross the system boundary as shown in Figure 1 to paragraph (a)(5) of this section. The system boundary is different for air-cooled engines than for liquid-cooled engines.

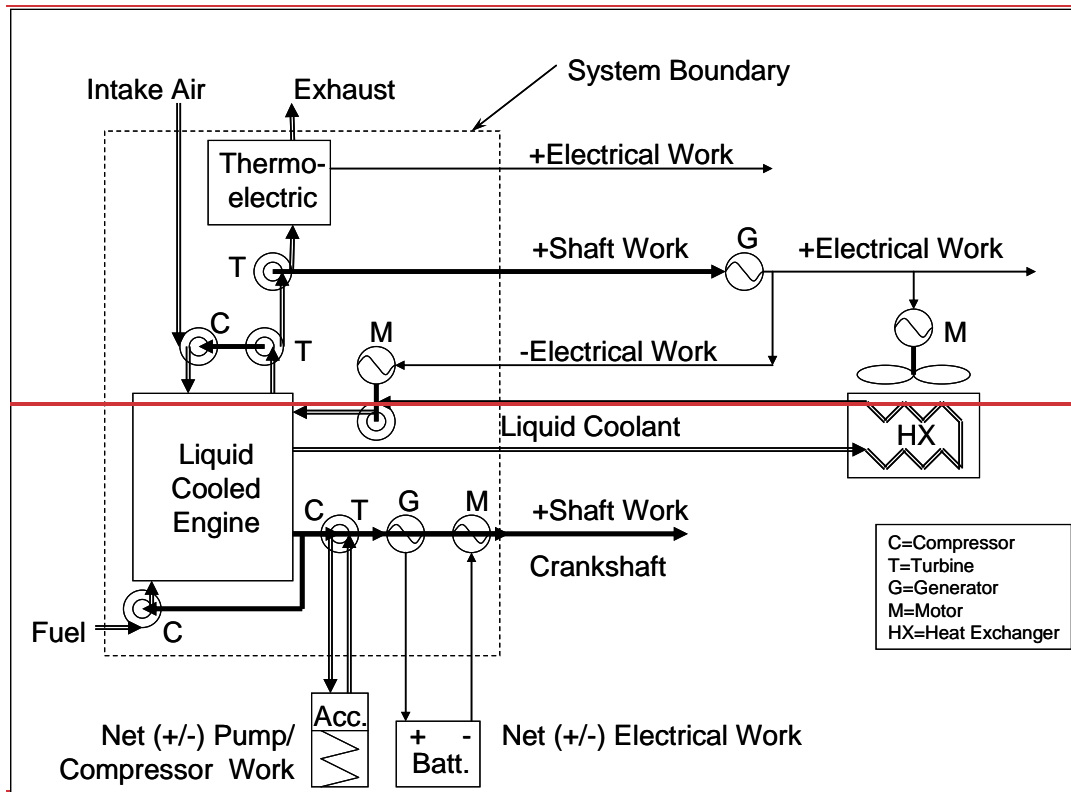
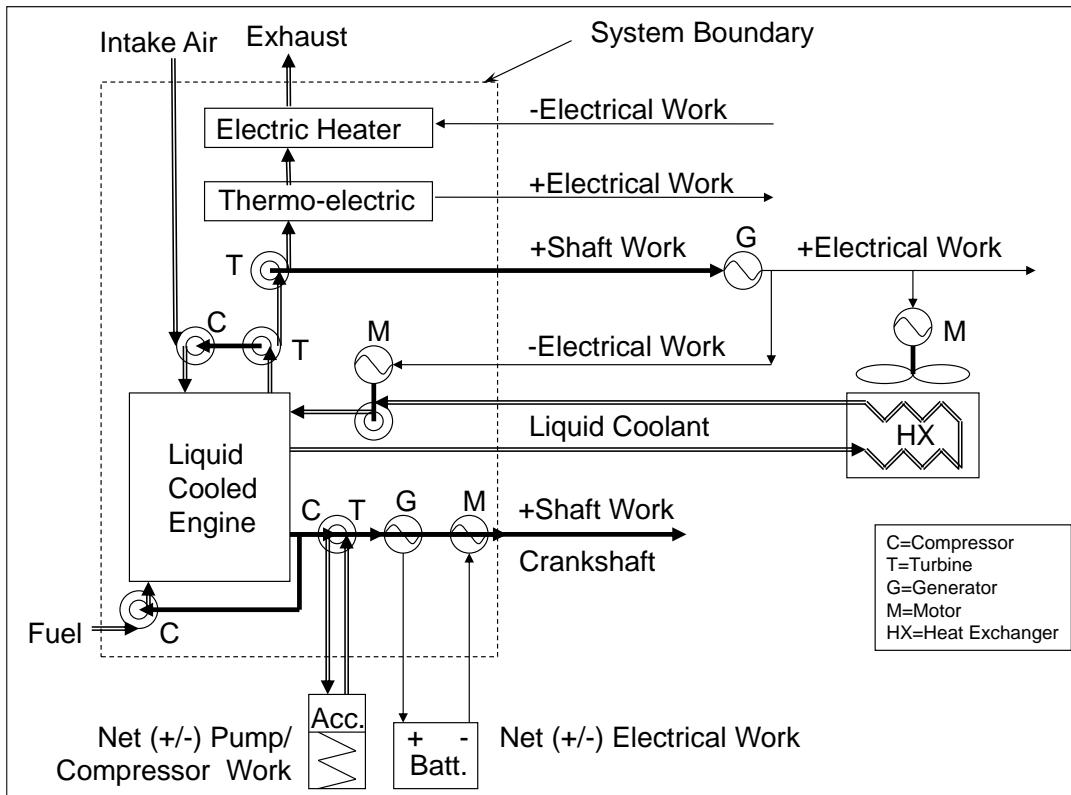
(2) For measurements involving work conversion relative to a system boundary ~~if you choose~~ use good engineering judgment to estimate any work-conversion losses in a way that avoids overestimation of total work ~~measure work before or after a work conversion, relative to the system boundary, use good engineering judgment to estimate any work-conversion losses in a way that avoids overestimation of total work.~~ For example, if it is impractical to instrument the shaft of an exhaust turbine generating electrical work, you may decide to measure its converted electrical work. ~~If your engine includes an externally powered electrical heater to heat engine exhaust, assume an electrical generator efficiency of 0.67 ($\eta = 0.67$) to account for the work needed to run the heater.~~ As another example, you may decide to measure the tractive (i.e., electrical output) power of a locomotive, rather than the brake power of the locomotive engine. For measuring tractive power based on electrical output ~~in these cases,~~ divide the electrical work by accurate values of electrical generator efficiency ($\eta < 1$), or assume an efficiency of 1 ($\eta = 1$), which would over-estimate brake-specific emissions. For the example of using locomotive tractive power with a generator efficiency of 1 ($\eta = 1$), this means using the tractive power as the brake power in emission calculations.

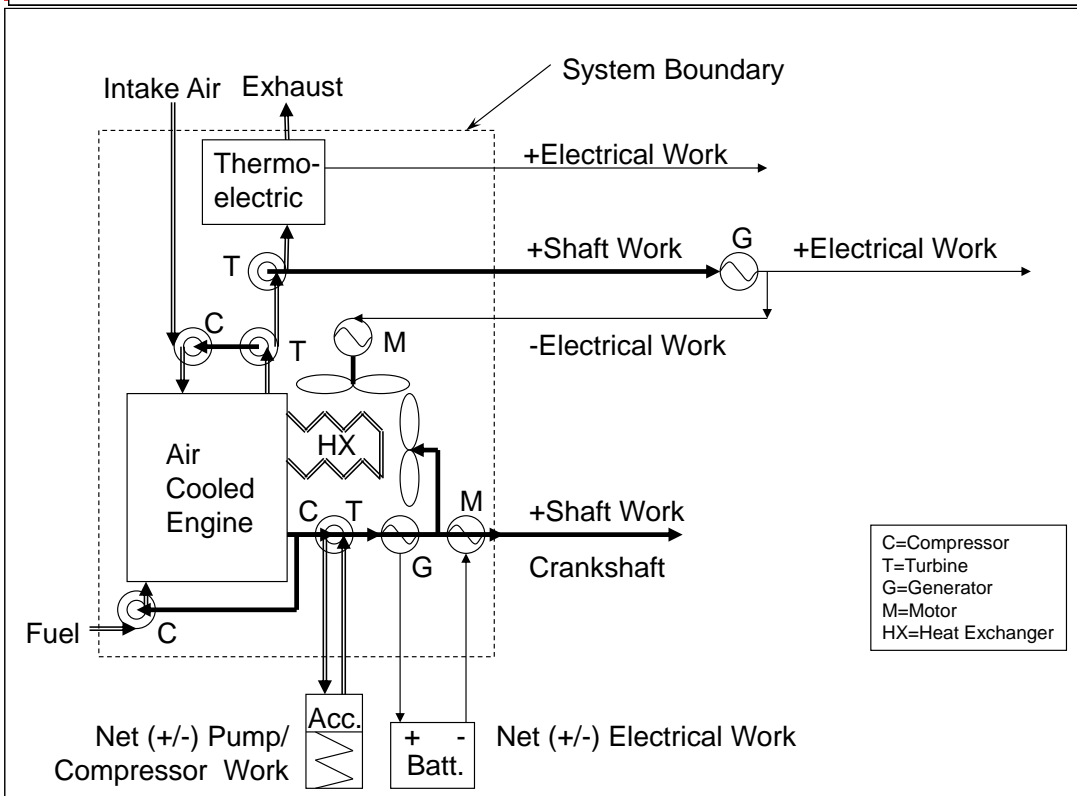
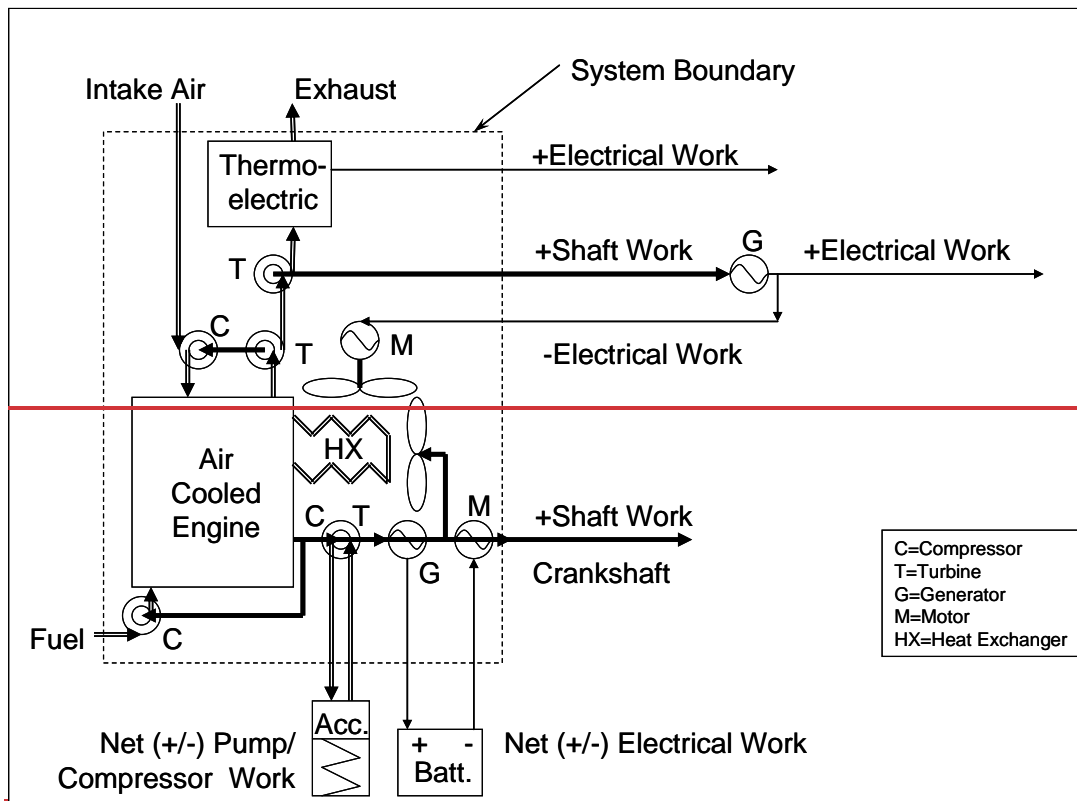
(3) If your engine includes an externally powered electrical heater to heat engine exhaust, assume an electrical generator efficiency of 0.67 ($\eta = 0.67$) to account for the work needed to run the heater.

(4) Do not underestimate any work conversion efficiencies for any components outside the system boundary that do not return work into the system boundary. And do not overestimate any work conversion efficiencies for components outside the system boundary that return work into the system boundary.

(5) In all cases, ensure that you are able to accurately demonstrate compliance with the applicable standards in this chapter. Figure 1 follows:

| FIGURE 1 TO PARAGRAPH (a)(5) OF § 1065.210: WORK INPUTS, OUTPUTS, AND SYSTEM BOUNDARIES





(b) *Shaft work*. Use speed and torque transducer outputs to calculate total work according to § 1065.650.

(1) *Speed*. Use a magnetic or optical shaft-position detector with a resolution of at least 60 counts per revolution, in combination with a frequency counter that rejects common-mode noise.

(2) *Torque*. You may use a variety of methods to determine engine torque. As needed, and based on good engineering judgment, compensate for torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor. Use any of the following methods to determine engine torque:

(i) Measure torque by mounting a strain gage or similar instrument in-line between the engine and dynamometer.

(ii) Measure torque by mounting a strain gage or similar instrument on a lever arm connected to the dynamometer housing.

(iii) Calculate torque from internal dynamometer signals, such as armature current, as long as you calibrate this measurement as described in § 1065.310.

(c) *Electrical work*. Use a watt-hour meter output to calculate total work according to § 1065.650. Use a watt-hour meter that outputs active power. Watt-hour meters typically combine a Wheatstone bridge voltmeter and a Hall-effect clamp-on ammeter into a single microprocessor-based instrument that analyzes and outputs several parameters, such as alternating or direct current voltage, current, power factor, apparent power, reactive power, and active power.

(d) *Pump, compressor or turbine work*. Use pressure transducer and flow-meter outputs to calculate total work according to § 1065.650. For flow meters, see § 1065.220 through § 1065.248.

§ 1065.215 Pressure transducers, temperature sensors, and dewpoint sensors.

(a) *Application*. Use instruments as specified in this section to measure pressure, temperature, and dewpoint.

(b) *Component requirements*. We recommend that you use pressure transducers, temperature sensors, and dewpoint sensors that meet the specifications in Table 1 of § 1065.205. Note that your overall systems for measuring pressure, temperature, and dewpoint must meet the calibration and verifications in § 1065.315.

(c) *Temperature*. For PM-balance environments or other precision temperature measurements over a narrow temperature range, we recommend thermistors. For other applications we recommend thermocouples that are not grounded to the thermocouple sheath. You may use other temperature sensors, such as resistive temperature detectors (RTDs).

(d) *Pressure*. Pressure transducers must be located in a temperature-controlled environment, or they must compensate for temperature changes over their expected operating range. Transducer materials must be compatible with the fluid being measured. For atmospheric pressure or other precision pressure measurements, we recommend either capacitance-type, quartz crystal, or laser-interferometer transducers. For other applications, we recommend either strain gage or capacitance-type pressure transducers. You may use other pressure-measurement instruments, such as manometers, where appropriate.

(e) *Dewpoint*. For PM-stabilization environments, we recommend chilled-surface hygrometers, which include chilled mirror detectors and chilled surface acoustic wave (SAW) detectors. For other applications, we recommend thin-film capacitance sensors. You may use other dewpoint sensors, such as a wet-bulb/dry-bulb psychrometer, where appropriate.

FLOW-RELATED MEASUREMENTS

§ 1065.220 Fuel flow meter.

(a) *Application*. You may use fuel flow meters in combination with a chemical balance of fuel, DEF, intake air, and raw exhaust to calculate raw exhaust flow as described in § 1065.655(f). You may also use fuel flow meters to determine the mass flow rate of carbon-carrying fuel streams for performing carbon balance error verification in § 1065.543 and to calculate the mass of those fuel streams as described in § 1065.643. The following provisions apply for using fuel flow meters:

- (1) Use the actual value of calculated raw exhaust flow rate in the following cases:
 - (i) For multiplying raw exhaust flow rate with continuously sampled concentrations.
 - (ii) For multiplying total raw exhaust flow with batch-sampled concentrations.
 - (iii) For calculating the dilution air flow for background correction as described in § 1065.667.
- (2) In the following cases, you may use a fuel flow meter signal that does not give the actual value of raw exhaust, as long as it is linearly proportional to the exhaust molar flow rate's actual calculated value:
 - (i) For feedback control of a proportional sampling system, such as a partial-flow dilution system.
 - (ii) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

(b) *Component requirements*. We recommend that you use a fuel flow meter that meets the specifications in Table 1 of § 1065.205. We recommend a fuel flow meter that measures mass directly, such as one that relies on gravimetric or inertial measurement principles. This may involve using a meter with one or more scales for weighing fuel or using a Coriolis meter. Note that your overall system for measuring fuel flow must meet the linearity verification in § 1065.307 and the calibration and verifications in § 1065.320.

(c) *Recirculating fuel*. In any fuel-flow measurement, account for any fuel that bypasses the engine or returns from the engine to the fuel storage tank.

(d) *Flow conditioning*. For any type of fuel flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. You may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, straightening fins, or pneumatic pulsation dampeners to establish a steady and predictable velocity profile upstream of the meter. Condition the flow as needed to prevent any gas bubbles in the fuel from affecting the fuel meter.

§ 1065.225 Intake-air flow meter.

(a) *Application.* You may use intake-air flow meters in combination with a chemical balance of fuel, DEF, intake air, and raw exhaust to calculate raw exhaust flow as described in § 1065.655(f) and (g). You may also use intake-air flow meters to determine the amount of intake air input for performing carbon balance error verification in § 1065.543 and to calculate the measured amount of intake air, n_{int} , as described in § 1065.643. The following provisions apply for using intake air flow meters:

- (1) Use the actual value of calculated raw exhaust in the following cases:
 - (i) For multiplying raw exhaust flow rate with continuously sampled concentrations.
 - (ii) For multiplying total raw exhaust flow with batch-sampled concentrations.
 - (iii) For verifying minimum dilution ratio for PM batch sampling as described in § 1065.546.
 - (iv) For calculating the dilution air flow for background correction as described in § 1065.667.
- (2) In the following cases, you may use an intake-air flow meter signal that does not give the actual value of raw exhaust, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:
 - (i) For feedback control of a proportional sampling system, such as a partial-flow dilution system.
 - (ii) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

(b) *Component requirements.* We recommend that you use an intake-air flow meter that meets the specifications in Table 1 of § 1065.205. This may include a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer. Note that your overall system for measuring intake-air flow must meet the linearity verification in § 1065.307 and the calibration in § 1065.325.

(c) *Flow conditioning.* For any type of intake-air flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. You may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

§ 1065.230 Raw exhaust flow meter.

(a) *Application.* You may use measured raw exhaust flow, as follows:

- (1) Use the actual value of calculated raw exhaust in the following cases:
 - (i) Multiply raw exhaust flow rate with continuously sampled concentrations.
 - (ii) Multiply total raw exhaust with batch sampled concentrations.
- (2) In the following cases, you may use a raw exhaust flow meter signal that does not give the actual value of raw exhaust, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:

(i) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

(ii) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

(b) *Component requirements.* We recommend that you use a raw-exhaust flow meter that meets the specifications in Table 1 of § 1065.205. This may involve using an ultrasonic flow meter, a subsonic venturi, an averaging Pitot tube, a hot-wire anemometer, or other measurement principle. This would generally not involve a laminar flow element or a thermal-mass meter. Note that your overall system for measuring raw exhaust flow must meet the linearity verification in § 1065.307 and the calibration and verifications in § 1065.330. Any raw-exhaust meter must be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states.

(c) *Flow conditioning.* For any type of raw exhaust flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. You may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

(d) *Exhaust cooling.* You may cool raw exhaust upstream of a raw-exhaust flow meter, as long as you observe all the following provisions:

(1) Do not sample PM downstream of the cooling.

(2) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, do not sample NMHC downstream of the cooling for compression-ignition engines, two-stroke spark-ignition engines, or four-stroke spark-ignition engines at or below 19 kW.

(3) The cooling must not cause aqueous condensation.

§ 1065.240 Dilution air and diluted exhaust flow meters.

(a) *Application.* Use a diluted exhaust flow meter to determine instantaneous diluted exhaust flow rates or total diluted exhaust flow over a test interval. You may use the difference between a diluted exhaust flow meter and a dilution air meter to calculate raw exhaust flow rates or total raw exhaust flow over a test interval.

(b) *Component requirements.* We recommend that you use a diluted exhaust flow meter that meets the specifications in Table 1 of § 1065.205. Note that your overall system for measuring diluted exhaust flow must meet the linearity verification in § 1065.307 and the calibration and verifications in § 1065.340 and § 1065.341. You may use the following meters:

(1) For constant-volume sampling (CVS) of the total flow of diluted exhaust, you may use a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow meter (UFM). Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller in a CVS system. However, you may also combine any flow meter with any active flow control system to maintain proportional sampling of exhaust constituents. You may control the total flow of diluted exhaust, or one or more sample flows, or a combination of these flow controls to maintain proportional sampling.

(2) For any other dilution system, you may use a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer.

(c) *Flow conditioning*. For any type of diluted exhaust flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, you may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

(d) *Exhaust cooling*. You may cool diluted exhaust upstream of a dilute-exhaust flow meter, as long as you observe all the following provisions:

(1) Do not sample PM downstream of the cooling.

(2) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, do not sample NMHC downstream of the cooling for compression-ignition engines, two-stroke spark-ignition engines, or four-stroke spark-ignition engines at or below 19 kW.

(3) The cooling must not cause aqueous condensation as described in § 1065.140(c)(6).

§ 1065.245 Sample flow meter for batch sampling.

(a) *Application*. Use a sample flow meter to determine sample flow rates or total flow sampled into a batch sampling system over a test interval. You may use the difference between a diluted exhaust sample flow meter and a dilution air meter to calculate raw exhaust flow rates or total raw exhaust flow over a test interval.

(b) *Component requirements*. We recommend that you use a sample flow meter that meets the specifications in Table 1 of § 1065.205. This may involve a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer. Note that your overall system for measuring sample flow must meet the linearity verification in § 1065.307. For the special case where CFVs are used for both the diluted exhaust and sample-flow measurements and their upstream pressures and temperatures remain similar during testing, you do not have to quantify the flow rate of the sample-flow CFV. In this special case, the sample-flow CFV inherently flow-weights the batch sample relative to the diluted exhaust CFV.

(c) *Flow conditioning*. For any type of sample flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, you may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

§ 1065.247 Diesel exhaust fluid flow rate.

(a) *Application*. Determine diesel exhaust fluid (DEF) flow rate over a test interval for batch or continuous emission sampling using one of the three methods described in this section.

(b) *ECM*. Use the ECM signal directly to determine DEF flow rate. You may combine this with a gravimetric scale if that improves measurement quality. Prior to testing, you may characterize the ECM signal using a laboratory measurement and adjust the ECM signal, consistent with good engineering judgment.

(c) *Flow meter*. Measure DEF flow rate with a flow meter. We recommend that the flow meter that meets the specifications in Table 1 of § 1065.205. Note that your overall system for measuring DEF flow must meet the linearity verification in § 1065.307. Measure using the following procedure:

(1) Condition the flow of DEF as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. You may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, straightening fins, or pneumatic pulsation dampeners to establish a steady and predictable velocity profile upstream of the meter. Condition the flow as needed to prevent any gas bubbles in the fluid from affecting the flow meter.

(2) Account for any fluid that bypasses the DEF dosing unit or returns from the dosing unit to the fluid storage tank.

(d) *Gravimetric scale*. Use a gravimetric scale to determine the mass of DEF the engine uses over a discrete-mode test interval and divide by the time of the test interval.

§ 1065.248 Gas divider.

(a) *Application*. You may use a gas divider to blend calibration gases.

(b) *Component requirements*. Use a gas divider that blends gases to the specifications of § 1065.750 and to the flow-weighted concentrations expected during testing. You may use critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers. Note that your overall gas-divider system must meet the linearity verification in § 1065.307.

CO AND CO₂ MEASUREMENTS

§ 1065.250 Nondispersive infrared analyzer.

(a) *Application*. Use a nondispersive infrared (NDIR) analyzer to measure CO and CO₂ concentrations in raw or diluted exhaust for either batch or continuous sampling.

(b) *Component requirements*. We recommend that you use an NDIR analyzer that meets the specifications in Table 1 of § 1065.205. Note that your NDIR-based system must meet the calibration and verifications in §§ 1065.350 and 1065.355 and it must also meet the linearity verification in § 1065.307.

H₂ AND H₂O MEASUREMENTS

HYDROCARBON, H₂, AND H₂O MEASUREMENTS

§ 1065.255 H₂ measurement devices.

(a) Component requirements. We recommend that you use an analyzer that meets the specifications in Table 1 of § 1065.205. Note that your system must meet the linearity verification in § 1065.307.

(b) Instrument types. You may use any of the following analyzers to measure H₂:

(1) Magnetic sector mass spectrometer.

(2) Raman spectrometer.

(c) Interference verification. ~~Certain species compounds can positively interfere with magnetic sector mass spectroscopy and raman spectroscopy by causing a response similar to H₂. Use good engineering judgment to determine interference species when performing running the interference verification for these analyzers, use good engineering judgment to determine interference species.~~ In the case of raman spectroscopy, determine interference species that are appropriate for each H₂ infrared absorption band, or you may identify the interference species based on the instrument manufacturer's recommendations. ~~Note that for raman spectroscopy interference species are dependent on the H₂ infrared absorption band chosen by the instrument manufacturer. For each analyzer determine the H₂ infrared absorption band. For each H₂ infrared adsorption band, determine the interference species to use in the verification. Use the interference species specified by the instrument manufacturer or use good engineering judgment to determine the interference species.~~

§ 1065.257 Fourier transform infrared analyzer for H₂O measurement devices.

(a) Component requirements. We recommend that you use an ~~FTIR~~ analyzer that meets the specifications in Table 1 of § 1065.205. Note that your system must meet the linearity verification in § 1065.307 with a humidity generator meeting using a water generation system that meets the requirements of § 1065.750(a)(6).

(b) Measurement principles. Use appropriate analytical procedures for interpretation of infrared spectra. For example, EPA Test Method 320 (see § 1065.266(b)) and ASTM D6348 (incorporated by reference, see § 1065.1010) are considered valid methods for spectral interpretation. You must use heated ~~FTIR~~ analyzers that maintain all surfaces that are exposed to emissions at a temperature of (110 to 202) °C.

(c) Instrument types. You may use any of the following analyzers to measure H₂O:

(1) Fourier transform infrared (FTIR) analyzer.

(2) Laser infrared analyzer. Examples of laser infrared analyzers are pulsed-mode high-resolution narrow band mid-infrared analyzers and modulated continuous wave high-resolution narrow band near or mid-infrared analyzers.

~~(d)~~ Interference verification. ~~Certain species compounds can interfere with FTIR and laser infrared analyzers by causing a response similar to the water. Perform interference verification for the following interference species:~~

(1) Perform CO₂ interference verification for FTIR analyzers ~~for FTIR analyzers using the procedures of § 1065.357. Use good engineering judgment to determine other interference species for FTIR analyzers when performing interference verification for FTIR analyzers. Possible interference species include, but are not limited to, Consider at least CO, NO, C₂H₄, and C₇H₈. Perform interference verifications using the procedures of § 1065.357, replacing~~

~~occurrences of CO₂ (except for § 1065.357(e)(1)) with the each targeted interference species interferent specie. Note that Determine interference species under this paragraph (b)(2) that , with the exception of CO₂, are dependent on the appropriate for each H₂O infrared absorption band, or you may identify the interference species based on chosen by the instrument manufacturer's recommendations, as CO₂ gas can positively interfere with FTIR analyzers by causing a response similar to H₂O~~

~~(2) For each analyzer determine the H₂O infrared absorption band. For each H₂O infrared absorption band, use good engineering judgment to determine interference species to use in the verification. Perform interference verification for laser infrared analyzers using the procedures of § 1065.375. Use good engineering judgment to determine interference species for laser infrared analyzers. Note that interference species are dependent on the H₂O infrared absorption band chosen by the instrument manufacturer. For each analyzer determine the H₂O infrared absorption band. Determine interference species under this paragraph (d)(2) that are appropriate for each H₂O infrared absorption band, or you may identify the interference species based on the instrument manufacturer's recommendations.~~

§ 1065.260 Flame-ionization detector.

(a) *Application.* Use a flame-ionization detector (FID) analyzer to measure hydrocarbon concentrations in raw or diluted exhaust for either batch or continuous sampling. Determine hydrocarbon concentrations on a carbon number basis of one, C₁. For measuring THC or THCE you must use a FID analyzer. For measuring CH₄ you must meet the requirements of paragraph (g) of this section. See subpart I of this part for special provisions that apply to measuring hydrocarbons when testing with oxygenated fuels.

(b) *Component requirements.* We recommend that you use a FID analyzer that meets the specifications in Table 1 of § 1065.205. Note that your FID-based system for measuring THC, THCE, or CH₄ must meet all the verifications for hydrocarbon measurement in subpart D of this part, and it must also meet the linearity verification in § 1065.307.

(c) *Heated FID analyzers.* For measuring THC or THCE from compression-ignition engines, two-stroke spark-ignition engines, and four-stroke spark-ignition engines at or below 19 kW, you must use heated FID analyzers that maintain all surfaces that are exposed to emissions at a temperature of (191 ± 11) °C.

(d) *FID fuel and burner air.* Use FID fuel and burner air that meet the specifications of § 1065.750. Do not allow the FID fuel and burner air to mix before entering the FID analyzer to ensure that the FID analyzer operates with a diffusion flame and not a premixed flame.

(e) *NMHC and NMOG.* For demonstrating compliance with NMHC standards, you may either measure THC and determine NMHC mass as described in § 1065.660(b)(1), or you may measure THC and CH₄ and determine NMHC as described in § 1065.660(b)(2) or (3). You may also use the additive method in § 1065.660(b)(4) for natural gas-fueled engines as described in § 1065.266. See 40 CFR 1066.635 for methods to demonstrate compliance with NMOG standards for vehicle testing.

(f) *NMNEHC.* For demonstrating compliance with NMNEHC standards, you may either measure NMHC and determine NMNEHC mass as described in § 1065.660(c)(1), you may measure THC, CH₄, and C₂H₆ and determine NMNEHC as described in § 1065.660(c)(2), or you may use the additive method in § 1065.660(c)(3).

(g) *CH₄*. For reporting CH₄ or for demonstrating compliance with CH₄ standards, you may use a FID analyzer with a nonmethane cutter as described in § 1065.265 or you may use a GC-FID as described in § 1065.267. Determine CH₄ as described in § 1065.660(d).

§ 1065.265 Nonmethane cutter.

(a) *Application*. You may use a nonmethane cutter to measure CH₄ with a FID analyzer. A nonmethane cutter oxidizes all nonmethane hydrocarbons to CO₂ and H₂O. You may use a nonmethane cutter for raw or diluted exhaust for batch or continuous sampling.

(b) *System performance*. Determine nonmethane-cutter performance as described in § 1065.365 and use the results to calculate CH₄ or NMHC emissions in § 1065.660.

(c) *Configuration*. Configure the nonmethane cutter with a bypass line if it is needed for the verification described in § 1065.365.

(d) *Optimization*. You may optimize a nonmethane cutter to maximize the penetration of CH₄ and the oxidation of all other hydrocarbons. You may humidify a sample and you may dilute a sample with purified air or oxygen (O₂) upstream of the nonmethane cutter to optimize its performance. You must account for any sample humidification and dilution in emission calculations.

§ 1065.266 Fourier transform infrared analyzer.

(a) *Application*. For engines that run only on natural gas, you may use a Fourier transform infrared (FTIR) analyzer to measure nonmethane hydrocarbon (NMHC) and nonmethane-nonethane hydrocarbon (NMNEHC) for continuous sampling. You may use an FTIR analyzer with any gaseous-fueled engine, including dual-fuel and flexible-fuel engines, to measure CH₄ and C₂H₆, for either batch or continuous sampling (for subtraction from THC).

(b) *Component requirements*. We recommend that you use an FTIR analyzer that meets the specifications in [Table 1 of § 1065.205](#).

(c) *Measurement principles*. Note that your FTIR-based system must meet the linearity verification in § 1065.307. Use appropriate analytical procedures for interpretation of infrared spectra. For example, EPA Test Method 320 (see <https://www.epa.gov/emc/method-320-vapor-phase-organic-and-inorganic-emissions-extractive-ftir>) and ASTM D6348 (incorporated by reference, [see in](#) § 1065.1010) are considered valid methods for spectral interpretation. You must use heated FTIR analyzers that maintain all surfaces that are exposed to emissions at a temperature of (110 to 202) °C.

(d) *Hydrocarbon species for NMHC and NMNEHC additive determination*. To determine NMNEHC, measure ethene, ethyne, propane, propene, butane, formaldehyde, acetaldehyde, formic acid, and methanol. To determine NMHC, measure ethane in addition to those same hydrocarbon species. Determine NMHC and NMNEHC as described in § 1065.660(b)(4) and [§ 1065.660\(c\)\(3\)](#).

(e) *NMHC and NMNEHC determination from subtraction of CH₄ and C₂H₆ from THC*. Determine NMHC from subtraction of CH₄ from THC as described in § 1065.660(b)(3) and NMNEHC from subtraction of CH₄ and C₂H₆ as described § 1065.660(c)(2). Determine CH₄ as described in § 1065.660(d)(2) and C₂H₆ as described § 1065.660(e).

(fe) *Interference verification.* Perform interference verification for FTIR analyzers using the procedures of § 1065.366. Certain ~~interference-gases-species~~ can interfere with FTIR analyzers by causing a response similar to the hydrocarbon species of interest. When running the interference verification for these analyzers, use interference ~~gases-species~~ as follows:

- (1) The interference ~~gases-species~~ for CH₄ are CO₂, H₂O, and C₂H₆.
- (2) The interference ~~gases-species~~ for C₂H₆ are CO₂, H₂O, and CH₄.
- (3) The interference ~~gases-species~~ for other measured hydrocarbon species are CO₂, H₂O, CH₄, and C₂H₆.

§ 1065.267 Gas chromatograph with a flame ionization detector.

(a) *Application.* You may use a gas chromatograph with a flame ionization detector (GC-FID) to measure CH₄ and C₂H₆ concentrations of diluted exhaust for batch sampling. While you may also use a nonmethane cutter to measure CH₄, as described in § 1065.265, use a reference procedure based on a gas chromatograph for comparison with any proposed alternate measurement procedure under § 1065.10.

(b) *Component requirements.* We recommend that you use a GC-FID that meets the specifications in ~~Table 1 of~~ § 1065.205 and that the measurement be done according to SAE J1151 (incorporated by reference, ~~see in~~ § 1065.1010). The GC-FID must meet the linearity verification in § 1065.307.

§ 1065.269 Photoacoustic analyzer for ethanol and methanol.

(a) *Application.* You may use a photoacoustic analyzer to measure ethanol and/or methanol concentrations in diluted exhaust for batch sampling.

(b) *Component requirements.* We recommend that you use a photoacoustic analyzer that meets the specifications in Table 1 of § 1065.205. Note that your photoacoustic system must meet the verification in § 1065.369 and it must also meet the linearity verification in § 1065.307. Use an optical wheel configuration that gives analytical priority to measurement of the least stable components in the sample. Select a sample integration time of at least 5 seconds. Take into account sample chamber and sample line volumes when determining flush times for your instrument.

NO_x, ~~AND~~ N₂O, ~~AND~~ NH₃ MEASUREMENTS

§ 1065.270 Chemiluminescent ~~detector~~NO_x analyzer.

(a) *Application.* You may use a chemiluminescent detector (CLD) to measure NO_x concentration in raw or diluted exhaust for batch or continuous sampling. We generally accept a CLD for NO_x measurement, even though it measures only NO and NO₂, when coupled with an NO₂-to-NO converter, since conventional engines and aftertreatment systems do not emit significant amounts of NO_x species other than NO and NO₂. Measure other NO_x species if required by the standard-setting part. While you may also use other instruments to measure NO_x, as described in § 1065.272, use a reference procedure based on a chemiluminescent detector for comparison with any proposed alternate measurement procedure under § 1065.10.

(b) *Component requirements.* We recommend that you use a CLD that meets the specifications in Table 1 of § 1065.205. Note that your CLD-based system must meet the quench verification in § 1065.370 and it must also meet the linearity verification in § 1065.307. You may use a heated or unheated CLD, and you may use a CLD that operates at atmospheric pressure or under a vacuum.

(c) *NO₂-to-NO converter.* Place upstream of the CLD an internal or external NO₂-to-NO converter that meets the verification in § 1065.378. Configure the converter with a bypass line if it is needed to facilitate this verification.

(d) *Humidity effects.* You must maintain all CLD temperatures to prevent aqueous condensation. If you remove humidity from a sample upstream of a CLD, use one of the following configurations:

(1) Connect a CLD downstream of any dryer or chiller that is downstream of an NO₂-to-NO converter that meets the verification in § 1065.378.

(2) Connect a CLD downstream of any dryer or thermal chiller that meets the verification in § 1065.376.

(e) *Response time.* You may use a heated CLD to improve CLD response time.

§ 1065.272 Nondispersive ultraviolet NO_x analyzer.

(a) *Application.* You may use a nondispersive ultraviolet (NDUV) analyzer to measure NO_x concentration in raw or diluted exhaust for batch or continuous sampling. We generally accept an NDUV for NO_x measurement, even though it measures only NO and NO₂, since conventional engines and aftertreatment systems do not emit significant amounts of other NO_x species. Measure other NO_x species if required by the standard-setting part. Note that good engineering judgment may preclude you from using an NDUV analyzer if sampled exhaust from test engines contains oil (or other contaminants) in sufficiently high concentrations to interfere with proper operation.

(b) *Component requirements.* We recommend that you use an NDUV analyzer that meets the specifications in Table 1 of § 1065.205. Note that your NDUV-based system must meet the verifications in § 1065.372 and it must also meet the linearity verification in § 1065.307.

(c) *NO₂-to-NO converter.* If your NDUV analyzer measures only NO, place upstream of the NDUV analyzer an internal or external NO₂-to-NO converter that meets the verification in § 1065.378. Configure the converter with a bypass to facilitate this verification.

(d) *Humidity effects.* You must maintain NDUV temperature to prevent aqueous condensation, unless you use one of the following configurations:

(1) Connect an NDUV downstream of any dryer or chiller that is downstream of an NO₂-to-NO converter that meets the verification in § 1065.378.

(2) Connect an NDUV downstream of any dryer or thermal chiller that meets the verification in § 1065.376.

§ 1065.274 Zirconium dioxide (ZrO₂) NO_x analyzer.

(a) *Application.* You may use a zirconia oxide (ZrO₂) analyzer to measure NO_x in raw exhaust for field-testing engines.

(b) *Component requirements.* We recommend that you use a ZrO₂ analyzer that meets the specifications in Table 1 of § 1065.205. Note that your ZrO₂-based system must meet the linearity verification in § 1065.307.

(c) *Species measured.* The ZrO₂-based system must be able to measure and report NO and NO₂ together as NO_x. If the ZrO₂-based system cannot measure all of the NO₂, you may develop and apply correction factors based on good engineering judgment to account for this deficiency.

(d) *Interference.* You must account for NH₃ interference with the NO_x measurement.

§ 1065.275 N₂O measurement devices.

(a) *General component requirements.* We recommend that you use an analyzer that meets the specifications in Table 1 of § 1065.205. Note that your system must meet the linearity verification in § 1065.307.

(b) *Instrument types.* You may use any of the following analyzers to measure N₂O:

(1) Nondispersive infrared (NDIR) analyzer.

(2) Fourier transform infrared (FTIR) analyzer. Use appropriate analytical procedures for interpretation of infrared spectra. For example, EPA Test Method 320 (see § 1065.266(c)) and ASTM D6348 (incorporated by reference, [see-in](#) § 1065.1010) are considered valid methods for spectral interpretation.

(3) Laser infrared analyzer. Examples of laser infrared analyzers are pulsed-mode high-resolution narrow band mid-infrared analyzers, and modulated continuous wave high-resolution narrow band mid-infrared analyzers.

(4) Photoacoustic analyzer. Use an optical wheel configuration that gives analytical priority to measurement of the least stable components in the sample. Select a sample integration time of at least 5 seconds. Take into account sample chamber and sample line volumes when determining flush times for your instrument.

(5) Gas chromatograph analyzer. You may use a gas chromatograph with an electron-capture detector (GC-ECD) to measure N₂O concentrations of diluted exhaust for batch sampling.

(i) You may use a packed or porous layer open tubular (PLOT) column phase of suitable polarity and length to achieve adequate resolution of the N₂O peak for analysis. Examples of acceptable columns are a PLOT column consisting of bonded polystyrene-divinylbenzene or a Porapak Q packed column. Take the column temperature profile and carrier gas selection into consideration when setting up your method to achieve adequate N₂O peak resolution.

(ii) Use good engineering judgment to zero your instrument and correct for drift. You do not need to follow the specific procedures in §§ 1065.530 and 1065.550(b) that would otherwise apply. For example, you may perform a span gas measurement before and after sample analysis without zeroing and use the average area counts of the pre-span and post-span measurements to generate a response factor (area counts/span gas concentration), which you then multiply by the area counts from your sample to generate the sample concentration.

(c) *Interference verification.* [Certain compounds can positively interfere with NDIR, FTIR, laser infrared analyzers, and photoacoustic analyzers by causing a response similar to N₂O.](#) Perform interference verification for NDIR, FTIR, laser infrared analyzers, and photoacoustic analyzers using the procedures of § 1065.375. Interference verification is not required for GC-ECD.

~~Certain interference gasses/species can positively interfere with NDIR, FTIR, and photoacoustic analyzers by causing a response similar to N₂O. When running the Perform interference verification for the following for these analyzers, use interference gasses/species as follows:~~

- ~~(1) The interference gasses/species for NDIR analyzers are CO, CO₂, H₂O, CH₄, and SO₂. Note that interference species, with the exception of H₂O, are dependent on the N₂O infrared absorption band chosen by the instrument manufacturer. For each analyzer determine the N₂O infrared absorption band. For each N₂O infrared absorption band, use good engineering judgment to determine which interference gasses/species to use in the evaluate for interference verification.~~
- ~~(2) Use good engineering judgment to determine interference gasses/species for FTIR, and laser infrared analyzers. Note that interference species, with the exception of H₂O, are dependent on the N₂O infrared absorption band chosen by the instrument manufacturer. For each analyzer determine the N₂O infrared absorption band. Determine interference species under this paragraph (b)(2) that are appropriate fFor each N₂O infrared absorption band, or you may identify use the interference species gasses specified by based on the instrument manufacturer's recommendations or use good engineering judgment to determine interference gasses/species to use in the verification.~~
- ~~(3) The interference gasses/species for photoacoustic analyzers are CO, CO₂, and H₂O.~~

§ 1065.277 NH₃ measurement devices.

~~(a) General component requirements. We recommend that you use an analyzer that meets the specifications in Table 1 of § 1065.205. Note that your system must meet the linearity verification in § 1065.307.~~

~~(b) Instrument types. You may use any of the following analyzers to measure NH₃:~~

- ~~(1) Nondispersive ultraviolet (NDUV) analyzer.~~
- ~~(2) Fourier transform infrared (FTIR) analyzer. Use appropriate analytical procedures for interpretation of infrared spectra. For example, EPA Test Method 320 (see § 1065.266(c)) and ASTM D6348 (incorporated by reference, see § 1065.1010) are considered valid methods for spectral interpretation.~~
- ~~(3) Laser infrared analyzer. Examples of laser infrared analyzers are pulsed-mode high-resolution narrow-band mid-infrared analyzers, modulated continuous wave high-resolution narrow band near and mid-infrared analyzers, and modulated continuous-wave high-resolution near-infrared analyzers. A quantum cascade laser, for example, can emit coherent light in the mid-infrared region where nitrogen compounds including NH₃ and other nitrogen compounds can effectively absorb the laser's energy have strong absorption.~~

~~(c) Sampling system. NH₃ has a tendency to adsorb to surfaces that it encounters. Minimize NH₃ losses and sampling artifacts related to NH₃ adsorbing to surfaces by using sampling system components (sample lines, prefilters and valves) made of stainless steel or PTFE heated to (110 to 202) °C. If surface temperatures exceed you heat these components to temperatures >130 °C, take steps to prevent any DEF in the sample gas from thermally decomposing and hydrolyzing to form NH₃ use good engineering judgement to minimize NH₃ formation due to thermal decomposition and hydrolysis of any DEF present in the sample gas. Use a sample line that is as short as practically possible.~~

(d) Interference verification. Certain species can positively interfere with NDUV, FTIR, and laser infrared analyzers by causing a response similar to NH₃. Perform interference verification as follows:

(1) Perform SO₂ and H₂O interference verification for NDUV analyzers using the procedures of § 1065.372, replacing occurrences of NO_x with NH₃ and interference species with those listed in paragraph (d)(1) of this section. NDUV analyzers must have combined interference that is within (0.0 ±2.0) µmol/mol.

(2) Perform interference verification for FTIR and laser infrared analyzers using the procedures of § 1065.377. When running the interference verification for these analyzers, use interference species as follows:(1) For NDUV analyzers, use SO₂ and H₂O as the interference species.(2) Use good engineering judgment to determine interference species for FTIR and laser infrared analyzers. Note that interference species, with the exception of H₂O, are dependent on the NH₃ infrared absorption band chosen by the instrument manufacturer. Determine interference species under this paragraph (b)(2) that are appropriate fFor each analyzer determine the NH₃ infrared absorption band, or you may identify :For each NH₃ infrared absorption band, use the interference gases specified byspecies based on the instrument manufacturer's or use good engineering judgment to determine the interference gases to use in the verification recommendations.

O₂ AND AIR-TO-FUEL RATIO MEASUREMENTS

§ 1065.280 Paramagnetic and magnetopneumatic O₂ detection analyzers.

(a) *Application.* You may use a paramagnetic detection (PMD) or magnetopneumatic detection (MPD) analyzer to measure O₂ concentration in raw or diluted exhaust for batch or continuous sampling. You may use good engineering judgment to develop calculations that use O₂ measurements with a chemical balance of fuel, DEF, intake air, and exhaust to calculate exhaust flow rate.

(b) *Component requirements.* We recommend that you use a PMD or MPD analyzer that meets the specifications in Table 1 of § 1065.205. Note that it must meet the linearity verification in § 1065.307.

AIR TO FUEL RATIO MEASUREMENTS

§ 1065.284 Zirconium dioxide (ZrO₂) air-fuel ratio and O₂ analyzer.

(a) *Application.* You may use a zirconia (ZrO₂) analyzer to measure air-to-fuel ratio in raw exhaust for continuous sampling. You may use O₂ measurements with intake air or fuel flow measurements to calculate exhaust flow rate according to § 1065.650.

(b) *Component requirements.* We recommend that you use a ZrO₂ analyzer that meets the specifications in Table 1 of § 1065.205. Note that your ZrO₂-based system must meet the linearity verification in § 1065.307.

PM MEASUREMENTS

§ 1065.290 PM gravimetric balance.

- (a) *Application.* Use a balance to weigh net PM on a sample medium for laboratory testing.
- (b) *Component requirements.* We recommend that you use a balance that meets the specifications in Table 1 of § 1065.205. Note that your balance-based system must meet the linearity verification in § 1065.307. If the balance uses internal calibration weights for routine spanning and the weights do not meet the specifications in § 1065.790, the weights must be verified independently with external calibration weights meeting the requirements of § 1065.790. While you may also use an inertial balance to measure PM, as described in § 1065.295, use a reference procedure based on a gravimetric balance for comparison with any proposed alternate measurement procedure under § 1065.10.
- (c) *Pan design.* We recommend that you use a balance pan designed to minimize corner loading of the balance, as follows:
 - (1) Use a pan that centers the PM sample media (such as a filter) on the weighing pan. For example, use a pan in the shape of a cross that has upswept tips that center the PM sample media on the pan.
 - (2) Use a pan that positions the PM sample as low as possible.
- (d) *Balance configuration.* Configure the balance for optimum settling time and stability at your location.

§ 1065.295 PM inertial balance for field-testing analysis.

- (a) *Application.* You may use an inertial balance to quantify net PM on a sample medium for field testing.
- (b) *Component requirements.* We recommend that you use a balance that meets the specifications in Table 1 of § 1065.205. Note that your balance-based system must meet the linearity verification in § 1065.307. If the balance uses an internal calibration process for routine spanning and linearity verifications, the process must be NIST-traceable.
- (c) *Loss correction.* You may use PM loss corrections to account for PM loss in the inertial balance, including the sample handling system.
- (d) *Deposition.* You may use electrostatic deposition to collect PM, as long as its collection efficiency is at least 95 %.

§ 1065.298 Correcting real-time PM measurement based on gravimetric PM filter measurement for field-testing analysis.

- (a) *Application.* You may quantify net PM on a sample medium for field testing with a continuous PM measurement with correction based on gravimetric PM filter measurement.
- (b) *Measurement principles.* Photoacoustic or electrical aerosol instruments used in field-testing typically under-report PM emissions. Apply the verifications and corrections described in this section to meet accuracy requirements.
- (c) *Component requirements.* (1) Gravimetric PM measurement must meet the laboratory measurement requirements of this part 1065, noting that there are specific exceptions to some laboratory requirements and specification for field testing given in § 1065.905(d)(2). In addition

to those exceptions, field testing does not require you to verify proportional flow control as specified in § 1065.545. Note also that the linearity requirements of § 1065.307 apply only as specified in this section.

(2) Check the calibration and linearity of the photoacoustic and electrical aerosol instruments according to the instrument manufacturer's instructions and the following recommendations:

(i) For photoacoustic instruments we recommend one of the following:

(A) Use a reference elemental carbon-based PM source to calibrate the instrument. Verify the photoacoustic instrument by comparing results either to a gravimetric PM measurement collected on the filter or to an elemental carbon analysis of collected PM.

(B) Use a light absorber that has a known amount of laser light absorption to periodically verify the instrument's calibration factor. Place the light absorber in the path of the laser beam. This verification checks the integrity of the microphone sensitivity, the power of the laser diode, and the performance of the analog-to-digital converter.

(C) Verify that you meet the linearity requirements in Table 1 of § 1065.307 by generating a maximum reference PM mass concentration (verified gravimetrically) and then using partial-flow sampling to dilute to various evenly distributed concentrations.

(ii) For electrical aerosol instruments we recommend one of the following:

(A) Use reference monodisperse or polydisperse PM-like particles with a mobility diameter or count median diameter greater than 45 nm. Use an electrometer or condensation particle counter that has a d_{50} at or below 10 nm to verify the reference values.

(B) Verify that you meet the linearity requirements in Table 1 of § 1065.307 using a maximum reference particle concentration, a zero-reference concentration, and at least two other evenly distributed points. Use partial-flow dilution to create the additional reference PM concentrations. The difference between measured values from the electrical aerosol and reference instruments at each point must be no greater than 15 % of the mean value from the two measurements at that point.

(d) *Loss correction.* You may use PM loss corrections to account for PM loss in the sample handling system.

(e) *Correction.* Develop a multiplicative correction factor to ensure that total PM measured by photoacoustic or electrical aerosol instruments equate to the gravimetric filter-based total PM measurement. Calculate the correction factor by dividing the mass of PM captured on the gravimetric filter by the quantity represented by the total concentration of PM measured by the instrument multiplied by the time over the test interval multiplied by the gravimetric filter sample flow rate.

Subpart D—Calibrations and Verifications

§ 1065.301 Overview and general provisions.

- (a) This subpart describes required and recommended calibrations and verifications of measurement systems. See subpart C of this part for specifications that apply to individual instruments.
- (b) You must generally use complete measurement systems when performing calibrations or verifications in this subpart. For example, this would generally involve evaluating instruments based on values recorded with the complete system you use for recording test data, including analog-to-digital converters. For some calibrations and verifications, we may specify that you disconnect part of the measurement system to introduce a simulated signal.
- (c) If we do not specify a calibration or verification for a portion of a measurement system, calibrate that portion of your system and verify its performance at a frequency consistent with any recommendations from the measurement-system manufacturer, consistent with good engineering judgment.
- (d) Use NIST-traceable standards to the tolerances we specify for calibrations and verifications. Where we specify the need to use NIST-traceable standards, you may alternatively use international standards recognized by the CIPM Mutual Recognition Arrangement that are not NIST-traceable.

§ 1065.303 Summary of required calibration and verifications.

The following table summarizes the required and recommended calibrations and verifications described in this subpart and indicates when these have to be performed:

TABLE 1 OF § 1065.303—SUMMARY OF REQUIRED CALIBRATION AND VERIFICATIONS

Type of calibration or verification	Minimum frequency ^a
§ 1065.305: Accuracy, repeatability and noise	<p><i>Accuracy</i>: Not required, but recommended for initial installation.</p> <p><i>Repeatability</i>: Not required, but recommended for initial installation.</p> <p><i>Noise</i>: Not required, but recommended for initial installation.</p>
§ 1065.307: Linearity verification	<p><i>Speed</i>: Upon initial installation, within 370 days before testing and after major maintenance.</p> <p><i>Torque</i>: Upon initial installation, within 370 days before testing and after major maintenance.</p> <p><i>Electrical power, current, and voltage</i>: Upon initial installation, within 370 days before testing and after major maintenance.^b</p> <p><i>Fuel mass flow rate</i>: Upon initial installation, within 370 days before testing, and after major maintenance.</p> <p><i>Fuel mass scale</i>: Upon initial installation, within 370 days before testing, and after major maintenance.</p> <p><i>DEF mass flow rate</i>: Upon initial installation, within 370 days before testing, and after major maintenance.^c</p> <p><i>DEF mass scale</i>: Upon initial installation, within 370 days before testing, and after major maintenance.</p> <p><i>Intake-air, dilution air, diluted exhaust, and batch sampler flow rates</i>: Upon initial installation, within 370 days before testing and after major maintenance.^d</p> <p><i>Raw exhaust flow rate</i>: Upon initial installation, within 185 days before testing and after major maintenance.^d</p> <p><i>Gas dividers</i>: Upon initial installation, within 370 days before testing, and after major maintenance.</p> <p><i>Gas analyzers (unless otherwise noted)</i>: Upon initial installation, within 35 days before testing and after major maintenance.</p> <p><i>FTIR and photoacoustic analyzers</i>: Upon initial installation, within 370 days before testing and after major maintenance.</p> <p><i>GC-ECD</i>: Upon initial installation and after major maintenance.</p> <p><i>PM balance</i>: Upon initial installation, within 370 days before testing and after major maintenance.</p> <p><i>Pressure, temperature, and dewpoint</i>: Upon initial installation, within 370 days before testing and after major maintenance.</p>
§ 1065.308: Continuous gas analyzer system response and updating-recording verification—for gas analyzers not continuously compensated for other gas species	Upon initial installation or after system modification that would affect response.
§ 1065.309: Continuous gas analyzer system-response and updating-recording verification—for gas analyzers continuously compensated for other gas species	Upon initial installation or after system modification that would affect response.
§ 1065.310: Torque	Upon initial installation and after major maintenance.
§ 1065.315: Pressure, temperature, dewpoint	Upon initial installation and after major maintenance.
§ 1065.320: Fuel flow	Upon initial installation and after major maintenance.
§ 1065.325: Intake flow	Upon initial installation and after major maintenance.
§ 1065.330: Exhaust flow	Upon initial installation and after major maintenance.
§ 1065.340: Diluted exhaust flow (CVS)	Upon initial installation and after major maintenance.
§ 1065.341: CVS and PFD flow verification (propane check)	Upon initial installation, within 35 days before testing, and after major maintenance. ^e
§ 1065.342 Sample dryer verification	<p>For thermal chillers: upon installation and after major maintenance.</p> <p>For osmotic membranes: upon installation, within 35 days of testing, and after major maintenance.</p>
§ 1065.345: Vacuum leak	<p>For laboratory testing: upon initial installation of the sampling system, within 8 hours before the start of the first test interval of each duty-cycle sequence, and after maintenance such as pre-filter changes.</p> <p>For field testing: after each installation of the sampling system on the vehicle, prior to the start of the field test, and after maintenance such as pre-filter changes.</p>

§ 1065.350: CO ₂ NDIR H ₂ O interference	Upon initial installation and after major maintenance.
§ 1065.355: CO NDIR CO ₂ and H ₂ O interference	Upon initial installation and after major maintenance.
§ 1065.360: FID calibration THC FID optimization, and THC FID verification	Calibrate all FID analyzers: upon initial installation and after major maintenance. Optimize and determine CH ₄ response for THC FID analyzers: upon initial installation and after major maintenance. Verify CH ₄ response for THC FID analyzers: upon initial installation, within 185 days before testing, and after major maintenance. Verify C ₂ H ₆ response for THC FID analyzers if used for NMNEHC determination: upon initial installation, within 185 days before testing, and after major maintenance.
§ 1065.362: Raw exhaust FID O ₂ interference	For all FID analyzers: upon initial installation, and after major maintenance. For THC FID analyzers: upon initial installation, after major maintenance, and after FID optimization according to § 1065.360.
§ 1065.365: Nonmethane cutter penetration	Upon initial installation, within 185 days before testing, and after major maintenance.
§ 1065.366: Interference verification for FTIR analyzers	Upon initial installation and after major maintenance.
§ 1065.369: H ₂ O, CO, and CO ₂ interference verification for ethanol photoacoustic analyzers	Upon initial installation and after major maintenance.
§ 1065.370: CLD CO ₂ and H ₂ O quench	Upon initial installation and after major maintenance.
§ 1065.372: NDUV HC and H ₂ O interference	Upon initial installation and after major maintenance.
§ 1065.375: N ₂ O analyzer interference	Upon initial installation and after major maintenance.
§ 1065.376: Chiller NO ₂ penetration	Upon initial installation and after major maintenance.
§ 1065.378: NO ₂ -to-NO converter conversion	Upon initial installation, within 35 days before testing, and after major maintenance.
§ 1065.390: PM balance and weighing	Independent verification: upon initial installation, within 370 days before testing, and after major maintenance. Zero, span, and reference sample verifications: within 12 hours of weighing, and after major maintenance.
§ 1065.395: Inertial PM balance and weighing	Independent verification: upon initial installation, within 370 days before testing, and after major maintenance. Other verifications: upon initial installation and after major maintenance.

^aPerform calibrations and verifications more frequently than we specify, according to measurement system manufacturer instructions and good engineering judgment.

^bPerform linearity verification either for electrical power or for current and voltage.

^cLinearity verification is not required if DEF flow rate comes directly from the ECM signal as described in § 1065.247(b).

^dLinearity verification is not required if the flow signal's accuracy is verified by carbon balance error verification as described in § 1065.307(e)(5) or a propane check as described in § 1065.341.

^eCVS and PFD flow verification (propane check) is not required for measurement systems verified by linearity verification as described in § 1065.307 or carbon balance error verification as described in § 1065.341(h).

§ 1065.305 Verifications for accuracy, repeatability, and noise.

- (a) This section describes how to determine the accuracy, repeatability, and noise of an instrument. Table 1 of § 1065.205 specifies recommended values for individual instruments.
- (b) We do not require you to verify instrument accuracy, repeatability, or noise. However, it may be useful to consider these verifications to define a specification for a new instrument, to verify the performance of a new instrument upon delivery, or to troubleshoot an existing instrument.
- (c) In this section we use the letter “y” to denote a generic measured quantity, the superscript over-bar to denote an arithmetic mean (such as \bar{y}), and the subscript “ref” to denote the reference quantity being measured.

(d) Conduct these verifications as follows:

(1) Prepare an instrument so it operates at its specified temperatures, pressures, and flows. Perform any instrument linearization or calibration procedures prescribed by the instrument manufacturer.

(2) Zero the instrument as you would before an emission test by introducing a zero signal. Depending on the instrument, this may be a zero-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a zero gas that meets the specifications of § 1065.750.

(3) Span the instrument as you would before an emission test by introducing a span signal. Depending on the instrument, this may be a span-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a span gas that meets the specifications of § 1065.750.

(4) Use the instrument to quantify a NIST-traceable reference quantity, y_{ref} . For gas analyzers the reference gas must meet the specifications of § 1065.750. Select a reference quantity near the mean value expected during testing. For all gas analyzers, use a quantity near the flow-weighted mean concentration expected at the standard or expected during testing, whichever is greater. For noise verification, use the same zero gas from paragraph (d)(2) of this section as the reference quantity. In all cases, allow time for the instrument to stabilize while it measures the reference quantity. Stabilization time may include time to purge an instrument and time to account for its response.

(5) Sample and record values for 30 seconds (you may select a longer sampling period if the recording update frequency is less than 0.5 Hz), record the arithmetic mean, \bar{y}_i and record the standard deviation, σ_i of the recorded values. Refer to § 1065.602 for an example of calculating arithmetic mean and standard deviation.

(6) Also, if the reference quantity is not absolutely constant, which might be the case with a reference flow, sample and record values of $y_{\text{ref}i}$ for 30 seconds and record the arithmetic mean of the values, \bar{y}_{ref} . Refer to § 1065.602 for an example of calculating arithmetic mean.

(7) Subtract the reference value, y_{ref} (or $\bar{y}_{\text{ref}i}$), from the arithmetic mean, \bar{y}_i . Record this value as the error, ϵ_i .

(8) Repeat the steps specified in paragraphs (d)(2) through (7) of this section until you have ten arithmetic means ($\bar{y}_1, \bar{y}_2, \bar{y}_i, \dots, \bar{y}_{10}$), ten standard deviations, ($\sigma_1, \sigma_2, \sigma_i, \dots, \sigma_{10}$), and ten errors ($\epsilon_1, \epsilon_2, \epsilon_i, \dots, \epsilon_{10}$).

(9) Use the following values to quantify your measurements:

(i) *Accuracy*. Instrument accuracy is the absolute difference between the reference quantity, y_{ref} (or \bar{y}_{ref}), and the arithmetic mean of the ten \bar{y}_i values, \bar{y} . Refer to the example of an accuracy calculation in § 1065.602. We recommend that instrument accuracy be within the specifications in Table 1 of § 1065.205.

(ii) *Repeatability*. Repeatability is two times the standard deviation of the ten errors (that is, repeatability = $2 \sigma_\epsilon$). Refer to the example of a standard-deviation calculation in § 1065.602. We recommend that instrument repeatability be within the specifications in Table 1 of § 1065.205.

(iii) *Noise*. Noise is two times the root-mean-square of the ten standard deviations (that is, noise = $2 \cdot rms_\sigma$) when the reference signal is a zero-quantity signal. Refer to the example

of a root-mean-square calculation in § 1065.602. We recommend that instrument noise be within the specifications in Table 1 of § 1065.205.

- (10) You may use a measurement instrument that does not meet the accuracy, repeatability, or noise specifications in Table 1 of § 1065.205, as long as you meet the following criteria:
- (i) Your measurement systems meet all the other required calibration, verification, and validation specifications that apply as specified in the regulations.
 - (ii) The measurement deficiency does not adversely affect your ability to demonstrate compliance with the applicable standards in this chapter.

§ 1065.307 Linearity verification.

(a) *Scope and frequency.* Perform linearity verification on each measurement system listed in Table 1 of this section at least as frequently as indicated in Table 1 of § 1065.303, consistent with measurement system manufacturer's recommendations and good engineering judgment. The intent of linearity verification is to determine that a measurement system responds accurately and proportionally over the measurement range of interest. Linearity verification generally consists of introducing a series of at least 10 reference values to a measurement system. The measurement system quantifies each reference value. The measured values are then collectively compared to the reference values by using a least-squares linear regression and the linearity criteria specified in Table 1 of this section.

(b) *Performance requirements.* If a measurement system does not meet the applicable linearity criteria referenced in Table 1 of this section, correct the deficiency by re-calibrating, servicing, or replacing components as needed. Repeat the linearity verification after correcting the deficiency to ensure that the measurement system meets the linearity criteria. Before you may use a measurement system that does not meet linearity criteria, you must demonstrate to us that the deficiency does not adversely affect your ability to demonstrate compliance with the applicable standards in this chapter.

(c) *Procedure.* Use the following linearity verification protocol, or use good engineering judgment to develop a different protocol that satisfies the intent of this section, as described in paragraph (a) of this section:

(1) In this paragraph (c), the letter "y" denotes a generic measured quantity, the superscript over-bar denotes an arithmetic mean (such as \bar{y}), and the subscript "ref" denotes the known or reference quantity being measured.

(2) Use good engineering judgment to operate a measurement system at normal operating conditions. This may include any specified adjustment or periodic calibration of the measurement system.

(3) If applicable, zero the instrument as you would before an emission test by introducing a zero signal. Depending on the instrument, this may be a zero-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a zero gas that meets the specifications of § 1065.750 and introduce it directly at the analyzer port.

(4) If applicable, span the instrument as you would before an emission test by introducing a span signal. Depending on the instrument, this may be a span-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas

analyzers, use a span gas that meets the specifications of § 1065.750 and introduce it directly at the analyzer port.

(5) If applicable, after spanning the instrument, check zero with the same signal you used in paragraph (c)(3) of this section. Based on the zero reading, use good engineering judgment to determine whether or not to rezero and or re-span the instrument before continuing.

(6) For all measured quantities, use the instrument manufacturer's recommendations and good engineering judgment to select reference values, $y_{\text{ref}i}$, that cover a range of values that you expect would prevent extrapolation beyond these values during emission testing. We recommend selecting a zero reference signal as one of the reference values for the linearity verification. For pressure, temperature, dewpoint, power, current, voltage, photoacoustic analyzers, and GC-ECD linearity verifications, we recommend at least three reference values. For all other linearity verifications select at least ten reference values.

(7) Use the instrument manufacturer's recommendations and good engineering judgment to select the order in which you will introduce the series of reference values. For example, you may select the reference values randomly to avoid correlation with previous measurements and to avoid hysteresis; you may select reference values in ascending or descending order to avoid long settling times of reference signals; or you may select values to ascend and then descend to incorporate the effects of any instrument hysteresis into the linearity verification.

(8) Generate reference quantities as described in paragraph (d) of this section. For gas analyzers, use gas concentrations known to be within the specifications of § 1065.750 and introduce them directly at the analyzer port.

(9) Introduce a reference signal to the measurement instrument.

(10) Allow time for the instrument to stabilize while it measures the value at the reference condition. Stabilization time may include time to purge an instrument and time to account for its response.

(11) At a recording frequency of at least f Hz, specified in Table 1 of § 1065.205, measure the value at the reference condition for 30 seconds (you may select a longer sampling period if the recording update frequency is less than 0.5 Hz) and record the arithmetic mean of the recorded values, \bar{y}_i . Refer to § 1065.602 for an example of calculating an arithmetic mean.

(12) Repeat the steps in paragraphs (c)(9) through (11) of this section until measurements are complete at each of the reference conditions.

(13) Use the arithmetic means, \bar{y}_i , and reference values, $y_{\text{ref}i}$, to calculate least-squares linear regression parameters and statistical values to compare to the minimum performance criteria specified in Table 1 of this section. Use the calculations for a floating intercept described in § 1065.602. Using good engineering judgment, you may weight the results of individual data pairs (i.e., $(y_{\text{ref}i}, \bar{y}_i)$), in the linear regression calculations.

(d) *Reference signals.* This paragraph (d) describes recommended methods for generating reference values for the linearity-verification protocol in paragraph (c) of this section. Use reference values that simulate actual values, or introduce an actual value and measure it with a reference-measurement system. In the latter case, the reference value is the value reported by the reference-measurement system. Reference values and reference-measurement systems must be NIST-traceable. We recommend using calibration reference quantities that are NIST-traceable within ± 0.5 % uncertainty, if not specified elsewhere in this part 1065. Use the following

recommended methods to generate reference values or use good engineering judgment to select a different reference:

(1) *Speed*. Run the engine or dynamometer at a series of steady-state speeds and use a strobe, photo tachometer, or laser tachometer to record reference speeds.

(2) *Torque*. Use a series of calibration weights and a calibration lever arm to simulate engine torque. You may instead use the engine or dynamometer itself to generate a nominal torque that is measured by a reference load cell or proving ring in series with the torque-measurement system. In this case, use the reference load cell measurement as the reference value. Refer to § 1065.310 for a torque-calibration procedure similar to the linearity verification in this section.

(3) *Electrical power, current, and voltage*. You must perform linearity verification for either electrical power meters, or for current and voltage meters. Perform linearity verifications using a reference meter and controlled sources of current and voltage. We recommend using a complete calibration system that is suitable for the electrical power distribution industry.

(4) *Fuel and DEF mass flow rate*. Use a gravimetric reference measurement (such as a scale, balance, or mass comparator) and a container. Use a stopwatch or timer to measure the time intervals over which reference masses of fluid pass through the mass flow rate meter. Use good engineering judgment to correct the reference mass flowing through the mass flow rate meter for buoyancy effects from any tubes, temperature probes, or objects submerged in the fluid in the container that are not attached to the container. If the container has any tubes or wires connected to the container, recalibrate the gravimetric reference measurement device with them connected and at normal operating pressure using calibration weights that meet the requirements in § 1065.790. The corrected reference mass that flowed through the mass flow rate meter during a time interval divided by the duration of the time interval is the average reference mass flow rate. For meters that report a different quantity (such as actual volume, standard volume, or moles), convert the reported quantity to mass. For meters that report a cumulative quantity calculate the average measured mass flow rate as the difference in the reported cumulative mass during the time interval divided by the duration of the time interval. For measuring flow rate of gaseous fuel prevent condensation on the fuel container and any attached tubes, fittings, or regulators.

(5) *Flow rates—inlet air, dilution air, diluted exhaust, raw exhaust, and sample flow*. Use a reference flow meter with a blower or pump to simulate flow rates. Use a restrictor, diverter valve, a variable-speed blower or a variable-speed pump to control the range of flow rates. Use the reference meter's response as the reference values.

(i) *Reference flow meters*. Because the flow range requirements for these various flows are large, we allow a variety of reference meters. For example, for diluted exhaust flow for a full-flow dilution system, we recommend a reference subsonic venturi flow meter with a restrictor valve and a blower to simulate flow rates. For inlet air, dilution air, diluted exhaust for partial-flow dilution, raw exhaust, or sample flow, we allow reference meters such as critical flow orifices, critical flow venturis, laminar flow elements, master mass flow standards, or Roots meters. Make sure the reference meter is calibrated and its calibration is NIST-traceable. If you use the difference of two flow measurements to determine a net flow rate, you may use one of the measurements as a reference for the other.

(ii) *Reference flow values.* Because the reference flow is not absolutely constant, sample and record values of \dot{n}_{refi} for 30 seconds and use the arithmetic mean of the values, $\bar{\dot{n}}_{\text{ref}}$, as the reference value. Refer to § 1065.602 for an example of calculating arithmetic mean.

(6) *Gas division.* Use one of the two reference signals:

(i) At the outlet of the gas-division system, connect a gas analyzer that meets the linearity verification described in this section and has not been linearized with the gas divider being verified. For example, verify the linearity of an analyzer using a series of reference analytical gases directly from compressed gas cylinders that meet the specifications of § 1065.750. We recommend using a FID analyzer or a PMD or MPD O₂ analyzer because of their inherent linearity. Operate this analyzer consistent with how you would operate it during an emission test. Connect a span gas containing only a single constituent of interest with balance of purified air or purified N₂ to the gas-divider inlet. Use the gas-division system to divide the span gas with purified air or nitrogen. Select gas divisions that you typically use. Use a selected gas division as the measured value. Use the analyzer response divided by the span gas concentration as the reference gas-division value. Because the instrument response is not absolutely constant, sample and record values of x_{refi} for 30 seconds and use the arithmetic mean of the values, \bar{x}_{ref} , as the reference value. Refer to § 1065.602 for an example of calculating arithmetic mean.

(ii) Using good engineering judgment and the gas divider manufacturer's recommendations, use one or more reference flow meters to measure the flow rates of the gas divider and verify the gas-division value.

(7) *Continuous constituent concentration.* For reference values, use a series of gas cylinders of known gas concentration containing only a single constituent of interest with balance of purified air or purified N₂ or use a gas-division system that is known to be linear with a span gas. Gas cylinders, gas-division systems, and span gases that you use for reference values must meet the specifications of § 1065.750.

(8) *Temperature.* You may perform the linearity verification for temperature measurement systems with thermocouples, RTDs, and thermistors by removing the sensor from the system and using a simulator in its place. Use a NIST-traceable simulator that is independently calibrated and, as appropriate, cold-junction-compensated. The simulator uncertainty scaled to absolute temperature must be less than 0.5 % of T_{max} . If you use this option, you must use sensors that the supplier states are accurate to better than 0.5 % of T_{max} compared with their standard calibration curve.

(9) *Mass.* For linearity verification for gravimetric PM balances, fuel mass scales, and DEF mass scales, use external calibration weights that meet the requirements in § 1065.790. Perform the linearity verification for fuel mass scales and DEF mass scales with the in-use container, installing all objects that interface with the container. For example, this includes all tubes, temperature probes, and objects submerged in the fluid in the container; it also includes tubes, fittings, regulators, and wires, and any other objects attached to the container. We recommend that you develop and apply appropriate buoyancy corrections for the configuration of your mass scale during normal testing, consistent with good engineering judgment. Account for the scale weighing a calibration weight instead of fluid if you calculate buoyancy corrections. You may also correct for the effect of natural convection

currents from temperature differences between the container and ambient air. Prepare for linearity verification by taking the following steps for vented and unvented containers:

- (i) If the container is vented to ambient, fill the container and tubes with fluid above the minimum level used to trigger a fill operation; drain the fluid down to the minimum level; tare the scale; and perform the linearity verification.
- (ii) If the container is rigid and not vented, drain the fluid down to the minimum level; fill all tubes attached to the container to normal operating pressure; tare the scale; and perform the linearity verification.

(e) *Measurement systems that require linearity verification.* Table 1 of this section indicates measurement systems that require linearity verification, subject to the following provisions:

- (1) Perform linearity verification more frequently based on the instrument manufacturer's recommendation or good engineering judgment.
- (2) The expression " x_{\min} " refers to the reference value used during linearity verification that is closest to zero. This is the value used to calculate the first tolerance in Table 1 of this section using the intercept, a_0 . Note that this value may be zero, positive, or negative depending on the reference values. For example, if the reference values chosen to validate a pressure transducer vary from -10 to -1 kPa, x_{\min} is -1 kPa. If the reference values used to validate a temperature device vary from 290 to 390 K, x_{\min} is 290 K.
- (3) The expression "max" generally refers to the absolute value of the reference value used during linearity verification that is furthest from zero. This is the value used to scale the first and third tolerances in Table 1 of this section using a_0 and *SEE*. For example, if the reference values chosen to validate a pressure transducer vary from -10 to -1 kPa, then p_{\max} is $+10$ kPa. If the reference values used to validate a temperature device vary from 290 to 390 K, then T_{\max} is 390 K. For gas dividers where "max" is expressed as, x_{\max}/x_{span} ; x_{\max} is the maximum gas concentration used during the verification, x_{span} is the undivided, undiluted, span gas concentration, and the resulting ratio is the maximum divider point reference value used during the verification (typically 1). The following are special cases where "max" refers to a different value:

- (i) For linearity verification of a PM balance, m_{\max} is the typical mass of a PM filter.
- (ii) For linearity verification of a torque measurement system used with the engine's primary output shaft, T_{\max} is the manufacturer's specified peak torque of the lowest torque engine expected during testing.
- (iii) For linearity verification of a fuel mass scale, m_{\max} is determined based on the range of engines and test interval durations expected during testing. It is the minimum, over all engines expected during testing, of the fuel consumption expected over the minimum test interval duration at the engine's maximum fuel rate. If the minimum test interval duration used during testing does not change with engine power or if the minimum test interval duration used during testing increases with engine power, m_{\max} is given by Eq. 1065.307-1. Calculate m_{\max} using the following equation:

$$m_{\max, \text{fuel scale}} = \dot{m}_{\max, \text{fuel}} \cdot t_{\min}$$

Eq. 1065.307-1

Where:

$\dot{m}_{\max,\text{fuel}}$ = the manufacturer's specified maximum fuel rate on the lowest-power engine expected during testing.

t_{\min} = the minimum test interval duration expected during testing. If the minimum test interval duration decreases with engine power, evaluate Eq. 1065.307-1 for the range of engines expected during testing and use the minimum calculated value of $m_{\max,\text{fuel}}$ scale.

(iv) For linearity verification of a DEF mass scale, m_{\max} is 10 % of the value determined for a fuel mass scale in paragraph (e)(3)(iii) of this section. You may determine m_{\max} for a DEF mass scale by evaluating m_{\max} for a fuel mass scale based only on the DEF-using engines expected during testing.

(v) For linearity verification of a fuel flow rate meter, \dot{m}_{\max} is the manufacturer's specified maximum fuel rate of the lowest-power engine expected during testing.

(vi) For linearity verification of a DEF flow rate meter, \dot{m}_{\max} is 10 % of the manufacturer's specified maximum fuel rate of the lowest-power DEF-using engine expected during testing.

(vii) For linearity verification of an intake-air flow rate meter, \dot{n}_{\max} is the manufacturer's specified maximum intake-air flow rate (converted to molar flow rate) of the lowest-power engine expected during testing.

(viii) For linearity verification of a raw exhaust flow rate meter, \dot{n}_{\max} is the manufacturer's specified maximum exhaust flow rate (converted to molar flow rate) of the lowest-power engine expected during testing.

(ix) For linearity verification of an electrical-power measurement system used to determine the engine's primary output shaft torque, P_{\max} is the manufacturer's specified maximum power of the lowest-power engine expected during testing.

(x) For linearity verification of an electrical-current measurement system used to determine the engine's primary output shaft torque, I_{\max} is the maximum current expected on the lowest-power engine expected during testing.

(xi) For linearity verification of an electrical-voltage measurement system used to determine the engine's primary output shaft torque, V_{\max} is the minimum peak voltage expected on the range of engines expected during testing.

(4) The specified ranges are inclusive. For example, a specified range of 0.98-1.02 for a_1 means $0.98 \leq a_1 \leq 1.02$.

(5) Table 2 of this section describes optional verification procedures you may perform instead of linearity verification for certain systems. The following provisions apply for the alternative verification procedures:

(i) Perform the propane check verification described in § 1065.341 at the frequency specified in Table 1 of § 1065.303.

(ii) Perform the carbon balance error verification described in § 1065.543 on all test sequences that use the corresponding system. It must also meet the restrictions listed in Table 2 of this section. You may evaluate the carbon balance error verification multiple ways with different inputs to validate multiple flow-measurement systems.

(6) You must meet the a_1 criteria for these quantities only if the absolute value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value.

(7) Linearity verification is required for the following temperature measurements:

- (i) The following temperature measurements always require linearity verification:
 - (A) Air intake.
 - (B) Aftertreatment bed(s), for engines tested with aftertreatment devices subject to cold-start testing.
 - (C) Dilution air for gaseous and PM sampling, including CVS, double-dilution, and partial-flow systems.
 - (D) PM sample.
 - (E) Chiller sample, for gaseous sampling systems that use thermal chillers to dry samples and use chiller temperature to calculate the dewpoint at the outlet of the chiller. For your testing, if you choose to use a high alarm temperature setpoint for the chiller temperature as a constant value in determining the amount of water removed from the emission sample, you may use good engineering judgment to verify the accuracy of the high alarm temperature setpoint instead of linearity verification on the chiller temperature. To verify that the alarm trip point value is no less than 2.0 °C below the reference value at the trip point, we recommend that you input a reference simulated temperature signal below the alarm trip point and increase this signal until the high alarm trips.
 - (F) Transmission oil.
 - (G) Axle gear oil.
- (ii) Linearity verification is required for the following temperature measurements if these temperature measurements are specified by the engine manufacturer:
 - (A) Fuel inlet.
 - (B) Air outlet to the test cell's charge air cooler air outlet, for engines tested with a laboratory heat exchanger that simulates an installed charge air cooler.
 - (C) Coolant inlet to the test cell's charge air cooler, for engines tested with a laboratory heat exchanger that simulates an installed charge air cooler.
 - (D) Oil in the sump/pan.
 - (E) Coolant before the thermostat, for liquid-cooled engines.
- (8) Linearity verification is required for the following pressure measurements:
 - (i) The following pressure measurements always require linearity verification:
 - (A) Air intake restriction.
 - (B) Exhaust back pressure as required in § 1065.130(h).
 - (C) Barometer.
 - (D) CVS inlet gage pressure where the raw exhaust enters the tunnel.
 - (E) Sample dryer, for gaseous sampling systems that use either osmotic-membrane or thermal chillers to dry samples. For your testing, if you choose to use a low alarm pressure setpoint for the sample dryer pressure as a constant value in determining the amount of water removed from the emission sample, you may use good engineering judgment to verify the accuracy of the low alarm pressure setpoint instead of linearity verification on the sample dryer pressure. To verify that the trip point value is no more than 4.0 kPa above the reference value at the trip point, we recommend that you input a reference pressure signal above the alarm trip point and decrease this signal until the low alarm trips.

(ii) Linearity verification is required for the following pressure measurements if these pressure measurements are specified by the engine manufacturer:

(A) The test cell's charge air cooler and interconnecting pipe pressure drop, for turbo-charged engines tested with a laboratory heat exchanger that simulates an installed charge air cooler.

(B) Fuel outlet.

(f) *Performance criteria for measurement systems.* Table 1 follows:

TABLE 1 OF § 1065.307—MEASUREMENT SYSTEMS THAT REQUIRE LINEARITY VERIFICATION

Measurement system	Quantity	Linearity criteria			
		$ x_{\min}(a_1-1)+a_0 $	a_1	SEE	r^2
Speed	f_n	$\leq 0.05\% \cdot f_{n\max}$	0.98-1.02	$\leq 2\% \cdot f_{n\max}$	≥ 0.990
Torque	T	$\leq 1\% \cdot T_{\max}$	0.98-1.02	$\leq 2\% \cdot T_{\max}$	≥ 0.990
Electrical power	P	$\leq 1\% \cdot P_{\max}$	0.98-1.02	$\leq 2\% \cdot P_{\max}$	≥ 0.990
Current	I	$\leq 1\% \cdot I_{\max}$	0.98-1.02	$\leq 2\% \cdot I_{\max}$	≥ 0.990
Voltage	U	$\leq 1\% \cdot U_{\max}$	0.98-1.02	$\leq 2\% \cdot U_{\max}$	≥ 0.990
Fuel flow rate	\dot{m}	$\leq 1\% \cdot \dot{m}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{m}_{\max}$	≥ 0.990
Fuel mass scale	m	$\leq 0.3\% \cdot m_{\max}$	0.996-1.004	$\leq 0.4\% \cdot m_{\max}$	≥ 0.999
DEF flow rate	\dot{m}	$\leq 1\% \cdot \dot{m}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{m}_{\max}$	≥ 0.990
DEF mass scale	m	$\leq 0.3\% \cdot m_{\max}$	0.996-1.004	$\leq 0.4\% \cdot m_{\max}$	≥ 0.999
Intake-air flow rate ^a	\dot{n}	$\leq 1\% \cdot \dot{n}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{\max}$	≥ 0.990
Dilution air flow rate ^a	\dot{n}	$\leq 1\% \cdot \dot{n}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{\max}$	≥ 0.990
Diluted exhaust flow rate ^a	\dot{n}	$\leq 1\% \cdot \dot{n}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{\max}$	≥ 0.990
Raw exhaust flow rate ^a	\dot{n}	$\leq 1\% \cdot \dot{n}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{\max}$	≥ 0.990
Batch sampler flow rates ^a	\dot{n}	$\leq 1\% \cdot \dot{n}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{\max}$	≥ 0.990
Gas dividers	x/x_{span}	$\leq 0.5\% \cdot x_{\max}/x_{\text{span}}$	0.98-1.02	$\leq 2\% \cdot x_{\max}/x_{\text{span}}$	≥ 0.990
Gas analyzers for laboratory testing	x	$\leq 0.5\% \cdot x_{\max}$	0.99-1.01	$\leq 1\% \cdot x_{\max}$	≥ 0.998
Gas analyzers for field testing	x	$\leq 1\% \cdot x_{\max}$	0.99-1.01	$\leq 1\% \cdot x_{\max}$	≥ 0.998
Electrical aerosol analyzer for field testing	x	$\leq 5\% \cdot x_{\max}$	0.85-1.15	$\leq 10\% \cdot x_{\max}$	≥ 0.950
Photoacoustic analyzer for field testing	x	$\leq 5\% \cdot x_{\max}$	0.90-1.10	$\leq 10\% \cdot x_{\max}$	≥ 0.980
PM balance	m	$\leq 1\% \cdot m_{\max}$	0.99-1.01	$\leq 1\% \cdot m_{\max}$	≥ 0.998
Pressures	p	$\leq 1\% \cdot p_{\max}$	0.99-1.01	$\leq 1\% \cdot p_{\max}$	≥ 0.998
Dewpoint for intake air, PM-stabilization and balance environments	T_{dew}	$\leq 0.5\% \cdot T_{\text{dewmax}}$	0.99-1.01	$\leq 0.5\% \cdot T_{\text{dewmax}}$	≥ 0.998
Other dewpoint measurements	T_{dew}	$\leq 1\% \cdot T_{\text{dewmax}}$	0.99-1.01	$\leq 1\% \cdot T_{\text{dewmax}}$	≥ 0.998
Analog-to-digital conversion of temperature signals	T	$\leq 1\% \cdot T_{\max}$	0.99-1.01	$\leq 1\% \cdot T_{\max}$	≥ 0.998

^aFor flow meters that determine volumetric flow rate, \dot{V}_{std} , you may substitute \dot{V}_{std} for \dot{n} as the quantity and substitute \dot{V}_{stdmax} for \dot{n}_{\max} .

(g) Alternative verification procedures. Table 2 follows:

TABLE 2 OF § 1065.307—OPTIONAL VERIFICATION TO LINEARITY VERIFICATION

Measurement system	§ 1065.341	§ 1065.543	Restrictions for § 1065.543
Intake-air flow rate	Yes	Yes	Determine raw exhaust flow rate using the intake-air flow rate signal as an input into Eq. 1065.655-24 and determine mass of CO ₂ over each test interval input into Eq. 1065.643-6 using samples taken from the raw exhaust (continuous or bag, and with or without a PFD).
Dilution air flow rate for CVS	Yes	No	Not allowed.
Diluted exhaust flow rate for CVS	Yes	Yes	Determine mass of CO ₂ over each test interval input into Eq. 1065.643-6 using samples taken from the CVS (continuous or bag, and with or without a PFD).
Raw exhaust flow rate for exhaust stack	Yes	Yes	Determine mass of CO ₂ over each test interval input into Eq. 1065.643-6 using samples taken from the raw exhaust (continuous or bag, and with or without a PFD).
Flow measurements in a PFD (usually dilution air and diluted exhaust streams) used to determine the dilution ratio in the PFD	Yes	Yes	Determine mass of CO ₂ over each test interval input into Eq. 1065.643-6 using samples taken from the PFD (continuous or bag).
Batch sampler flow rates	Yes	No	Not allowed.
Fuel mass flow rate	No	Yes	Determine mass of a carbon-carrying fluid stream used as an input into Eq. 1065.643-1 using the fuel mass flow rate meter.
Fuel mass scale	No	Yes	Determine mass of a carbon-carrying fluid stream used as an input into Eq. 1065.643-1 using the fuel mass scale.

§ 1065.308 Continuous gas analyzer system-response and updating-recording

verification—for gas analyzers not continuously compensated for other gas species.

(a) *Scope and frequency.* This section describes a verification procedure for system response and updating-recording frequency for continuous gas analyzers that output a gas species mole fraction (i.e., concentration) using a single gas detector, i.e., gas analyzers not continuously compensated for other gas species measured with multiple gas detectors. See § 1065.309 for verification procedures that apply to continuous gas analyzers that are continuously compensated for other gas species measured with multiple gas detectors. Perform this verification to determine the system response of the continuous gas analyzer and its sampling system. This verification is required for continuous gas analyzers used for transient or ramped-modal testing. You need not perform this verification for batch gas analyzer systems or for continuous gas analyzer systems that are used only for discrete-mode testing. Perform this verification after initial installation (i.e., test cell commissioning) and after any modifications to the system that would change system response. For example, perform this verification if you add a significant volume to the transfer lines by increasing their length or adding a filter; or if you reduce the frequency at which

the gas analyzer updates its output or the frequency at which you sample and record gas-analyzer concentrations.

(b) *Measurement principles.* This test verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. Gas analyzers and their sampling systems must be optimized such that their overall response to a rapid change in concentration is updated and recorded at an appropriate frequency to prevent loss of information. This test also verifies that the measurement system meets a minimum response time. You may use the results of this test to determine transformation time, t_{50} , for the purposes of time alignment of continuous data in accordance with § 1065.650(c)(2)(i). You may also use an alternate procedure to determine t_{50} in accordance with good engineering judgment. Note that any such procedure for determining t_{50} must account for both transport delay and analyzer response time.

(c) *System requirements.* Demonstrate that each continuous analyzer has adequate update and recording frequencies and has a minimum rise time and a minimum fall time during a rapid change in gas concentration. You must meet one of the following criteria:

(1) The product of the mean rise time, t_{10-90} , and the frequency at which the system records an updated concentration must be at least 5, and the product of the mean fall time, t_{90-10} , and the frequency at which the system records an updated concentration must be at least 5. If the recording frequency is different than the analyzer's output update frequency, you must use the lower of these two frequencies for this verification, which is referred to as the updating-recording frequency. This verification applies to the nominal updating and recording frequencies. This criterion makes no assumption regarding the frequency content of changes in emission concentrations during emission testing; therefore, it is valid for any testing. Also, the mean rise time must be at or below 10 seconds and the mean fall time must be at or below 10 seconds.

(2) The frequency at which the system records an updated concentration must be at least 5 Hz. This criterion assumes that the frequency content of significant changes in emission concentrations during emission testing do not exceed 1 Hz. Also, the mean rise time must be at or below 10 seconds and the mean fall time must be at or below 10 seconds.

(3) You may use other criteria if we approve the criteria in advance.

(4) You may meet the overall PEMS verification in § 1065.920 instead of the verification in this section for field testing with PEMS.

(d) *Procedure.* Use the following procedure to verify the response of each continuous gas analyzer:

(1) *Instrument setup.* Follow the analyzer manufacturer's start-up and operating instructions. Adjust the measurement system as needed to optimize performance. Run this verification with the analyzer operating in the same manner you will use for emission testing. If the analyzer shares its sampling system with other analyzers, and if gas flow to the other analyzers will affect the system response time, then start up and operate the other analyzers while running this verification test. You may run this verification test on multiple analyzers sharing the same sampling system at the same time. If you use any analog or real-time digital filters during emission testing, you must operate those filters in the same manner during this verification.

(2) *Equipment setup.* We recommend using minimal lengths of gas transfer lines between all connections and fast-acting three-way valves (2 inlets, 1 outlet) to control the flow of zero and blended span gases to the sample system's probe inlet or a tee near the outlet of the probe. If you inject the gas at a tee near the outlet of the probe, you may correct the transformation time, t_{50} , for an estimate of the transport time from the probe inlet to the tee. Normally the gas flow rate is higher than the sample flow rate and the excess is overflowed out the inlet of the probe. If the gas flow rate is lower than the sample flow rate, the gas concentrations must be adjusted to account for the dilution from ambient air drawn into the probe. We recommend you use the final, stabilized analyzer reading as the final gas concentration. Select span gases for the species being measured. You may use binary or multi-gas span gases. You may use a gas blending or mixing device to blend span gases. A gas blending or mixing device is recommended when blending span gases diluted in N₂ with span gases diluted in air. You may use a multi-gas span gas, such as NO-CO-CO₂-C₃H₈-CH₄, to verify multiple analyzers at the same time. If you use standard binary span gases, you must run separate response tests for each analyzer. In designing your experimental setup, avoid pressure pulsations due to stopping the flow through the gas-blending device. The change in gas concentration must be at least 20 % of the analyzer's range.

(3) *Data collection.* (i) Start the flow of zero gas.

(ii) Allow for stabilization, accounting for transport delays and the slowest analyzer's full response.

(iii) Start recording data. For this verification you must record data at a frequency greater than or equal to that of the updating-recording frequency used during emission testing. You may not use interpolation or filtering to alter the recorded values.

(iv) Switch the flow to allow the blended span gases to flow to the analyzer. If you intend to use the data from this test to determine t_{50} for time alignment, record this time as t_0 .

(v) Allow for transport delays and the slowest analyzer's full response.

(vi) Switch the flow to allow zero gas to flow to the analyzer. If you intend to use the data from this test to determine t_{50} for time alignment, record this time as t_{100} .

(vii) Allow for transport delays and the slowest analyzer's full response.

(viii) Repeat the steps in paragraphs (d)(3)(iv) through (vii) of this section to record seven full cycles, ending with zero gas flowing to the analyzers.

(ix) Stop recording.

(e) *Performance evaluation.* (1) If you choose to demonstrate compliance with paragraph (c)(1) of this section, use the data from paragraph (d)(3) of this section to calculate the mean rise time, t_{10-90} , and mean fall time, t_{90-10} , for each of the analyzers being verified. You may use interpolation between recorded values to determine rise and fall times. If the recording frequency used during emission testing is different from the analyzer's output update frequency, you must use the lower of these two frequencies for this verification. Multiply these times (in seconds) by their respective updating-recording frequencies in Hertz (1/second). The resulting product must be at least 5 for both rise time and fall time. If either value is less than 5, increase the updating-recording frequency, or adjust the flows or design of the sampling system to increase the rise time and fall time as needed. You may also configure analog or digital filters before recording to increase rise and fall times. In no case may the mean rise time or mean fall time be greater than 10 seconds.

(2) If a measurement system fails the criterion in paragraph (e)(1) of this section, ensure that signals from the system are updated and recorded at a frequency of at least 5 Hz. In no case may the mean rise time or mean fall time be greater than 10 seconds.

(3) If a measurement system fails the criteria in paragraphs (e)(1) and (2) of this section, you may use the measurement system only if the deficiency does not adversely affect your ability to show compliance with the applicable standards in this chapter.

(f) *Transformation time, t_{50} , determination.* If you choose to determine t_{50} for purposes of time alignment using data generated in paragraph (d)(3) of this section, calculate the mean t_{0-50} and the mean t_{100-50} from the recorded data. Average these two values to determine the final t_{50} for the purposes of time alignment in accordance with § 1065.650(c)(2)(i).

(g) *Optional procedure.* Instead of using a three-way valve to switch between zero and span gases, you may use a fast-acting two-way valve to switch sampling between ambient air and span gas at the probe inlet. For this alternate procedure, the following provisions apply:

(1) If your probe is sampling from a continuously flowing gas stream (e.g., a CVS tunnel), you may adjust the span gas flow rate to be different than the sample flow rate.

(2) If your probe is sampling from a gas stream that is not continuously flowing (e.g., a raw exhaust stack), you must adjust the span gas flow rate to be less than the sample flow rate so ambient air is always being drawn into the probe inlet. This avoids errors associated with overflowing span gas out of the probe inlet and drawing it back in when sampling ambient air.

(3) When sampling ambient air or ambient air mixed with span gas, all the analyzer readings must be stable within $\pm 0.5\%$ of the target gas concentration step size. If any analyzer reading is outside the specified range, you must resolve the problem and verify that all the analyzer readings meet this specification.

(4) For oxygen analyzers, you may use purified N_2 as the zero gas and ambient air (plus purified N_2 if needed) as the reference gas. Perform the verification with seven repeat measurements that each consist of stabilizing with purified N_2 , switching to ambient air and observing the analyzer's rise and stabilized reading, followed by switching back to purified N_2 and observing the analyzer's fall and stabilized reading.

§ 1065.309 Continuous gas analyzer system-response and updating-recording

verification—for gas analyzers continuously compensated for other gas species.

(a) *Scope and frequency.* This section describes a verification procedure for system response and updating-recording frequency for continuous gas analyzers that output a single gas species mole fraction (i.e., concentration) based on a continuous combination of multiple gas species measured with multiple detectors (i.e., gas analyzers continuously compensated for other gas species). See § 1065.308 for verification procedures that apply to continuous gas analyzers that are not continuously compensated for other gas species or that use only one detector for gaseous species. Perform this verification to determine the system response of the continuous gas analyzer and its sampling system. This verification is required for continuous gas analyzers used for transient or ramped-modal testing. You need not perform this verification for batch gas analyzers or for continuous gas analyzers that are used only for discrete-mode testing. For this check we consider water vapor a gaseous constituent. This verification does not apply to any

processing of individual analyzer signals that are time-aligned to their t_{50} times and were verified according to § 1065.308. For example, this verification does not apply to correction for water removed from the sample done in post-processing according to § 1065.659 (40 CFR 1066.620 for vehicle testing) and it does not apply to NMHC determination from THC and CH₄ according to § 1065.660. Perform this verification after initial installation (i.e., test cell commissioning) and after any modifications to the system that would change the system response.

(b) *Measurement principles.* This procedure verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. It indirectly verifies the time-alignment and uniform response of all the continuous gas detectors used to generate a continuously combined/compensated concentration measurement signal. Gas analyzer systems must be optimized such that their overall response to rapid change in concentration is updated and recorded at an appropriate frequency to prevent loss of information. This test also verifies that the measurement system meets a minimum response time. For this procedure, ensure that all compensation algorithms and humidity corrections are turned on. You may use the results of this test to determine transformation time, t_{50} , for the purposes of time alignment of continuous data in accordance with § 1065.650(c)(2)(i). You may also use an alternate procedure to determine t_{50} consistent with good engineering judgment. Note that any such procedure for determining t_{50} must account for both transport delay and analyzer response time.

(c) *System requirements.* Demonstrate that each continuously combined/compensated concentration measurement has adequate updating and recording frequencies and has a minimum rise time and a minimum fall time during a system response to a rapid change in multiple gas concentrations, including H₂O concentration if H₂O compensation is applied. You must meet one of the following criteria:

(1) The product of the mean rise time, t_{10-90} , and the frequency at which the system records an updated concentration must be at least 5, and the product of the mean fall time, t_{90-10} , and the frequency at which the system records an updated concentration must be at least 5. If the recording frequency is different than the update frequency of the continuously combined/compensated signal, you must use the lower of these two frequencies for this verification. This criterion makes no assumption regarding the frequency content of changes in emission concentrations during emission testing; therefore, it is valid for any testing. Also, the mean rise time must be at or below 10 seconds and the mean fall time must be at or below 10 seconds.

(2) The frequency at which the system records an updated concentration must be at least 5 Hz. This criterion assumes that the frequency content of significant changes in emission concentrations during emission testing do not exceed 1 Hz. Also, the mean rise time must be at or below 10 seconds and the mean fall time must be at or below 10 seconds.

(3) You may use other criteria if we approve them in advance.

(4) You may meet the overall PEMS verification in § 1065.920 instead of the verification in this section for field testing with PEMS.

(d) *Procedure.* Use the following procedure to verify the response of each continuously compensated analyzer (verify the combined signal, not each individual continuously combined concentration signal):

(1) *Instrument setup.* Follow the analyzer manufacturer's start-up and operating instructions. Adjust the measurement system as needed to optimize performance. Run this verification with the analyzer operating in the same manner you will use for emission testing. If the analyzer shares its sampling system with other analyzers, and if gas flow to the other analyzers will affect the system response time, then start up and operate the other analyzers while running this verification test. You may run this verification test on multiple analyzers sharing the same sampling system at the same time. If you use any analog or real-time digital filters during emission testing, you must operate those filters in the same manner during this verification.

(2) *Equipment setup.* We recommend using minimal lengths of gas transfer lines between all connections and fast-acting three-way valves (2 inlets, 1 outlet) to control the flow of zero and blended span gases to the sample system's probe inlet or a tee near the outlet of the probe. If you inject the gas at a tee near the outlet of the probe, you may correct the transformation time, t_{50} , for an estimate of the transport time from the probe inlet to the tee. Normally the gas flow rate is higher than the sample flow rate and the excess is overflowed out the inlet of the probe. If the gas flow rate is lower than the sample flow rate, the gas concentrations must be adjusted to account for the dilution from ambient air drawn into the probe. We recommend you use the final, stabilized analyzer reading as the final gas concentration. Select span gases for the species being continuously combined, other than H₂O. Select concentrations of compensating species that will yield concentrations of these species at the analyzer inlet that covers the range of concentrations expected during testing. You may use binary or multi-gas span gases. You may use a gas blending or mixing device to blend span gases. A gas blending or mixing device is recommended when blending span gases diluted in N₂ with span gases diluted in air. You may use a multi-gas span gas, such as NO-CO-CO₂-C₃H₈-CH₄, to verify multiple analyzers at the same time. In designing your experimental setup, avoid pressure pulsations due to stopping the flow through the gas blending device. The change in gas concentration must be at least 20 % of the analyzer's range. If H₂O correction is applicable, then span gases must be humidified before entering the analyzer; however, you may not humidify NO₂ span gas by passing it through a sealed humidification vessel that contains H₂O. You must humidify NO₂ span gas with another moist gas stream. We recommend humidifying your NO-CO-CO₂-C₃H₈-CH₄, balance N₂, blended gas by bubbling the gas mixture that meets the specifications in § 1065.750 through distilled H₂O in a sealed vessel and then mixing the gas with dry NO₂ gas, balance purified air, or by using a device that introduces distilled H₂O as vapor into a controlled span gas flow. If the sample does not pass through a dryer during emission testing, humidify your span gas to an H₂O level at or above the maximum expected during emission testing. If the sample passes through a dryer during emission testing, it must pass the sample dryer verification check in § 1065.342, and you must humidify your span gas to an H₂O level at or above the level determined in § 1065.145(e)(2) for that dryer. If you are humidifying span gases without NO₂, use good engineering judgment to ensure that the wall temperatures in the transfer lines, fittings, and valves from the humidifying system to the probe are above the dewpoint required for the target H₂O content. If you are humidifying span gases with NO₂, use good engineering judgment to ensure that there is no condensation in the transfer lines, fittings, or valves from the point where humidified gas is mixed with NO₂ span gas to the

probe. We recommend that you design your setup so that the wall temperatures in the transfer lines, fittings, and valves from the humidifying system to the probe are at least 5 °C above the local sample gas dewpoint. Operate the measurement and sample handling system as you do for emission testing. Make no modifications to the sample handling system to reduce the risk of condensation. Flow humidified gas through the sampling system before this check to allow stabilization of the measurement system's sampling handling system to occur, as it would for an emission test.

(3) *Data collection.* (i) Start the flow of zero gas.

(ii) Allow for stabilization, accounting for transport delays and the slowest analyzer's full response.

(iii) Start recording data. For this verification you must record data at a frequency greater than or equal to that of the updating-recording frequency used during emission testing. You may not use interpolation or filtering to alter the recorded values.

(iv) Switch the flow to allow the blended span gases to flow to the analyzer. If you intend to use the data from this test to determine t_{50} for time alignment, record this time as t_0 .

(v) Allow for transport delays and the slowest analyzer's full response.

(vi) Switch the flow to allow zero gas to flow to the analyzer. If you intend to use the data from this test to determine t_{50} for time alignment, record this time as t_{100} .

(vii) Allow for transport delays and the slowest analyzer's full response.

(viii) Repeat the steps in paragraphs (d)(3)(iv) through (vii) of this section to record seven full cycles, ending with zero gas flowing to the analyzers.

(ix) Stop recording.

(e) *Performance evaluations.* (1) If you choose to demonstrate compliance with paragraph (c)(1) of this section, use the data from paragraph (d)(3) of this section to calculate the mean rise time, t_{10-90} , and mean fall time, t_{90-10} , for the continuously combined signal from each analyzer being verified. You may use interpolation between recorded values to determine rise and fall times. If the recording frequency used during emission testing is different from the analyzer's output update frequency, you must use the lower of these two frequencies for this verification. Multiply these times (in seconds) by their respective updating-recording frequencies in Hz (1/second). The resulting product must be at least 5 for both rise time and fall time. If either value is less than 5, increase the updating-recording frequency or adjust the flows or design of the sampling system to increase the rise time and fall time as needed. You may also configure analog or digital filters before recording to increase rise and fall times. In no case may the mean rise time or mean fall time be greater than 10 seconds.

(2) If a measurement system fails the criterion in paragraph (e)(1) of this section, ensure that signals from the system are updated and recorded at a frequency of at least 5 Hz. In no case may the mean rise time or mean fall time be greater than 10 seconds.

(3) If a measurement system fails the criteria in paragraphs (e)(1) and (2) of this section, you may use the measurement system only if the deficiency does not adversely affect your ability to show compliance with the applicable standards in this chapter.

(f) *Transformation time, t_{50} , determination.* If you choose to determine t_{50} for purposes of time alignment using data generated in paragraph (d)(3) of this section, calculate the mean t_{0-50} and the mean t_{100-50} from the recorded data. Average these two values to determine the final t_{50} for the purposes of time alignment in accordance with § 1065.650(c)(2)(i).

(g) *Optional procedure.* Follow the optional procedures in § 1065.308(g), noting that you may use compensating gases mixed with ambient air for oxygen analyzers.

(h) *Analyzers with H₂O compensation sampling downstream of a sample dryer.* You may omit humidifying the span gas as described in this paragraph (h). If an analyzer compensates only for H₂O, you may apply the requirements of § 1065.308 instead of the requirements of this section. You may omit humidifying the span gas if you meet the following conditions:

(1) The analyzer is located downstream of a sample dryer.

(2) The maximum value for H₂O mole fraction downstream of the dryer must be less than or equal to 0.010. Verify this during each sample dryer verification according to § 1065.342.

MEASUREMENT OF ENGINE PARAMETERS AND AMBIENT CONDITIONS

§ 1065.310 Torque calibration.

(a) *Scope and frequency.* Calibrate all torque-measurement systems including dynamometer torque measurement transducers and systems upon initial installation and after major maintenance. Use good engineering judgment to repeat the calibration. Follow the torque transducer manufacturer's instructions for linearizing your torque sensor's output. We recommend that you calibrate the torque-measurement system with a reference force and a lever arm.

(b) *Recommended procedure to quantify lever-arm length.* Quantify the lever-arm length, NIST-traceable within ± 0.5 % uncertainty. The lever arm's length must be measured from the centerline of the dynamometer to the point at which the reference force is measured. The lever arm must be perpendicular to gravity (i.e., horizontal), and it must be perpendicular to the dynamometer's rotational axis. Balance the lever arm's torque or quantify its net hanging torque, NIST-traceable within ± 1 % uncertainty, and account for it as part of the reference torque.

(c) *Recommended procedure to quantify reference force.* We recommend dead-weight calibration, but you may use either of the following procedures to quantify the reference force, NIST-traceable within ± 0.5 % uncertainty.

(1) *Dead-weight calibration.* This technique applies a known force by hanging known weights at a known distance along a lever arm. Make sure the weights' lever arm is perpendicular to gravity (i.e., horizontal) and perpendicular to the dynamometer's rotational axis. Apply at least six calibration-weight combinations for each applicable torque-measuring range, spacing the weight quantities about equally over the range. Oscillate or rotate the dynamometer during calibration to reduce frictional static hysteresis. Determine each weight's reference force by multiplying its NIST-traceable mass by the local acceleration of Earth's gravity, as described in § 1065.630. Calculate the reference torque as the weights' reference force multiplied by the lever arm reference length.

(2) *Strain gage, load transducer, or proving ring calibration.* This technique applies force either by hanging weights on a lever arm (these weights and their lever arm length are not used as part of the reference torque determination) or by operating the dynamometer at different torques. Apply at least six force combinations for each applicable torque-measuring range, spacing the force quantities about equally over the range. Oscillate or rotate the dynamometer during calibration to reduce frictional static hysteresis. In this case, the reference torque is determined by multiplying the force output from the reference meter

(such as a strain gage, load transducer, or proving ring) by its effective lever-arm length, which you measure from the point where the force measurement is made to the dynamometer's rotational axis. Make sure you measure this length perpendicular to the reference meter's measurement axis and perpendicular to the dynamometer's rotational axis.

§ 1065.315 Pressure, temperature, and dewpoint calibration.

(a) Calibrate instruments for measuring pressure, temperature, and dewpoint upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration, as follows:

(1) *Pressure*. We recommend temperature-compensated, digital-pneumatic, or deadweight pressure calibrators, with data-logging capabilities to minimize transcription errors. We recommend using calibration reference quantities that are NIST-traceable within ± 0.5 % uncertainty.

(2) *Temperature*. We recommend digital dry-block or stirred-liquid temperature calibrators, with data logging capabilities to minimize transcription errors. We recommend using calibration reference quantities [for absolute temperature](#) that are NIST-traceable within ± 0.5 % uncertainty ~~of absolute temperature~~. You may perform linearity verification for temperature measurement systems with thermocouples, RTDs, and thermistors by removing the sensor from the system and using a simulator in its place. Use a NIST-traceable simulator that is independently calibrated and, as appropriate, cold-junction compensated. The simulator uncertainty scaled to absolute temperature must be less than 0.5 % of T_{\max} . If you use this option, you must use sensors that the supplier states are accurate to better than 0.5 % of T_{\max} compared with their standard calibration curve.

(3) *Dewpoint*. We recommend a minimum of three different temperature-equilibrated and temperature-monitored calibration salt solutions in containers that seal completely around the dewpoint sensor. We recommend using calibration reference quantities [for absolute dewpoint temperature](#) that are NIST-traceable within ± 0.5 % uncertainty ~~of absolute dewpoint temperature~~.

(b) You may remove system components for off-site calibration. We recommend specifying calibration reference quantities that are NIST-traceable within ± 0.5 % uncertainty.

FLOW-RELATED MEASUREMENTS

§ 1065.320 Fuel-flow calibration.

(a) Calibrate fuel-flow meters upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration.

(b) [Reserved]

(c) You may remove system components for off-site calibration. When installing a flow meter with an off-site calibration, we recommend that you consider the effects of the tubing configuration upstream and downstream of the flow meter. We recommend specifying calibration reference quantities that are NIST-traceable within ± 0.5 % uncertainty.

§ 1065.325 Intake-flow calibration.

- (a) Calibrate intake-air flow meters upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration. We recommend using a calibration subsonic venturi, ultrasonic flow meter or laminar flow element. We recommend using calibration reference quantities that are NIST-traceable within ± 0.5 % uncertainty.
- (b) You may remove system components for off-site calibration. When installing a flow meter with an off-site calibration, we recommend that you consider the effects of the tubing configuration upstream and downstream of the flow meter. We recommend specifying calibration reference quantities that are NIST-traceable within ± 0.5 % uncertainty.
- (c) If you use a subsonic venturi or ultrasonic flow meter for intake flow measurement, we recommend that you calibrate it as described in § 1065.340.

§ 1065.330 Exhaust-flow calibration.

- (a) Calibrate exhaust-flow meters upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration. We recommend that you use a calibration subsonic venturi or ultrasonic flow meter and simulate exhaust temperatures by incorporating a heat exchanger between the calibration meter and the exhaust-flow meter. If you can demonstrate that the flow meter to be calibrated is insensitive to exhaust temperatures, you may use other reference meters such as laminar flow elements, which are not commonly designed to withstand typical raw exhaust temperatures. We recommend using calibration reference quantities that are NIST-traceable within ± 0.5 % uncertainty.
- (b) You may remove system components for off-site calibration. When installing a flow meter with an off-site calibration, we recommend that you consider the effects of the tubing configuration upstream and downstream of the flow meter. We recommend specifying calibration reference quantities that are NIST-traceable within ± 0.5 % uncertainty.
- (c) If you use a subsonic venturi or ultrasonic flow meter for raw exhaust flow measurement, we recommend that you calibrate it as described in § 1065.340.

§ 1065.340 Diluted exhaust flow (CVS) calibration.

- (a) *Overview.* This section describes how to calibrate flow meters for diluted exhaust constant-volume sampling (CVS) systems.
- (b) *Scope and frequency.* Perform this calibration while the flow meter is installed in its permanent position, except as allowed in paragraph (c) of this section. Perform this calibration after you change any part of the flow configuration upstream or downstream of the flow meter that may affect the flow-meter calibration. Perform this calibration upon initial CVS installation and whenever corrective action does not resolve a failure to meet the diluted exhaust flow verification (i.e., propane check) in § 1065.341.
- (c) *Ex-situ CFV and SSV calibration.* You may remove a CFV or SSV from its permanent position for calibration as long as it meets the following requirements when installed in the CVS:
 - (1) Upon installation of the CFV or SSV into the CVS, use good engineering judgment to verify that you have not introduced any leaks between the CVS inlet and the venturi.

(2) After ex-situ venturi calibration, you must verify all venturi flow combinations for CFVs or at minimum of 10 flow points for an SSV using the propane check as described in § 1065.341. Your propane check result for each venturi flow point may not exceed the tolerance in § 1065.341(f)(5).

(3) To verify your ex-situ calibration for a CVS with more than a single CFV, perform the following check to verify that there are no flow meter entrance effects that can prevent you from passing this verification.

(i) Use a constant flow device like a CFO kit to deliver a constant flow of propane to the dilution tunnel.

(ii) Measure hydrocarbon concentrations at a minimum of 10 separate flow rates for an SSV flow meter, or at all possible flow combinations for a CFV flow meter, while keeping the flow of propane constant. We recommend selecting CVS flow rates in a random order.

(iii) Measure the concentration of hydrocarbon background in the dilution air at the beginning and end of this test. Subtract the average background concentration from each measurement at each flow point before performing the regression analysis in paragraph (c)(3)(iv) of this section.

(iv) Perform a power regression using all the paired values of flow rate and corrected concentration to obtain a relationship in the form of $y = a \cdot x^b$. Use concentration as the independent variable and flow rate as the dependent variable. For each data point, calculate the difference between the measured flow rate and the value represented by the curve fit. The difference at each point must be less than ± 1 % of the appropriate regression value. The value of b must be between -1.005 and -0.995 . If your results do not meet these limits, take corrective action consistent with § 1065.341(a).

(v) If your results do not meet the limits set in paragraph (iv) of this section, determine the source of error, which are described in § 1065.341(a), and take corrective action as necessary.

(d) *Reference flow meter.* Calibrate a CVS flow meter using a reference flow meter such as a subsonic venturi flow meter, a long-radius ASME/NIST flow nozzle, a smooth approach orifice, a laminar flow element, a set of critical flow venturis, or an ultrasonic flow meter. Use a reference flow meter that reports quantities that are NIST-traceable within ± 1 % uncertainty. Use this reference flow meter's response to flow as the reference value for CVS flow-meter calibration.

(e) *Configuration.* Calibrate the system with any upstream screens or other restrictions that will be used during testing and that could affect the flow ahead of the CVS flow meter, using good engineering judgment to minimize the effect on the flow distribution. You may not use any upstream screen or other restriction that could affect the flow ahead of the reference flow meter, unless the flow meter has been calibrated with such a restriction. In the case of a free standing SSV reference flow meter, you may not have any upstream screens.

(f) *PDP calibration.* Calibrate a positive-displacement pump (PDP) to determine a flow-versus-PDP speed equation that accounts for flow leakage across sealing surfaces in the PDP as a function of PDP inlet pressure. Determine unique equation coefficients for each speed at which you operate the PDP. Calibrate a PDP flow meter as follows:

(1) Connect the system as shown in Figure 1 of this section.

- (2) Leaks between the calibration flow meter and the PDP must be less than 0.3 % of the total flow at the lowest calibrated flow point; for example, at the highest restriction and lowest PDP-speed point.
- (3) While the PDP operates, maintain a constant temperature at the PDP inlet within ± 2 % of the mean absolute inlet temperature, \bar{T}_{in} .
- (4) Set the PDP speed to the first speed point at which you intend to calibrate.
- (5) Set the variable restrictor to its wide-open position.
- (6) Operate the PDP for at least 3 min to stabilize the system. Continue operating the PDP and record the mean values of at least 30 seconds of sampled data of each of the following quantities:
 - (i) The mean flow rate of the reference flow meter, \bar{n}_{ref} . This may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating \bar{n}_{ref} .
 - (ii) The mean temperature at the PDP inlet, \bar{T}_{in} .
 - (iii) The mean static absolute pressure at the PDP inlet, \bar{p}_{in} .
 - (iv) The mean static absolute pressure at the PDP outlet, \bar{p}_{out} .
 - (v) The mean PDP speed, \bar{f}_{nPDP} .
- (7) Incrementally close the restrictor valve to decrease the absolute pressure at the inlet to the PDP, p_{in} .
- (8) Repeat the steps in paragraphs (e)(6) and (7) of this section to record data at a minimum of six restrictor positions ranging from the wide open restrictor position to the minimum expected pressure at the PDP inlet or the maximum expected differential (outlet minus inlet) pressure across the PDP during testing.
- (9) Calibrate the PDP by using the collected data and the equations in § 1065.640.
- (10) Repeat the steps in paragraphs (e)(6) through (9) of this section for each speed at which you operate the PDP.
- (11) Use the equations in § 1065.642 to determine the PDP flow equation for emission testing.
- (12) Verify the calibration by performing a CVS verification (i.e., propane check) as described in § 1065.341.
- (13) During emission testing ensure that the PDP is not operated either below the lowest inlet pressure point or above the highest differential pressure point in the calibration data.
- (g) *SSV calibration.* Calibrate a subsonic venturi (SSV) to determine its calibration coefficient, C_d , for the expected range of inlet pressures. Calibrate an SSV flow meter as follows:
 - (1) Connect the system as shown in Figure 1 of this section.
 - (2) Verify that any leaks between the calibration flow meter and the SSV are less than 0.3 % of the total flow at the highest restriction.
 - (3) Start the blower downstream of the SSV.
 - (4) While the SSV operates, maintain a constant temperature at the SSV inlet within ± 2 % of the mean absolute inlet temperature, \bar{T}_{in} .
 - (5) Set the variable restrictor or variable-speed blower to a flow rate greater than the greatest flow rate expected during testing. You may not extrapolate flow rates beyond calibrated values, so we recommend that you make sure the Reynolds number, $Re^\#$, at the SSV throat at the greatest calibrated flow rate is greater than the maximum $Re^\#$ expected during testing.

(6) Operate the SSV for at least 3 min to stabilize the system. Continue operating the SSV and record the mean of at least 30 seconds of sampled data of each of the following quantities:

(i) The mean flow rate of the reference flow meter \bar{n}_{ref} . This may include several measurements of different quantities for calculating \bar{n}_{ref} , such as reference meter pressures and temperatures.

(ii) Optionally, the mean dewpoint of the calibration air, \bar{T}_{dew} . See § 1065.640 for permissible assumptions.

(iii) The mean temperature at the venturi inlet, \bar{T}_{in} .

(iv) The mean static absolute pressure at the venturi inlet, \bar{p}_{in} .

(v) The mean static differential pressure between the static pressure at the venturi inlet and the static pressure at the venturi throat, $\Delta\bar{p}_{\text{SSV}}$.

(7) Incrementally close the restrictor valve or decrease the blower speed to decrease the flow rate.

(8) Repeat the steps in paragraphs (g)(6) and (7) of this section to record data at a minimum of ten flow rates.

(9) Determine an equation to quantify C_d as a function of $Re^{\#}$ by using the collected data and the equations in § 1065.640. Section 1065.640 also includes statistical criteria for validating the C_d versus $Re^{\#}$ equation.

(10) Verify the calibration by performing a CVS verification (i.e., propane check) as described in § 1065.341 using the new C_d versus $Re^{\#}$ equation.

(11) Use the SSV only between the minimum and maximum calibrated $Re^{\#}$. If you want to use the SSV at a lower or higher $Re^{\#}$, you must recalibrate the SSV.

(12) Use the equations in § 1065.642 to determine SSV flow during a test.

(h) *CFV calibration.* Calibrate a critical-flow venturi (CFV) to verify its discharge coefficient, C_d , up to the highest expected pressure ratio, r , according to § 1065.640. Calibrate a CFV flow meter as follows:

(1) Connect the system as shown in Figure 1 of this section.

(2) Verify that any leaks between the calibration flow meter and the CFV are less than 0.3 % of the total flow at the highest restriction.

(3) Start the blower downstream of the CFV.

(4) While the CFV operates, maintain a constant temperature at the CFV inlet within ± 2 % of the mean absolute inlet temperature, \bar{T}_{in} .

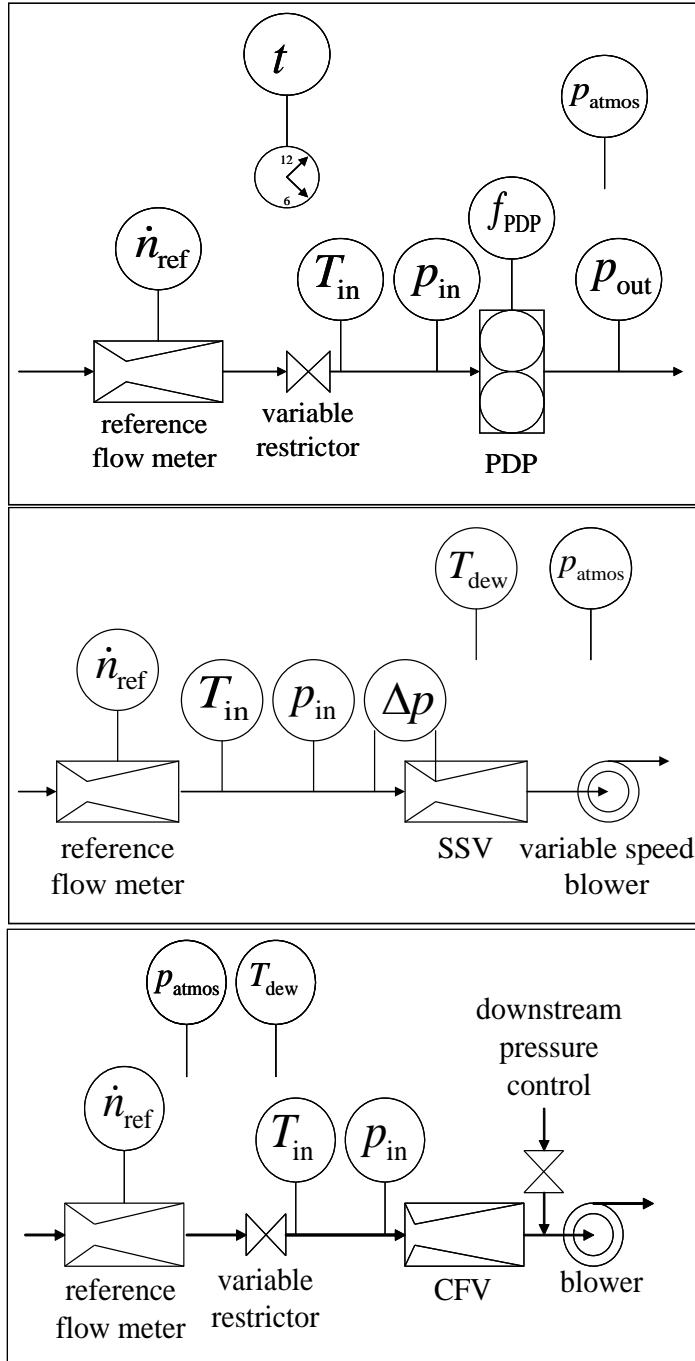
(5) Set the variable restrictor to its wide-open position. Instead of a variable restrictor, you may alternately vary the pressure downstream of the CFV by varying blower speed or by introducing a controlled leak. Note that some blowers have limitations on nonloaded conditions.

(6) Operate the CFV for at least 3 min to stabilize the system. Continue operating the CFV and record the mean values of at least 30 seconds of sampled data of each of the following quantities:

(i) The mean flow rate of the reference flow meter, \bar{n}_{ref} . This may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating \bar{n}_{ref} .

- (ii) The mean dewpoint of the calibration air, \bar{T}_{dew} . See § 1065.640 for permissible assumptions during emission measurements.
 - (iii) The mean temperature at the venturi inlet, \bar{T}_{in} .
 - (iv) The mean static absolute pressure at the venturi inlet, \bar{p}_{in} .
 - (v) The mean static differential pressure between the CFV inlet and the CFV outlet, $\Delta\bar{p}_{\text{CFV}}$.
- (7) Incrementally close the restrictor valve or decrease the downstream pressure to decrease the differential pressure across the CFV, Δp_{CFV} .
- (8) Repeat the steps in paragraphs (f)(6) and (7) of this section to record mean data at a minimum of ten restrictor positions, such that you test the fullest practical range of $\Delta\bar{p}_{\text{CFV}}$ expected during testing. We do not require that you remove calibration components or CVS components to calibrate at the lowest possible restrictions.
- (9) Determine C_d and the highest allowable pressure ratio, r , according to § 1065.640.
- (10) Use C_d to determine CFV flow during an emission test. Do not use the CFV above the highest allowed r , as determined in § 1065.640.
- (11) Verify the calibration by performing a CVS verification (i.e., propane check) as described in § 1065.341.
- (12) If your CVS is configured to operate more than one CFV at a time in parallel, calibrate your CVS by one of the following:
- (i) Calibrate every combination of CFVs according to this section and § 1065.640. Refer to § 1065.642 for instructions on calculating flow rates for this option.
 - (ii) Calibrate each CFV according to this section and § 1065.640. Refer to § 1065.642 for instructions on calculating flow rates for this option.
- (i) *Ultrasonic flow meter calibration.* [Reserved]

FIGURE 1 OF 1065.340—CVS CALIBRATION CONFIGURATIONS.



§ 1065.341 CVS and PFD flow verification (propane check).

This section describes two optional methods, using propane as a tracer gas, to verify CVS and PFD flow streams. You may use good engineering judgment and safe practices to use other tracer gases, such as CO₂ or CO. The first method, described in paragraphs (a) through (e) of this section, applies for the CVS diluted exhaust flow measurement system. The first method may also apply for other single-flow measurement systems as described in Table 2 of § 1065.307. Paragraph (g) of this section describes a second method you may use to verify flow measurements in a PFD for determining the PFD dilution ratio.

(a) A propane check uses either a reference mass or a reference flow rate of C₃H₈ as a tracer gas in a CVS. Note that if you use a reference flow rate, account for any non-ideal gas behavior of C₃H₈ in the reference flow meter. Refer to §§ 1065.640 and 1065.642, which describe how to calibrate and use certain flow meters. Do not use any ideal gas assumptions in §§ 1065.640 and 1065.642. The propane check compares the calculated mass of injected C₃H₈ using HC measurements and CVS flow rate measurements with the reference value.

(b) Prepare for the propane check as follows:

- (1) If you use a reference mass of C₃H₈ instead of a reference flow rate, obtain a cylinder charged with C₃H₈. Determine the reference cylinder's mass of C₃H₈ within ±0.5 % of the amount of C₃H₈ that you expect to use. You may substitute a C₃H₈ analytical gas mixture (i.e., a prediluted tracer gas) for pure C₃H₈. This would be most appropriate for lower flow rates. The analytical gas mixture must meet the specifications in § 1065.750(a)(3).
- (2) Select appropriate flow rates for the CVS and C₃H₈.
- (3) Select a C₃H₈ injection port in the CVS. Select the port location to be as close as practical to the location where you introduce engine exhaust into the CVS, or at some point in the laboratory exhaust tubing upstream of this location. Connect the C₃H₈ cylinder to the injection system.
- (4) Operate and stabilize the CVS.
- (5) Preheat or pre-cool any heat exchangers in the sampling system.
- (6) Allow heated and cooled components such as sample lines, filters, chillers, and pumps to stabilize at operating temperature.
- (7) You may purge the HC sampling system during stabilization.
- (8) If applicable, perform a vacuum side leak verification of the HC sampling system as described in § 1065.345.
- (9) You may also conduct any other calibrations or verifications on equipment or analyzers.

(c) If you performed the vacuum-side leak verification of the HC sampling system as described in paragraph (b)(8) of this section, you may use the HC contamination procedure in § 1065.520(fg) to verify HC contamination. Otherwise, zero, span, and verify contamination of the HC sampling system, as follows:

- (1) Select the lowest HC analyzer range that can measure the C₃H₈ concentration expected for the CVS and C₃H₈ flow rates.
- (2) Zero the HC analyzer using zero air introduced at the analyzer port.
- (3) Span the HC analyzer using C₃H₈ span gas introduced at the analyzer port.
- (4) Overflow zero air at the HC probe inlet or into a tee near the outlet of the probe.
- (5) Measure the stable HC concentration of the HC sampling system as overflow zero air flows. For batch HC measurement, fill the batch container (such as a bag) and measure the HC overflow concentration.

- (6) If the overflow HC concentration exceeds $2 \mu\text{mol/mol}$, do not proceed until contamination is eliminated. Determine the source of the contamination and take corrective action, such as cleaning the system or replacing contaminated portions.
- (7) When the overflow HC concentration does not exceed $2 \mu\text{mol/mol}$, record this value as x_{THCinit} and use it to correct for HC contamination as described in § 1065.660.
- (d) Perform the propane check as follows:
- (1) For batch HC sampling, connect clean storage media, such as evacuated bags.
 - (2) Operate HC measurement instruments according to the instrument manufacturer's instructions.
 - (3) If you will correct for dilution air background concentrations of HC, measure and record background HC in the dilution air.
 - (4) Zero any integrating devices.
 - (5) Begin sampling, and start any flow integrators.
 - (6) Release the contents of the C_3H_8 reference cylinder at the rate you selected. If you use a reference flow rate of C_3H_8 , start integrating this flow rate.
 - (7) Continue to release the cylinder's contents until at least enough C_3H_8 has been released to ensure accurate quantification of the reference C_3H_8 and the measured C_3H_8 .
 - (8) Shut off the C_3H_8 reference cylinder and continue sampling until you have accounted for time delays due to sample transport and analyzer response.
 - (9) Stop sampling and stop any integrators.
- (e) Perform post-test procedure as follows:
- (1) If you used batch sampling, analyze batch samples as soon as practical.
 - (2) After analyzing HC, correct for contamination and background.
 - (3) Calculate total C_3H_8 mass based on your CVS and HC data as described in § 1065.650 (40 CFR 1066.605 for vehicle testing) and § 1065.660, using the molar mass of C_3H_8 , $M_{\text{C}_3\text{H}_8}$, instead of the effective molar mass of HC, M_{HC} .
 - (4) If you use a reference mass, determine the cylinder's propane mass within $\pm 0.5\%$ and determine the C_3H_8 reference mass by subtracting the empty cylinder propane mass from the full cylinder propane mass.
 - (5) Subtract the reference C_3H_8 mass from the calculated mass. If this difference is within $\pm 2\%$ of the reference mass, the CVS passes this verification. If not, take corrective action as described in paragraph (f) of this section.
- (f) A failed propane check might indicate one or more problems requiring corrective action, as follows:

TABLE 1 OF § 1065.341—TROUBLESHOOTING GUIDE FOR PROPANE CHECKS

Problem	Recommended Corrective Action
Incorrect analyzer calibration	Recalibrate, repair, or replace the FID analyzer.
Leaks	Inspect CVS tunnel, connections, fasteners, and HC sampling system. Repair or replace components.
Poor mixing	Perform the verification as described in this section while traversing a sampling probe across the tunnel's diameter, vertically and horizontally. If the analyzer response indicates any deviation exceeding ± 2 % of the mean measured concentration, consider operating the CVS at a higher flow rate or installing a mixing plate or orifice to improve mixing.
Hydrocarbon contamination in the sample system	Perform the hydrocarbon-contamination verification as described in § 1065.520.
Change in CVS calibration	Perform a calibration of the CVS flow meter as described in § 1065.340.
Flow meter entrance effects	Inspect the CVS tunnel to determine whether the entrance effects from the piping configuration upstream of the flow meter adversely affect the flow measurement.
Other problems with the CVS or sampling verification hardware or software	Inspect the CVS system and related verification hardware, and software for discrepancies.

(g) You may verify flow measurements in a PFD (usually dilution air and diluted exhaust streams) for determining the dilution ratio in the PFD using the following method:

- (1) Configure the HC sampling system to extract a sample from the PFD's diluted exhaust stream (such as near a PM filter). If the absolute pressure at this location is too low to extract an HC sample, you may sample HC from the PFD's pump exhaust. Use caution when sampling from pump exhaust because an otherwise acceptable pump leak downstream of a PFD diluted exhaust flow meter will cause a false failure of the propane check.
- (2) Perform the propane check described in paragraphs (b), (c), and (d) of this section, but sample HC from the PFD's diluted exhaust stream. Inject the propane in the same exhaust stream that the PFD is sampling from (either CVS or raw exhaust stack).
- (3) Calculate C_3H_8 mass, taking into account the dilution from the PFD.
- (4) Subtract the reference C_3H_8 mass from the calculated mass. If this difference is within ± 2 % of the reference mass, all PFD flow measurements for determining PFD dilution ratio pass this verification. If not, take corrective action as described in paragraph (f) of this section. For PFDs sampling only for PM, the allowed difference is ± 5 %.

(h) Table 2 of § 1065.307 describes optional verification procedures you may perform instead of linearity verification for certain flow-measurement systems. Performing carbon balance error verification also replaces any required propane checks.

§ 1065.342 Sample dryer verification.

- (a) *Scope and frequency.* If you use a sample dryer as allowed in § 1065.145(e)(2) to remove water from the sample gas, verify the performance upon installation, after major maintenance, for thermal chiller. For osmotic membrane dryers, verify the performance upon installation, after major maintenance, and within 35 days of testing.
- (b) *Measurement principles.* Water can inhibit an analyzer's ability to properly measure the exhaust component of interest and thus is sometimes removed before the sample gas reaches the analyzer. For example water can negatively interfere with a CLD's NO_x response through

collisional quenching and can positively interfere with an NDIR analyzer by causing a response similar to CO.

(c) *System requirements.* The sample dryer must meet the specifications as determined in § 1065.145(e)(2) for dewpoint, T_{dew} , and absolute pressure, p_{total} , downstream of the osmotic-membrane dryer or thermal chiller.

(d) *Sample dryer verification procedure.* Use the following method to determine sample dryer performance. Run this verification with the dryer and associated sampling system operating in the same manner you will use for emission testing (including operation of sample pumps). You may run this verification test on multiple sample dryers sharing the same sampling system at the same time. You may run this verification on the sample dryer alone, but you must use the maximum gas flow rate expected during testing. You may use good engineering judgment to develop a different protocol.

(1) Use PTFE or stainless steel tubing to make necessary connections.

(2) Humidify room air, purified N₂, or purified air by bubbling it through distilled H₂O in a sealed vessel or use a device that injects distilled H₂O as vapor into a controlled gas flow to humidify the gas to the highest sample H₂O content that you estimate during emission sampling.

(3) Introduce the humidified gas upstream of the sample dryer. You may disconnect the transfer line from the probe and introduce the humidified gas at the inlet of the transfer line of the sample system used during testing. You may use the sample pumps in the sample system to draw gas through the vessel.

(4) Maintain the sample lines, fittings, and valves from the location where the humidified gas water content is measured to the inlet of the sampling system at a temperature at least 5 °C above the local humidified gas dewpoint. For dryers used in NO_x sample systems, verify the sample system components used in this verification prevent aqueous condensation as required in § 1065.145(d)(1)(i). We recommend that the sample system components be maintained at least 5 °C above the local humidified gas dewpoint to prevent aqueous condensation.

(5) Measure the humidified gas dewpoint, T_{dew} , and absolute pressure, p_{total} , as close as possible to the inlet of the sample dryer or inlet of the sample system to verify the water content is at least as high as the highest value that you estimated during emission sampling. You may verify the water content based on any humidity parameter (e.g. mole fraction water, local dewpoint, or absolute humidity).

(6) Measure the humidified gas dewpoint, T_{dew} , and absolute pressure, p_{total} , as close as possible to the outlet of the sample dryer. Note that the dewpoint changes with absolute pressure. If the dewpoint at the sample dryer outlet is measured at a different pressure, then this reading must be corrected to the dewpoint at the sample dryer absolute pressure, p_{total} .

(7) The sample dryer meets the verification if the dewpoint at the sample dryer pressure as measured in paragraph (d)(6) of this section is less than the dewpoint corresponding to the sample dryer specifications as determined in § 1065.145(e)(2) plus 2 °C or if the mole fraction of water as measured in (d)(6) is less than the corresponding sample dryer specifications plus 0.002 mol/mol.

(e) *Alternate sample dryer verification procedure.* The following method may be used in place of the sample dryer verification procedure in (d) of this section. If you use a humidity sensor for continuous monitoring of dewpoint at the sample dryer outlet you may skip the performance

check in § 1065.342(d), but you must make sure that the dryer outlet humidity is at or below the minimum value used for quench, interference, and compensation checks.

§ 1065.345 Vacuum-side leak verification.

(a) *Scope and frequency.* Verify that there are no significant vacuum-side leaks using one of the leak tests described in this section. For laboratory testing, perform the vacuum-side leak verification upon initial sampling system installation, within 8 hours before the start of the first test interval of each duty-cycle sequence, and after maintenance such as pre-filter changes. For field testing, perform the vacuum-side leak verification after each installation of the sampling system on the vehicle, prior to the start of the field test, and after maintenance such as pre-filter changes. This verification does not apply to any full-flow portion of a CVS dilution system.

(b) *Measurement principles.* A leak may be detected either by measuring a small amount of flow when there should be zero flow, or by detecting the dilution of a known concentration of span gas when it flows through the vacuum side of a sampling system.

(c) *Low-flow leak test.* Test a sampling system for low-flow leaks as follows:

(1) Seal the probe end of the system by taking one of the following steps:

(i) Cap or plug the end of the sample probe.

(ii) Disconnect the transfer line at the probe and cap or plug the transfer line.

(iii) Close a leak-tight valve located in the sample transfer line within 92 cm of the probe.

(2) Operate all vacuum pumps. After stabilizing, verify that the flow through the vacuum-side of the sampling system is less than 0.5 % of the system's normal in-use flow rate. You may estimate typical analyzer and bypass flows as an approximation of the system's normal in-use flow rate.

(d) *Dilution-of-span-gas leak test.* You may use any gas analyzer for this test. If you use a FID for this test, correct for any HC contamination in the sampling system according to § 1065.660. If you use an O₂ analyzer described in § 1065.280 for this test, you may use purified N₂ to detect a leak. To avoid misleading results from this test, we recommend using only analyzers that have a repeatability of 0.5 % or better at the reference gas concentration used for this test. Perform a vacuum-side leak test as follows:

(1) Prepare a gas analyzer as you would for emission testing.

(2) Supply reference gas to the analyzer span port and record the measured value.

(3) Route overflow reference gas to the inlet of the sample probe or at a tee fitting in the transfer line near the exit of the probe. You may use a valve upstream of the overflow fitting to prevent overflow of reference gas out of the inlet of the probe, but you must then provide an overflow vent in the overflow supply line.

(4) Verify that the measured overflow reference gas concentration is within ± 0.5 % of the concentration measured in paragraph (d)(2) of this section. A measured value lower than expected indicates a leak, but a value higher than expected may indicate a problem with the reference gas or the analyzer itself. A measured value higher than expected does not indicate a leak.

(e) *Vacuum-decay leak test.* To perform this test you must apply a vacuum to the vacuum-side volume of your sampling system and then observe the leak rate of your system as a decay in the applied vacuum. To perform this test you must know the vacuum-side volume of your sampling system to within ± 10 % of its true volume. For this test you must also use measurement instruments that meet the specifications of subpart C of this part and of this subpart D. Perform a vacuum-decay leak test as follows:

- (1) Seal the probe end of the system as close to the probe opening as possible by taking one of the following steps:
 - (i) Cap or plug the end of the sample probe.
 - (ii) Disconnect the transfer line at the probe and cap or plug the transfer line.
 - (iii) Close a leak-tight valve located in the sample transfer line within 92 cm of the probe.
- (2) Operate all vacuum pumps. Draw a vacuum that is representative of normal operating conditions. In the case of sample bags, we recommend that you repeat your normal sample bag pump-down procedure twice to minimize any trapped volumes.
- (3) Turn off the sample pumps and seal the system. Measure and record the absolute pressure of the trapped gas and optionally the system absolute temperature. Wait long enough for any transients to settle and long enough for a leak at 0.5 % to have caused a pressure change of at least 10 times the resolution of the pressure transducer, then again record the pressure and optionally temperature.
- (4) Calculate the leak flow rate based on an assumed value of zero for pumped-down bag volumes and based on known values for the sample system volume, the initial and final pressures, optional temperatures, and elapsed time. Using the calculations specified in § 1065.644, verify that the vacuum-decay leak flow rate is less than 0.5 % of the system's normal in-use flow rate.

CO AND CO₂ MEASUREMENTS

§ 1065.350 H₂O interference verification for CO₂ NDIR analyzers.

- (a) *Scope and frequency.* If you measure CO₂ using an NDIR analyzer, verify the amount of H₂O interference after initial analyzer installation and after major maintenance.
- (b) *Measurement principles.* H₂O can interfere with an NDIR analyzer's response to CO₂. If the NDIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, [a correct result depends on](#) simultaneously conducting these other measurements to test the compensation algorithms during the analyzer interference verification.
- (c) *System requirements.* A CO₂ NDIR analyzer must have an H₂O interference that is within (0.0 ±0.4) mmol/mol, though we strongly recommend a lower interference that is within (0.0 ±0.2) mmol/mol.
- (d) *Procedure.* Perform the interference verification as follows:
 - (1) Start, operate, zero, and span the CO₂ NDIR analyzer as you would before an emission test. If the sample is passed through a dryer during emission testing, you may run this verification test with the dryer if it meets the requirements of § 1065.342. Operate the dryer at the same conditions as you will for an emission test. You may also run this verification test without the sample dryer.
 - (2) Create a humidified test gas by bubbling zero gas that meets the specifications in § 1065.750 through distilled H₂O in a sealed vessel or use a device that introduces distilled H₂O as vapor into a controlled gas flow. If the sample does not pass through a dryer during emission testing, humidify your test gas to an H₂O level at or above the maximum expected during emission testing. If the sample passes through a dryer during emission testing, you must humidify your test gas to an H₂O level at or above the level determined in § 1065.145(e)(2) for that dryer.
 - (3) Introduce the humidified test gas into the sample system. You may introduce it downstream of any sample dryer, if one is used during testing.

(4) If the sample is not passed through a dryer during this verification test, measure the H₂O mole fraction, $x_{\text{H}_2\text{O}}$, of the humidified test gas, as close as possible to the inlet of the analyzer. For example, measure dewpoint, T_{dew} , and absolute pressure, p_{total} , to calculate $x_{\text{H}_2\text{O}}$. Verify that the H₂O content meets the requirement in paragraph (d)(2) of this section. If the sample is passed through a dryer during this verification test, you must verify that the H₂O content of the humidified test gas downstream of the vessel meets the requirement in paragraph (d)(2) of this section based on either direct measurement of the H₂O content (e.g., dewpoint and pressure) or an estimate based on the vessel pressure and temperature. Use good engineering judgment to estimate the H₂O content. For example, you may use previous direct measurements of H₂O content to verify the vessel's level of saturation.

(5) If a sample dryer is not used in this verification test, use good engineering judgment to prevent condensation in the transfer lines, fittings, or valves from the point where $x_{\text{H}_2\text{O}}$ is measured to the analyzer. We recommend that you design your system so the wall temperatures in the transfer lines, fittings, and valves from the point where $x_{\text{H}_2\text{O}}$ is measured to the analyzer are at least 5 °C above the local sample gas dewpoint.

(6) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(7) Operate the analyzer to get a reading for CO₂ concentration and record results for 30 seconds. While the analyzer measures the sample's concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of this data.

(8) The analyzer meets the interference verification if ~~this value is within (0.0 ± 0.4) mmol/mol~~ the result of paragraph (d)(7) of this section meets the tolerance in paragraph (c) of this section.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your CO₂ sampling system and your emission-calculation procedures, the H₂O interference for your CO₂ NDIR analyzer always affects your brake-specific emission results within ±0.5 % of each of the applicable standards in this chapter. This specification also applies for vehicle testing, except that it relates to emission results in g/mile or g/kilometer.

(2) You may use a CO₂ NDIR analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

§ 1065.355 H₂O and CO₂ interference verification for CO NDIR analyzers.

(a) *Scope and frequency.* If you measure CO using an NDIR analyzer, verify the amount of H₂O and CO₂ interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles.* H₂O and CO₂ can positively interfere with an NDIR analyzer by causing a response similar to CO. If the NDIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, a correct result depends on simultaneously conducting these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) *System requirements.* A CO NDIR analyzer must have combined H₂O and CO₂ interference that is within ±2 % of the flow-weighted mean concentration of CO expected at the standard, though we strongly recommend a lower interference that is within ±1 %.

(d) *Procedure.* Perform the interference verification as follows:

(1) Start, operate, zero, and span the CO NDIR analyzer as you would before an emission test. If the sample is passed through a dryer during emission testing, you may run this verification test with the dryer if it meets the requirements of § 1065.342. Operate the dryer at the same conditions as you will for an emission test. You may also run this verification test without the sample dryer.

(2) Create a humidified CO₂ test gas by bubbling a CO₂ span gas that meets the specifications in § 1065.750 through distilled H₂O in a sealed vessel or use a device that introduces distilled H₂O as vapor into a controlled gas flow. If the sample does not pass through a dryer during emission testing, humidify your test gas to an H₂O level at or above the maximum expected during emission testing. If the sample passes through a dryer during emission testing, you must humidify your test gas to an H₂O at or above the level determined in § 1065.145(e)(2) for that dryer. Use a CO₂ span gas concentration at least as high as the maximum expected during testing.

(3) Introduce the humidified CO₂ test gas into the sample system. You may introduce it downstream of any sample dryer, if one is used during testing.

(4) If the sample is not passed through a dryer during this verification test, measure the H₂O mole fraction, x_{H_2O} , of the humidified CO₂ test gas as close as possible to the inlet of the analyzer. For example, measure dewpoint, T_{dew} , and absolute pressure, p_{total} , to calculate x_{H_2O} . Verify that the H₂O content meets the requirement in paragraph (d)(2) of this section. If the sample is passed through a dryer during this verification test, you must verify that the H₂O content of the humidified test gas downstream of the vessel meets the requirement in paragraph (d)(2) of this section based on either direct measurement of the H₂O content (e.g., dewpoint and pressure) or an estimate based on the vessel pressure and temperature. Use good engineering judgment to estimate the H₂O content. For example, you may use previous direct measurements of H₂O content to verify the vessel's level of saturation.

(5) If a sample dryer is not used in this verification test, use good engineering judgment to prevent condensation in the transfer lines, fittings, or valves from the point where x_{H_2O} is measured to the analyzer. We recommend that you design your system so that the wall temperatures in the transfer lines, fittings, and valves from the point where x_{H_2O} is measured to the analyzer are at least 5 °C above the local sample gas dewpoint.

(6) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(7) Operate the analyzer to get a reading for CO concentration and record results for 30 seconds. ~~While the analyzer measures the sample's concentration, record its output for 30 seconds.~~ Calculate the arithmetic mean of this data.

(8) The analyzer meets the interference verification if the result of paragraph (d)(7) of this section meets the tolerance in paragraph (c) of this section.

(9) You may also run interference procedures for CO₂ and H₂O separately. If the CO₂ and H₂O levels used are higher than the maximum levels expected during testing, you may scale down each observed interference value by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. You may run separate interference concentrations of H₂O (down to 0.025 mol/mol H₂O content) that are lower than the maximum levels expected during testing, but you must scale up the observed H₂O interference by multiplying the observed interference by the ratio of the maximum expected H₂O concentration value to the actual value used during this procedure.

The sum of the two scaled interference values must meet the tolerance in paragraph (c) of this section.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your CO sampling system and your emission-calculation procedures, the combined CO₂ and H₂O interference for your CO NDIR analyzer always affects your brake-specific CO emission results within $\pm 0.5\%$ of the applicable CO standard.

(2) You may use a CO NDIR analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

H₂O MEASUREMENTS

§ 1065.357 CO₂ interference verification for H₂O FTIR analyzers.

(a) Scope and frequency. If you measure H₂O using an FTIR analyzer, verify the amount of CO₂ interference after initial analyzer installation and after major maintenance.

(b) Measurement principles. CO₂ can interfere with an FTIR analyzer's response to H₂O. If the FTIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, a correct result depends on simultaneously conducting these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) System requirements. An H₂O FTIR analyzer must have a CO₂ interference that is within (0.0 \pm 0.4) mmol/mol, though we strongly recommend a lower interference that is within (0.0 \pm 0.2) mmol/mol.

(d) Procedure. Perform the interference verification as follows:

(1) Start, operate, zero, and span the H₂O FTIR analyzer as you would before an emission test.

(2) Use a CO₂ span gas that meets the specifications of § 1065.750 and a concentration that is approximately the maximum CO₂ concentration expected during emission testing.

(3) Introduce the CO₂ test gas into the sample system.

(4) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(5) ~~While the analyzer measures the sample's concentration, record 30 seconds of sampled data.~~ Operate the analyzer to get a reading for H₂O concentration and record results for 30 seconds. Calculate the arithmetic mean of these ~~this~~ data.

(6) The analyzer meets the interference verification if ~~this value is within (0.0 \pm 0.4) mmol/mol.~~ the result of paragraph (d)(5) of this section meets the tolerance in paragraph (c) of this section.

(e) Exceptions. The following exceptions apply:

(1) You may omit this verification for CO₂ for engines operating on fuels other than carbon-containing fuels.

(2) You may omit this verification if you can show by engineering analysis that for your H₂O sampling system and your emission-calculation procedures, the CO₂ interference for your H₂O FTIR analyzer always affects your brake-specific emission results within $\pm 0.5\%$ of each of the applicable standards in this chapter. This specification also applies for vehicle testing, except that it relates to emission results in g/mile or g/kilometer.

(3) You may use an H₂O FTIR analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

HYDROCARBON MEASUREMENTS

§ 1065.360 FID optimization and verification.

(a) *Scope and frequency.* For all FID analyzers, calibrate the FID upon initial installation. Repeat the calibration as needed using good engineering judgment. For a FID that measures THC, perform the following steps:

(1) Optimize the response to various hydrocarbons after initial analyzer installation and after major maintenance as described in paragraph (c) of this section.

(2) Determine the methane (CH₄) response factor after initial analyzer installation and after major maintenance as described in paragraph (d) of this section. Verify the CH₄ response within 185 days before testing as described in paragraph (e) of this section.

(3) If you determine NMNEHC by subtracting from measured THC, determine the ethane (C₂H₆) response factor after initial analyzer installation and after major maintenance as described in paragraph (f) of this section. Verify the C₂H₆ response within 185 days before testing as described in paragraph (f) of this section.

(4) ~~For any gaseous fueled engine, including dual fuel and flexible fuel engines, y~~ You may determine the methane (CH₄) and ethane (C₂H₆) response factors as a function of the molar water concentration in the raw or diluted exhaust. If you choose the option in this paragraph (a)(4), generate and verify the humidity level (or fraction) as described in § 1065.365(dg)(11).

(b) *Calibration.* Use good engineering judgment to develop a calibration procedure, such as one based on the FID-analyzer manufacturer's instructions and recommended frequency for calibrating the FID. Alternately, you may remove system components for off-site calibration. For a FID that measures THC, calibrate using C₃H₈ calibration gases that meet the specifications of § 1065.750. For a FID that measures CH₄, calibrate using CH₄ calibration gases that meet the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O₂ expected during testing. If you use a FID to measure CH₄ downstream of a nonmethane cutter (NMC), you may calibrate that FID using CH₄ calibration gases with the ~~cutter~~NMC. Regardless of the calibration gas composition, calibrate on a carbon number basis of one (C₁). For example, if you use a C₃H₈ span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol. As another example, if you use a CH₄ span gas with a concentration of 200 µmol/mol, span the FID to respond with a value of 200 µmol/mol.

(c) *THC FID response optimization.* This procedure is only for FID analyzers that measure THC. Use good engineering judgment for initial instrument start-up and basic operating adjustment using FID fuel and zero air. Heated FIDs must be within their required operating temperature ranges. Optimize FID response at the most common analyzer range expected during emission testing. Optimization involves adjusting flows and pressures of FID fuel, burner air, and sample to minimize response variations to various hydrocarbon species in the exhaust. Use good engineering judgment to trade off peak FID response to propane calibration gases to achieve minimal response variations to different hydrocarbon species. For an example of trading off response to propane for relative responses to other hydrocarbon species, see SAE 770141

(incorporated by reference, ~~see in~~ § 1065.1010). Determine the optimum flow rates and/or pressures for FID fuel, burner air, and sample and record them for future reference.

(d) *THC FID CH₄ response factor determination.* This procedure is only for FID analyzers that measure THC. Since FID analyzers generally have a different response to CH₄ versus C₃H₈, determine the THC-FID analyzer's CH₄ response factor, $RF_{CH_4[THC-FID]}$, after FID optimization. Use the most recent $RF_{CH_4[THC-FID]}$ measured according to this section in the calculations for HC determination described in § 1065.660 to compensate for CH₄ response. Determine $RF_{CH_4[THC-FID]}$ as follows, noting that you do not determine $RF_{CH_4[THC-FID]}$ for FIDs that are calibrated and spanned using CH₄ with a ~~n NMC nonmethane cutter~~:

(1) Select a C₃H₈ span gas concentration that you use to span your analyzers before emission testing. Use only span gases that meet the specifications of § 1065.750. Record the C₃H₈ concentration of the gas.

(2) Select a CH₄ span gas concentration that you use to span your analyzers before emission testing. Use only span gases that meet the specifications of § 1065.750. Record the CH₄ concentration of the gas.

(3) Start and operate the FID analyzer according to the manufacturer's instructions.

(4) Confirm that the FID analyzer has been calibrated using C₃H₈. Calibrate on a carbon number basis of one (C₁). For example, if you use a C₃H₈ span gas of concentration 200 μmol/mol, span the FID to respond with a value of 600 μmol/mol.

(5) Zero the FID with a zero gas that you use for emission testing.

(6) Span the FID with the C₃H₈ span gas that you selected under paragraph (d)(1) of this section.

(7) Introduce the CH₄ span gas that you selected under paragraph (d)(2) of this section into the FID analyzer.

(8) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the analyzer and to account for its response.

(9) While the analyzer measures the CH₄ concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these values.

(10) For analyzers with multiple ranges, you need to perform the procedure in this paragraph (d) only on a single range.

(11) Divide the mean measured concentration by the recorded span concentration of the CH₄ calibration gas. The result is the FID analyzer's response factor for CH₄, $RF_{CH_4[THC-FID]}$.

(12) ~~You may d~~Determine the response factor as a function of molar water concentration [using the following procedures](#) and use this response factor to account for the CH₄ response for NMHC determination described in § 1065.660(b)(2)(iii):

~~(i) If you use this option, h~~Humidify the CH₄ span gas as described in § 1065.365 ~~(dg)(11)~~ and repeat the steps in paragraphs (d)(7) through (9) of this section until measurements are complete for each setpoint in the selected range.

[\(ii\)](#) Divide each mean measured CH₄ concentration by the recorded span concentration of the CH₄ calibration gas, adjusted for water content, to determine the FID analyzer's CH₄ response factor, $RF_{CH_4[THC-FID]}$.

[\(iii\)](#) Use the CH₄ response factors at the different setpoints to create a functional relationship between response factor and molar water concentration, downstream of the last sample dryer if any sample dryers are present.

[\(iv\)](#) Use this functional relationship to determine the response factor during an emission test.

(e) *THC FID CH₄ response verification.* This procedure is only for FID analyzers that measure THC. Verify $RF_{CH_4[THC-FID]}$ as follows:

(1) Perform a CH₄ response factor determination as described in paragraph (d) of this section. If the resulting value of $RF_{CH_4[THC-FID]}$ is within $\pm 5\%$ of its most recent previously determined value, the THC FID passes the CH₄ response verification. For example, if the most recent previous value for $RF_{CH_4[THC-FID]}$ was 1.05 and it increased by 0.05 to become 1.10 or it decreased by 0.05 to become 1.00, either case would be acceptable because $\pm 4.8\%$ is less than $\pm 5\%$.

(2) If $RF_{CH_4[THC-FID]}$ is not within the tolerance specified in paragraph (e)(1) of this section, use good engineering judgment to verify that the flow rates and/or pressures of FID fuel, burner air, and sample are at their most recent previously recorded values, as determined in paragraph (c) of this section. You may adjust these flow rates as necessary. Then determine the $RF_{CH_4[THC-FID]}$ as described in paragraph (d) of this section and verify that it is within the tolerance specified in this paragraph (e).

(3) If $RF_{CH_4[THC-FID]}$ is not within the tolerance specified in this paragraph (e), re-optimize the FID response as described in paragraph (c) of this section.

(4) Determine a new $RF_{CH_4[THC-FID]}$ as described in paragraph (d) of this section. Use this new value of $RF_{CH_4[THC-FID]}$ in the calculations for HC determination, as described in § 1065.660.

(5) For analyzers with multiple ranges, you need to perform the procedure in this paragraph (e) only on a single range.

(f) *THC FID C₂H₆ response factor determination.* This procedure is only for FID analyzers that measure THC. Since FID analyzers generally have a different response to C₂H₆ than C₃H₈, determine the THC-FID analyzer's C₂H₆ response factor, $RF_{C_2H_6[THC-FID]}$, after FID optimization using the procedure described in paragraph (d) of this section, replacing CH₄ with C₂H₆. Use the most recent $RF_{C_2H_6[THC-FID]}$ measured according to this section in the calculations for HC determination described in § 1065.660 to compensate for C₂H₆ response.

§ 1065.362 Non-stoichiometric raw exhaust FID O₂ interference verification.

(a) *Scope and frequency.* If you use FID analyzers for raw exhaust measurements from engines that operate in a non-stoichiometric mode of combustion (e.g., compression-ignition, lean-burn), verify the amount of FID O₂ interference upon initial installation and after major maintenance.

(b) *Measurement principles.* Changes in O₂ concentration in raw exhaust can affect FID response by changing FID flame temperature. Optimize FID fuel, burner air, and sample flow to meet this verification. Verify FID performance with the compensation algorithms for FID O₂ interference that you have active during an emission test.

(c) *System requirements.* Any FID analyzer used during testing must meet the FID O₂ interference verification according to the procedure in this section.

(d) *Procedure.* Determine FID O₂ interference as follows, noting that you may use one or more gas dividers to create the reference gas concentrations that are required to perform this verification:

(1) Select three span reference gases that contain a C₃H₈ concentration that you use to span your analyzers before emission testing. Use only span gases that meet the specifications of § 1065.750. You may use CH₄ span reference gases for FIDs calibrated on CH₄ with a nonmethane cutter. Select the three balance gas concentrations such that the concentrations of O₂ and N₂ represent the minimum, maximum, and average O₂ concentrations expected during testing. The requirement for using the average O₂ concentration can be removed if

you choose to calibrate the FID with span gas balanced with the average expected oxygen concentration.

(2) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(3) Start and operate the FID analyzer as you would before an emission test. Regardless of the FID burner's air source during testing, use zero air as the FID burner's air source for this verification.

(4) Zero the FID analyzer using the zero gas used during emission testing.

(5) Span the FID analyzer using a span gas that you use during emission testing.

(6) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean zero response of 30 seconds of sampled data is within $\pm 0.5\%$ of the span reference value used in paragraph (d)(5) of this section, then proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(7) Check the analyzer response using the span gas that has the minimum concentration of O_2 expected during testing. Record the mean response of 30 seconds of stabilized sample data as $X_{O_2\min HC}$.

(8) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean zero response of 30 seconds of stabilized sample data is within $\pm 0.5\%$ of the span reference value used in paragraph (d)(5) of this section, then proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(9) Check the analyzer response using the span gas that has the average concentration of O_2 expected during testing. Record the mean response of 30 seconds of stabilized sample data as $X_{O_2\text{avg} HC}$.

(10) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean zero response of 30 seconds of stabilized sample data is within $\pm 0.5\%$ of the span reference value used in paragraph (d)(5) of this section, proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(11) Check the analyzer response using the span gas that has the maximum concentration of O_2 expected during testing. Record the mean response of 30 seconds of stabilized sample data as $X_{O_2\max HC}$.

(12) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean zero response of 30 seconds of stabilized sample data is within $\pm 0.5\%$ of the span reference value used in paragraph (d)(5) of this section, then proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(13) Calculate the percent difference between $X_{O_2\max HC}$ and its reference gas concentration.

Calculate the percent difference between $X_{O_2\text{avg} HC}$ and its reference gas concentration.

Calculate the percent difference between $X_{O_2\min HC}$ and its reference gas concentration.

Determine the maximum percent difference of the three. This is the O_2 interference.

(14) If the O_2 interference is within $\pm 2\%$, the FID passes the O_2 interference verification; otherwise perform one or more of the following to address the deficiency:

(i) Repeat the verification to determine if a mistake was made during the procedure.

(ii) Select zero and span gases for emission testing that contain higher or lower O_2 concentrations and repeat the verification.

(iii) Adjust FID burner air, fuel, and sample flow rates. Note that if you adjust these flow rates on a THC FID to meet the O_2 interference verification, you have reset RF_{CH_4} for the next RF_{CH_4} verification according to § 1065.360. Repeat the O_2 interference verification after adjustment and determine RF_{CH_4} .

- (iv) Repair or replace the FID and repeat the O₂ interference verification.
 - (v) Demonstrate that the deficiency does not adversely affect your ability to demonstrate compliance with the applicable emission standards.
- (15) For analyzers with multiple ranges, you need to perform the procedure in this paragraph (d) only on a single range.

§ 1065.365 Nonmethane cutter penetration fractions and NMC FID response factors.

(a) *Scope and frequency.* If you use a FID analyzer and an ~~nonmethane cutter~~ (NMC) to measure methane (CH₄), verify that the catalytic activity of the NMC has not deteriorated as described in this section. ~~determine~~ Determine the ~~nonmethane cutter~~ NMC's penetration fractions (PF) of ~~methane~~ CH₄, ~~PF_{CH4}~~, and ethane (C₂H₆) and, if applicable, the FID analyzer response factors using the appropriate procedures of paragraph (d), (e), or (f) of this section, ~~PF_{C2H6}~~. As detailed in this section, these penetration fractions may be determined as a combination of NMC penetration fractions and FID analyzer response factors, depending on your particular NMC and FID analyzer configuration. Perform this verification after installing the ~~nonmethane cutter~~ NMC. R and repeat this verification within 185 days of testing to verify that the catalytic activity of the cutter NMC has not deteriorated. Note that because ~~nonmethane cutters~~ NMCs can deteriorate rapidly and without warning if they are operated outside of certain ranges of gas concentrations and outside of certain temperature ranges, good engineering judgment may dictate that you determine an ~~nonmethane cutter~~ NMC's penetration fractions more frequently. Use the most recently determined penetration fraction from this section to calculate HC emissions according to § 1065.660 as applicable.

(b) *Measurement principles.* An ~~nonmethane cutter~~ NMC is a heated catalyst that removes nonmethane hydrocarbons from an exhaust sample stream before the FID analyzer measures the remaining hydrocarbon concentration. An ideal ~~nonmethane cutter~~ NMC would have a CH₄ penetration fraction, PF_{CH_4} , of 1.000, and the penetration fraction for all other nonmethane hydrocarbons would be 0.000, as represented by $PF_{C_2H_6}$. The emission calculations in § 1065.660 use the measured values from this verification to account for less than ideal NMC performance.

(c) *System requirements.* We do not require that you limit NMC penetration fractions to a certain range. However, we recommend that you optimize an ~~NMC nonmethane cutter~~ by adjusting its temperature to achieve a ~~PF_{CH4} > 0.85 and a PF_{C2H6} < 0.02~~, as determined by paragraphs (d), (e), or (f) of this section, as applicable, using dry gases. ~~If we use an NMC nonmethane cutter for testing, it will meet this recommendation.~~ If adjusting NMC temperature does not result in achieving ~~both of these specifications simultaneously~~ the recommended PF_{C2H6} level ~~this recommendation~~, we recommend that you replace the catalyst material. Note that, if we use an NMC for testing, we will optimize it to achieve a PF_{C2H6} < 0.02. ~~Use the most recently determined penetration values from this section to calculate HC emissions according to § 1065.660 and § 1065.665 as applicable.~~

(d) *Procedure for a FID calibrated with the NMC.* ~~The method described in this paragraph (d) is~~ The following procedure describes the recommended ~~over the procedures specified in paragraphs (e) and (f) of this section~~ method for verifying NMC performance and the required method for any gaseous-fueled engine, including dual-fuel and flexible-fuel engines. ~~If your FID arrangement is such that a FID is always calibrated to measure CH₄ with the NMC, then span that FID with the NMC using a CH₄ span gas, set the product of that FID's CH₄ response factor and CH₄ penetration fraction, RPF_{CH4(NMC FID)}, equal to 1.0 for all emission calculations, and~~

~~determine its combined C₂H₆ response factor and C₂H₆ penetration fraction, $RFPF_{C_2H_6[NMC-FID]}$, as follows. For any gaseous-fueled engine, including dual-fuel and flexible-fuel engines, you must determine the combined CH₄ response factor and penetration fraction, $RFPF_{CH_4[NMC-FID]}$, and combined C₂H₆ response factor and C₂H₆ penetration fraction, $RFPF_{C_2H_6[NMC-FID]}$, as a function of the molar water concentration in the raw or diluted exhaust as described in paragraphs (d)(10) and (12) of this section. Note that $RFPF_{CH_4[NMC-FID]}$ is set equal to 1.0 only for zero molar water concentration. For any other engine you may use the same procedure, or you may set $RFPF_{CH_4[NMC-FID]}$ equal to 1.0 and determine $RFPF_{C_2H_6[NMC-FID]}$ at zero molar water concentration. Generate and verify the humidity generation as described in paragraph (dg)(11) of this section. When using the option in this paragraph (d), note that the FID's CH₄ penetration fraction, $PF_{CH_4[NMC-FID]}$, is set equal to 1.0 only for 0 % molar water concentration. You are not required to meet the recommended lower limit for PF_{CH_4} of greater than 0.85 for any of the penetration fractions generated as a function of molar water concentration.~~

(1) Select CH₄ and C₂H₆ analytical gas mixtures and ensure that both mixtures meet the specifications of § 1065.750. Select a CH₄ concentration that you would use for spanning the FID during emission testing and select a C₂H₆ concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to the THC analyzer's span value. For CH₄ analyzers with multiple ranges, perform this procedure on the highest range used for emission testing.

(2) Start, operate, and optimize the ~~nonmethane-cutter~~NMC according to the manufacturer's instructions, including any temperature optimization.

(3) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(4) Start and operate the FID analyzer according to the manufacturer's instructions.

(5) Zero and span the FID with the ~~nonmethane-cutter~~NMC as you would during emission testing. Span the FID through the ~~cutter~~-NMC by using CH₄ span gas.

(6) Introduce the C₂H₆ analytical gas mixture upstream of the ~~nonmethane-cutter~~NMC. Use good engineering judgment to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.

(7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the ~~nonmethane-cutter~~NMC and to account for the analyzer's response.

(8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of ~~these data points~~the analytical gas mixture.

(9) ~~Divide the mean C₂H₆ concentration by the reference~~Calculate a reference concentration of C₂H₆, ~~by converted~~converting C₂H₆ to a C₁ basis ~~and adjusted for water content, if necessary.~~ The result is the C₂H₆ combined C₂H₆ response factor and penetration fraction, $RFPF_{C_2H_6[NMC-FID]}$. ~~Use this~~Calculate the combined C₂H₆ response factor and C₂H₆ penetration fraction-, $RFPF_{C_2H_6[NMC-FID]}$, ~~by dividing the mean C₂H₆ concentration from paragraph (d)(8) of this section by the reference concentration of C₂H₆.~~ For any gaseous-fueled engine, including dual-fuel and flexible-fuel engines, you must determine $RFPF_{C_2H_6[NMC-FID]}$ as a function of the molar water concentration in the raw or diluted exhaust using paragraph (g) of this section. Use $RFPF_{C_2H_6[NMC-FID]}$ at the different setpoints to create a functional relationship between $RFPF_{C_2H_6[NMC-FID]}$ and molar water concentration, downstream of the last sample dryer if any sample dryers are present. Use this functional relationship to determine the combined response factor and penetration fraction during the emission test. For any other engine you may use the same procedure or you may determine $RFPF_{C_2H_6[NMC-FID]}$ at zero molar water concentration, and the product of the CH₄ response

factor and CH₄ penetration fraction, $RFPF_{CH_4[NMHC-FID]}$, set to 1.0 in emission calculations according to § 1065.660(b)(2)(i) or (d)(1)(i) or § 1065.665, as applicable. If you are generating mixtures as a function of molar water concentration, follow the guidance in paragraph (g) of this section and repeat the steps in paragraphs (d)(6) to (9) of this section until all setpoints have been completed. Use $RFPF_{C_2H_6[NMHC-FID]}$ at the different setpoints to create a functional relationship between $RFPF_{C_2H_6[NMHC-FID]}$ and molar water concentration, downstream of the last sample dryer if any sample dryers are present. Use this functional relationship to determine the combined response factor and penetration fraction during the emission test.

(10) For any gaseous-fueled engine, including dual-fuel and flexible-fuel engines. If required by this paragraph (d), repeat the steps in paragraphs (d)(6) through (9) of this section, but with the CH₄ analytical gas mixture instead of C₂H₆ and determine $RFPF_{CH_4[NMHC-FID]}$ as a function of the molar water concentration in the raw or diluted exhaust using paragraph (g) of this section instead. Note that $RFPF_{CH_4[NMHC-FID]}$ is set equal to 1.0 only for zero molar water concentration. For any other engine you may use the same procedure, or you may set $RFPF_{CH_4[NMHC-FID]}$ equal to 1.0.

~~(11) Use this combined C₂H₆ response factor and penetration fraction, $RFPF_{C_2H_6[NMHC-FID]}$, and this combined CH₄ response factor and penetration fraction, $RFPF_{CH_4[NMHC-FID]}$, in emission calculations according to §§ 1065.660(b)(2)(i) and 1065.660(d)(1)(i). Determine the combined C₂H₆ response factor and C₂H₆ penetration fraction as a function of molar water concentration and use it to account for C₂H₆ response factor and C₂H₆ penetration fraction for NMHC determination as described in § 1065.660(b)(2)(iii) and for CH₄ determination in § 1065.660(d)(1)(iii). Humidify the C₂H₆ analytical gas mixture as described in paragraph (d)(11) of this section. Repeat the steps in paragraphs (d)(6) through (8) of this section until measurements are complete for each setpoint in the selected range. Divide each mean measured C₂H₆ concentration by the reference concentration of C₂H₆, converted to a C₁-basis and adjusted for water content to determine the FID analyzer's combined C₂H₆ response factor and C₂H₆ penetration fraction, $RFPF_{C_2H_6[NMHC-FID]}$. Use $RFPF_{C_2H_6[NMHC-FID]}$ at the different setpoints to create a functional relationship between the combined response factor and penetration fraction and molar water concentration, downstream of the last sample dryer if any sample dryers are present. Use this functional relationship to determine the combined response factor and penetration fraction during the emission test.~~

~~(11) Create a humidified test gas by bubbling the analytical gas mixture that meets the specifications in § 1065.750 through distilled H₂O in a sealed vessel or use a device that introduces distilled H₂O as vapor into a controlled gas flow. If the sample does not pass through a dryer during emission testing, generate at least five different H₂O concentrations that cover the range from less than the minimum expected to greater than the maximum expected water concentration during testing. Use good engineering judgment to determine the target concentrations. For analyzers where the sample passes through a dryer during emission testing, humidify your test gas to an H₂O level at or above the level determined in § 1065.145(e)(2) for that dryer and determine a single wet analyzer response to the dehumidified sample. Heat all transfer lines from the water generation system to a temperature at least 5 °C higher than the highest dewpoint generated. Determine H₂O concentration as an average value over intervals of at least 30 seconds. Monitor the humidified sample stream with a dewpoint analyzer, relative humidity sensor, FTIR, NDIR,~~

~~or other water analyzer during each test or, if the humidity generator achieves humidity levels with controlled flow rates, validate the instrument within 370 days before testing and after major maintenance using one of the following methods:~~

~~(i) Determine the linearity of each flow metering device. Use one or more reference flow meters to measure the humidity generator's flow rates and verify the H₂O level value based on the humidity generator manufacturer's recommendations and good engineering judgment. We recommend that you utilize at least 10 flow rates for each flow metering device.~~

~~(ii) Perform validation testing based on monitoring the humidified stream with a dewpoint analyzer, relative humidity sensor, FTIR, NDIR, or other water analyzer as described in this paragraph (d)(11). Compare the measured humidity to the humidity generator's value. Verify overall linearity performance for the generated humidity as described in § 1065.307 using the criteria for other dewpoint measurements or confirm all measured values are within ± 2 % of the target mole fraction. In the case of dry gas, the measured value may not exceed 0.002 mole fraction.~~

~~(iii) Follow the performance requirements in § 1065.307(b) if the humidity generator does not meet validation criteria.~~

~~(12) Determine the CH₄ penetration fraction as a function of molar water concentration and use this penetration fraction for NMHC determination in § 1065.660(b)(2)(iii) and for CH₄ determination in § 1065.660(d)(1)(iii). Repeat the steps in paragraphs (d)(6) through (11) of this section, but with the CH₄ analytical gas mixture instead of C₂H₆. Use this functional relationship to determine the penetration fraction during the emission test.~~

(e) *Procedure for a FID calibrated with propane, bypassing the NMC.* If you use a single FID for THC and CH₄ determination with an NMC that is calibrated with propane, C₃H₈, by bypassing the NMC, determine its penetration fractions, $PF_{C_2H_6[NMC-FID]}$ and $PF_{CH_4[NMC-FID]}$, as follows:

(1) Select CH₄ and C₂H₆ analytical gas mixtures and ensure that both mixtures meet the specifications of § 1065.750. Select a CH₄ concentration that you would use for spanning the FID during emission testing and select a C₂H₆ concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard and the C₂H₆ concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or equal to the THC analyzer's span value. For CH₄ analyzers with multiple ranges, perform this procedure on the highest range used for emission testing.

(2) Start and operate the ~~nonmethane cutter~~NMC according to the manufacturer's instructions, including any temperature optimization.

(3) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(4) Start and operate the FID analyzer according to the manufacturer's instructions.

(5) Zero and span the FID as you would during emission testing. Span the FID by bypassing the ~~cutter~~NMC and by using C₃H₈ span gas. Note that you must span the FID on a C₁ basis. For example, if your span gas has a propane reference value of 100 µmol/mol, the correct FID response to that span gas is 300 µmol/mol because there are three carbon atoms per C₃H₈ molecule.

(6) Introduce the C₂H₆ analytical gas mixture upstream of the ~~nonmethane cutter~~NMC. Use good engineering judgment to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.

(7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the ~~nonmethane cutter~~NMC and to account for the analyzer's response.

(8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of ~~these data points~~the analytical gas mixture.

(9) Reroute the flow path to bypass the ~~nonmethane cutter~~NMC, introduce the C₂H₆ analytical gas mixture, and repeat the steps in paragraphs (e)(7) ~~through and~~ (8) of this section.

(10) Divide the mean C₂H₆ concentration measured through the ~~nonmethane cutter~~NMC by the mean C₂H₆ concentration measured after bypassing the ~~nonmethane cutter~~NMC. The result is the C₂H₆ penetration fraction, $PF_{C_2H_6[NMC-FID]}$. Use this penetration fraction according to § 1065.660(b)(2)(ii), ~~and § 1065.660(d)(1)(ii), or § 1065.665, as applicable.~~

(11) Repeat the steps in paragraphs (e)(6) through (10) of this section, but with the CH₄ analytical gas mixture instead of C₂H₆. The result will be the CH₄ penetration fraction, $PF_{CH_4[NMC-FID]}$. Use this penetration fraction according to § 1065.660(b)(2)(ii) or § 1065.665, as applicable.

(f) *Procedure for a FID calibrated with CH₄, bypassing the NMC.* If you use a FID with an NMC that is calibrated with CH₄, by bypassing the NMC, determine its combined ~~ethane~~(C₂H₆) response factor and penetration fraction, $RFPF_{C_2H_6[NMC-FID]}$, as well as its CH₄ penetration fraction, $PF_{CH_4[NMC-FID]}$, as follows:

(1) Select CH₄ and C₂H₆ analytical gas mixtures and ensure that both mixtures meet the specifications of § 1065.750. Select a CH₄ concentration that you would use for spanning the FID during emission testing and select a C₂H₆ concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to the THC analyzer's span value. For CH₄ analyzers with multiple ranges, perform this procedure on the highest range used for emission testing.

(2) Start and operate the ~~nonmethane cutter~~NMC according to the manufacturer's instructions, including any temperature optimization.

(3) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(4) Start and operate the FID analyzer according to the manufacturer's instructions.

(5) Zero and span the FID as you would during emission testing. Span the FID by bypassing the ~~cutter~~NMC and by using CH₄ span gas.

(6) Introduce the C₂H₆ analytical gas mixture upstream of the ~~nonmethane cutter~~NMC. Use good engineering judgment to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.

(7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the ~~nonmethane cutter~~NMC and to account for the analyzer's response.

(8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of ~~these data points~~the analytical gas mixture.

(9) Divide the mean C₂H₆ concentration by the reference concentration of C₂H₆, converted to a C₁ basis. The result is the combined C₂H₆ response factor and C₂H₆ penetration fraction, $RFPF_{C_2H_6[NMC-FID]}$. Use this combined C₂H₆ response factor and ~~C₂H₆~~penetration fraction according to § 1065.660(b)(2)(iii) ~~or and~~ (d)(1)(iii) ~~or § 1065.665, as applicable.~~

(10) Introduce the CH₄ analytical gas mixture upstream of the ~~nonmethane cutter~~NMC. Use good engineering judgment to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.

(11) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the ~~nonmethane cutter~~NMC and to account for the analyzer's response.

(12) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.

(13) Reroute the flow path to bypass the ~~nonmethane cutter~~NMC, introduce the CH₄ analytical gas mixture, and repeat the steps in paragraphs (e)(11) and (12) of this section.

(14) Divide the mean CH₄ concentration measured through the ~~nonmethane cutter~~NMC by the mean CH₄ concentration measured after bypassing the ~~nonmethane cutter~~NMC. The result is the CH₄ penetration fraction, $PF_{CH_4[NMC-FID]}$. Use this CH₄ penetration fraction according to § 1065.660(b)(2)(iii) ~~or and~~ (d)(1)(iii) ~~or § 1065.665, as applicable.~~

(g) Test gas humidification. If you are generating gas mixtures as a function of the molar water concentration in the raw or diluted exhaust according to paragraph (d) of this section, create a humidified test gas by bubbling the analytical gas mixture that meets the specifications in § 1065.750 through distilled H₂O in a sealed vessel or use a device that introduces distilled H₂O as vapor into a controlled gas flow. Determine the mole fraction of H₂O concentration in the humidified calibration gas, x_{H_2Oref} , as an average value over intervals of at least 30 seconds. We recommend that you design your system so the walls to maintain temperatures in the transfer lines, fittings, and valves from the point where the mole fraction of H₂O in the humidified calibration gas, x_{H_2Oref} , is measured to the analyzer are at least 5 °C above the local calibration gas dewpoint in any transfer lines, fittings, and valves between the point at which you determine x_{H_2Oref} and the analyzer. Verify the humidity generator's uncertainty upon initial installation, within 370 days before verifying response factors and penetration fractions, and after major maintenance. Use the uncertainties from the calibration of the humidity generator's measurements and follow NIST Technical Note 1297 (incorporated by reference, see § 1065.1010) to verify that the amount of H₂O in x_{H_2Oref} is determined within ±3 % uncertainty, $U_{x_{H_2O}}$, for one of the options described in § 1065.750(a)(6). If the humidity generator requires assembly before use, after assembly follow the instrument manufacturer's instructions to check for leaks.

(1) If the sample does not pass through a dryer during emission testing, generate at least five different H₂O concentrations that cover the range from less than the minimum expected to greater than the maximum expected water concentration during testing. Use good engineering judgment to determine the target concentrations.

(2) If the sample passes through a dryer during emission testing, humidify your test gas to an H₂O level at or above the level determined in § 1065.145(e)(2) for that dryer and determine a single wet analyzer response to the dehumidified sample.

§ 1065.366 Interference verification for FTIR analyzers.

(a) *Scope and frequency.* If you measure CH₄, C₂H₆, NMHC, or NMNEHC using an FTIR analyzer, verify the amount of interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles.* ~~Interference gases~~Certain species can interfere with ~~certain~~ analyzers by causing a response similar to the target analyte. If the analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, a correct result depends on simultaneously conducting these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) *System requirements.* An FTIR analyzer must have combined interference that is within ±2 % of the flow-weighted mean concentration of CH₄, NMHC, or NMNEHC expected at the standard, though we strongly recommend a lower interference that is within ±1 %.

(d) *Procedure*. Perform the interference verification for an FTIR analyzer using the same procedure that applies for N₂O analyzers in § 1065.375(d).

§ 1065.369 H₂O, CO, and CO₂ interference verification for photoacoustic alcohol analyzers.

(a) *Scope and frequency*. If you measure ethanol or methanol using a photoacoustic analyzer, verify the amount of H₂O, CO, and CO₂ interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles*. H₂O, CO, and CO₂ can positively interfere with a photoacoustic analyzer by causing a response similar to ethanol or methanol. If the photoacoustic analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, [a correct result depends on](#) simultaneously conducting these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) *System requirements*. Photoacoustic analyzers must have combined interference that is within (0.0 ±0.5) µmol/mol. We strongly recommend a lower interference that is within (0.0 ±0.25) µmol/mol.

(d) *Procedure*. Perform the interference verification by following the procedure in § 1065.375(d), comparing the results to paragraph (c) of this section.

NO_x AND N₂O MEASUREMENTS

§ 1065.370 CLD CO₂ and H₂O quench verification.

(a) *Scope and frequency*. If you use a CLD analyzer to measure NO_x, verify the amount of H₂O and CO₂ quench after installing the CLD analyzer and after major maintenance.

(b) *Measurement principles*. H₂O and CO₂ can negatively interfere with a CLD's NO_x response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD utilizes to detect NO_x. This procedure and the calculations in § 1065.675 determine quench and scale the quench results to the maximum mole fraction of H₂O and the maximum CO₂ concentration expected during emission testing. If the CLD analyzer uses quench compensation algorithms that utilize H₂O and/or CO₂ measurement instruments, evaluate quench with these instruments active and evaluate quench with the compensation algorithms applied.

(c) *System requirements*. A CLD analyzer must have a combined H₂O and CO₂ quench of ±2 % or less, though we strongly recommend a quench of ±1 % or less. Combined quench is the sum of the CO₂ quench determined as described in paragraph (d) of this section, plus the H₂O quench determined in paragraph (e) of this section.

(d) *CO₂ quench verification procedure*. Use the following method to determine CO₂ quench by using a gas divider that blends binary span gases with zero gas as the diluent and meets the specifications in § 1065.248, or use good engineering judgment to develop a different protocol:

- (1) Use PTFE or stainless steel tubing to make necessary connections.
- (2) Configure the gas divider such that nearly equal amounts of the span and diluent gases are blended with each other.
- (3) If the CLD analyzer has an operating mode in which it detects NO-only, as opposed to total NO_x, operate the CLD analyzer in the NO-only operating mode.
- (4) Use a CO₂ span gas that meets the specifications of § 1065.750 and a concentration that is approximately twice the maximum CO₂ concentration expected during emission testing.

(5) Use an NO span gas that meets the specifications of § 1065.750 and a concentration that is approximately twice the maximum NO concentration expected during emission testing.

(6) Zero and span the CLD analyzer. Span the CLD analyzer with the NO span gas from paragraph (d)(5) of this section through the gas divider. Connect the NO span gas to the span port of the gas divider; connect a zero gas to the diluent port of the gas divider; use the same nominal blend ratio selected in paragraph (d)(2) of this section; and use the gas divider's output concentration of NO to span the CLD analyzer. Apply gas property corrections as necessary to ensure accurate gas division.

(7) Connect the CO₂ span gas to the span port of the gas divider.

(8) Connect the NO span gas to the diluent port of the gas divider.

(9) While flowing NO and CO₂ through the gas divider, stabilize the output of the gas divider. Determine the CO₂ concentration from the gas divider output, applying gas property correction as necessary to ensure accurate gas division, or measure it using an NDIR. Record this concentration, $x_{\text{CO}_2\text{act}}$, and use it in the quench verification calculations in § 1065.675. Alternatively, you may use a simple gas blending device and use an NDIR to determine this CO₂ concentration. If you use an NDIR, it must meet the requirements of this part for laboratory testing and you must span it with the CO₂ span gas from paragraph (d)(4) of this section.

(10) Measure the NO concentration downstream of the gas divider with the CLD analyzer. Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response. While the analyzer measures the sample's concentration, record the analyzer's output for 30 seconds. Calculate the arithmetic mean concentration from these data, x_{NOmeas} . Record x_{NOmeas} , and use it in the quench verification calculations in § 1065.675.

(11) Calculate the actual NO concentration at the gas divider's outlet, x_{NOact} , based on the span gas concentrations and $x_{\text{CO}_2\text{act}}$ according to Eq. 1065.675-2. Use the calculated value in the quench verification calculations in Eq. 1065.675-1.

(12) Use the values recorded according to this paragraph (d) and paragraph (e) of this section to calculate quench as described in § 1065.675.

(e) *H₂O quench verification procedure.* Use the following method to determine H₂O quench, or use good engineering judgment to develop a different protocol:

(1) Use PTFE or stainless steel tubing to make necessary connections.

(2) If the CLD analyzer has an operating mode in which it detects NO-only, as opposed to total NO_x, operate the CLD analyzer in the NO-only operating mode.

(3) Use an NO span gas that meets the specifications of § 1065.750 and a concentration that is near the maximum concentration expected during emission testing.

(4) Zero and span the CLD analyzer. Span the CLD analyzer with the NO span gas from paragraph (e)(3) of this section, record the span gas concentration as x_{NOdry} , and use it in the quench verification calculations in § 1065.675.

(5) Create a humidified NO span gas by bubbling a NO gas that meets the specifications in § 1065.750 through distilled H₂O in a sealed vessel or use a device that introduces distilled H₂O as vapor into a controlled gas flow. If the sample does not pass through a dryer during emission testing, humidify your test gas to an H₂O level approximately equal to the maximum mole fraction of H₂O expected during emission testing. If the humidified NO span gas sample does not pass through a sample dryer, the quench verification calculations in § 1065.675 scale the measured H₂O quench to the highest mole fraction of H₂O expected

during emission testing. If the sample passes through a dryer during emission testing, you must humidify your test gas to an H₂O level at or above the level determined in § 1065.145(e)(2) for that dryer. For this case, the quench verification calculations in § 1065.675 do not scale the measured H₂O quench.

(6) Introduce the humidified NO test gas into the sample system. You may introduce it upstream or downstream of any sample dryer that is used during emission testing. Note that the sample dryer must meet the sample dryer verification check in § 1065.342.

(7) Measure the mole fraction of H₂O in the humidified NO span gas downstream of the sample dryer, $x_{\text{H}_2\text{O}_{\text{meas}}}$. We recommend that you measure $x_{\text{H}_2\text{O}_{\text{meas}}}$ as close as possible to the CLD analyzer inlet. You may calculate $x_{\text{H}_2\text{O}_{\text{meas}}}$ from measurements of dewpoint, T_{dew} , and absolute pressure, p_{total} .

(8) Use good engineering judgment to prevent condensation in the transfer lines, fittings, or valves from the point where $x_{\text{H}_2\text{O}_{\text{meas}}}$ is measured to the analyzer. We recommend that you design your system so the wall temperatures in the transfer lines, fittings, and valves from the point where $x_{\text{H}_2\text{O}_{\text{meas}}}$ is measured to the analyzer are at least 5 °C above the local sample gas dewpoint.

(9) Measure the humidified NO span gas concentration with the CLD analyzer. Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response. While the analyzer measures the sample's concentration, record the analyzer's output for 30 seconds. Calculate the arithmetic mean of these data, $x_{\text{NO}_{\text{wet}}}$. Record $x_{\text{NO}_{\text{wet}}}$ and use it in the quench verification calculations in § 1065.675.

(f) *Corrective action.* If the sum of the H₂O quench plus the CO₂ quench is less than -2 % or greater than +2 %, take corrective action by repairing or replacing the analyzer. Before running emission tests, verify that the corrective action successfully restored the analyzer to proper functioning.

(g) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO_x sampling system and your emission calculation procedures, the combined CO₂ and H₂O interference for your NO_x CLD analyzer always affects your brake-specific NO_x emission results within no more than ±1 % of the applicable NO_x standard. If you certify to a combined emission standard (such as a NO_x + NMHC standard), scale your NO_x results to the combined standard based on the measured results (after incorporating deterioration factors, if applicable). For example, if your final NO_x + NMHC value is half of the emission standard, double the NO_x result to estimate the level of NO_x emissions corresponding to the applicable standard.

(2) You may use a NO_x CLD analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

§ 1065.372 NDUV analyzer HC and H₂O interference verification.

(a) *Scope and frequency.* If you measure NO_x using an NDUV analyzer, verify the amount of H₂O and hydrocarbon interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles.* Hydrocarbons and H₂O can positively interfere with an NDUV analyzer by causing a response similar to NO_x. If the NDUV analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, [a](#)

correct result depends on simultaneously conducting such measurements to test the algorithms during the analyzer interference verification.

(c) *System requirements.* A NO_x NDUV analyzer must have combined H₂O and HC interference within ±2 % of the flow-weighted mean concentration of NO_x expected at the standard, though we strongly recommend keeping interference within ±1 %.

(d) *Procedure.* Perform the interference verification as follows:

(1) Start, operate, zero, and span the NO_x NDUV analyzer according to the instrument manufacturer's instructions.

(2) We recommend that you extract engine exhaust to perform this verification. Use a CLD that meets the specifications of subpart C of this part to quantify NO_x in the exhaust. Use the CLD response as the reference value. Also measure HC in the exhaust with a FID analyzer that meets the specifications of subpart C of this part. Use the FID response as the reference hydrocarbon value.

(3) Upstream of any sample dryer, if one is used during testing, introduce the engine exhaust to the NDUV analyzer.

(4) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(5) While all analyzers measure the sample's concentration, record 30 seconds of sampled data, and calculate the arithmetic means for the three analyzers.

(6) Subtract the CLD mean from the NDUV mean.

(7) Multiply this difference by the ratio of the flow-weighted mean HC concentration expected at the standard to the HC concentration measured during the verification.

(8) The analyzer meets the interference verification of this section if ~~this result is within ±2 % of the NO_x concentration expected at the standard~~ the result of paragraph (d)(7) of this section meets the tolerance in paragraph (c) of this section.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO_x sampling system and your emission calculation procedures, the combined HC and H₂O interference for your NO_x NDUV analyzer always affects your brake-specific NO_x emission results by less than 0.5 % of the applicable NO_x standard.

(2) You may use a NO_x NDUV analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

§ 1065.375 Interference verification for N₂O analyzers.

(a) *Scope and frequency.* This section describes how to perform interference verification for certain analyzers as described in § 1065.275. Perform interference verification after initial analyzer installation and after major maintenance. See § 1065.275 to determine whether you need to verify the amount of interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles.* ~~Interference gases~~ Certain species can positively interfere with ~~certain~~ analyzers by causing a response similar to N₂O. If the analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, a correct result depends on simultaneously conducting these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) *System requirements.* Analyzers must have combined interference that is within (0.0 ± 1.0) $\mu\text{mol/mol}$. We strongly recommend a lower interference that is within (0.0 ± 0.5) $\mu\text{mol/mol}$.

(d) *Procedure.* Perform the interference verification as follows:

(1) Start, operate, zero, and span the N_2O analyzer as you would before an emission test. If the sample is passed through a dryer during emission testing, you may run this verification test with the dryer if it meets the requirements of § 1065.342. Operate the dryer at the same conditions as you will for an emission test. You may also run this verification test without the sample dryer.

(2) Create a humidified test gas by bubbling a multi component span gas that incorporates the target interference species and meets the specifications in § 1065.750 through distilled H_2O in a sealed vessel or use a device that introduces distilled H_2O as vapor into a controlled gas flow. If the sample does not pass through a dryer during emission testing, humidify your test gas to an H_2O level at or above the maximum expected during emission testing. If the sample passes through a dryer during emission testing, you must humidify your test gas to an H_2O level at or above the level determined in § 1065.145(e)(2) for that dryer. Use interference span gas concentrations that are at least as high as the maximum expected during testing.

(3) Introduce the humidified interference test gas into the sample system. ~~You may introduce~~ [it upstream or](#) downstream of any sample dryer, if one is used during testing.

(4) If the sample is not passed through a dryer during this verification test, measure the H_2O mole fraction, $x_{\text{H}_2\text{O}}$, of the humidified interference test gas as close as possible to the inlet of the analyzer. For example, measure dewpoint, T_{dew} , and absolute pressure, p_{total} , to calculate $x_{\text{H}_2\text{O}}$. Verify that the H_2O content meets the requirement in paragraph (d)(2) of this section. If the sample is passed through a dryer during this verification test, you must verify that the H_2O content of the humidified test gas downstream of the vessel meets the requirement in paragraph (d)(2) of this section based on either direct measurement of the H_2O content (e.g., dewpoint and pressure) or an estimate based on the vessel pressure and temperature. Use good engineering judgment to estimate the H_2O content. For example, you may use previous direct measurements of H_2O content to verify the vessel's level of saturation.

(5) If a sample dryer is not used in this verification test, use good engineering judgment to prevent condensation in the transfer lines, fittings, or valves from the point where $x_{\text{H}_2\text{O}}$ is measured to the analyzer. We recommend that you design your system so that the wall temperatures in the transfer lines, fittings, and valves from the point where $x_{\text{H}_2\text{O}}$ is measured to the analyzer are at least 5°C above the local sample gas dewpoint.

(6) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(7) While the analyzer measures the sample's concentration, record its output for 30 seconds. Calculate the arithmetic mean of this data. When performed with all the gases simultaneously, this is the combined interference.

(8) The analyzer meets the interference verification if the result of paragraph (d)(7) of this section meets the tolerance in paragraph (c) of this section.

(9) You may also run interference procedures separately for individual interference ~~gases~~[species](#). If the ~~concentrations of the~~[interference gas levels](#)~~species~~ used are higher than the maximum levels expected during testing, you may scale down each observed interference value (the arithmetic mean of 30 second data described in paragraph (d)(7) of this section) by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. You may run separate interference

concentrations of H₂O (down to 0.025 mol/mol H₂O content) that are lower than the maximum levels expected during testing, but you must scale up the observed H₂O interference by multiplying the observed interference by the ratio of the maximum expected H₂O concentration value to the actual value used during this procedure. The sum of the scaled interference values must meet the tolerance for combined interference as specified in paragraph (c) of this section.

§ 1065.376 Chiller NO₂ penetration.

(a) *Scope and frequency.* If you use a chiller to dry a sample upstream of a NO_x measurement instrument, but you don't use an NO₂-to-NO converter upstream of the chiller, you must perform this verification for chiller NO₂ penetration. Perform this verification after initial installation and after major maintenance.

(b) *Measurement principles.* A chiller removes H₂O, which can otherwise interfere with a NO_x measurement. However, liquid H₂O remaining in an improperly designed chiller can remove NO₂ from the sample. If a chiller is used without an NO₂-to-NO converter upstream, it could remove NO₂ from the sample prior NO_x measurement.

(c) *System requirements.* A chiller must allow for measuring at least 95 % of the total NO₂ at the maximum expected concentration of NO₂.

(d) *Procedure.* Use the following procedure to verify chiller performance:

(1) *Instrument setup.* Follow the analyzer and chiller manufacturers' start-up and operating instructions. Adjust the analyzer and chiller as needed to optimize performance.

(2) *Equipment setup and data collection.* (i) Zero and span the total NO_x gas analyzer(s) as you would before emission testing.

(ii) Select an NO₂ calibration gas, balance gas of dry air, that has an NO₂ concentration within ±5 % of the maximum NO₂ concentration expected during testing.

(iii) Overflow this calibration gas at the gas sampling system's probe or overflow fitting. Allow for stabilization of the total NO_x response, accounting only for transport delays and instrument response.

(iv) Calculate the mean of 30 seconds of recorded total NO_x data and record this value as x_{NO_xref} .

(v) Stop flowing the NO₂ calibration gas.

(vi) Next saturate the sampling system by overflowing a dewpoint generator's output, set at a dewpoint of 50 °C, to the gas sampling system's probe or overflow fitting. Sample the dewpoint generator's output through the sampling system and chiller for at least 10 minutes until the chiller is expected to be removing a constant rate of H₂O.

(vii) Immediately switch back to overflowing the NO₂ calibration gas used to establish x_{NO_xref} . Allow for stabilization of the total NO_x response, accounting only for transport delays and instrument response. Calculate the mean of 30 seconds of recorded total NO_x data and record this value as x_{NO_xmeas} .

(viii) Correct x_{NO_xmeas} to x_{NO_xdry} based upon the residual H₂O vapor that passed through the chiller at the chiller's outlet temperature and pressure.

(3) *Performance evaluation.* If x_{NO_xdry} is less than 95 % of x_{NO_xref} , repair or replace the chiller.

(e) *Exceptions.* The following exceptions apply:

- (1) You may omit this verification if you can show by engineering analysis that for your NO_x sampling system and your emission calculations procedures, the chiller always affects your brake-specific NO_x emission results by less than 0.5 % of the applicable NO_x standard.
- (2) You may use a chiller that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

§ 1065.377 Interference verification for NH₃ analyzers.

(a) Scope and frequency. This section describes how to perform interference verification for certain analyzers as described in § 1065.277. ~~See § 1065.277 to determine whether you need to verify the amount of interference.~~ Perform interference verification after initial analyzer installation and after major maintenance.

(b) Measurement principles. Certain species-compounds can positively interfere with analyzers by causing a response similar to NH₃. If the analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, a correct result depends on simultaneously conducting these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) System requirements. Analyzers must have combined interference that is within (0.0 ±2.0) µmol/mol.

(d) Procedure. Perform the interference verification as follows:

(1) Start, operate, zero, and span the NH₃ analyzer as you would before an emission test. If the sample is passed through a dryer during emission testing, you may run this verification test with the dryer if it meets the requirements of § 1065.342. Operate the dryer at the same conditions as you will for an emission test. You may also run this verification test without the sample dryer.

(2) ~~Create a humidified test gas using~~ Except as specified in paragraph (d)(9) of this section, select a multi-component span gas meeting the specification of § 1065.750 that incorporates the all the appropriate target interference species. ~~and meets the specifications in § 1065.750 and a~~ Use a humidity generator device that introduces distilled H₂O as vapor into a controlled gas flow meets the requirements in § 1065.750(a)(6) to humidify the span gas. If the sample does not pass through a dryer during emission testing, humidify your test gas to an H₂O level at or above the maximum expected during emission testing. If the sample passes through a dryer during emission testing, ~~you must~~ humidify your test gas to an H₂O level at or above the level determined in § 1065.145(e)(2) for that dryer. Use interference span gas concentrations that are at least as high as the maximum expected during testing.

(3) Introduce the humidified interference test gas into the sample system upstream or - ~~You may introduce it~~ downstream of any sample dryer, if one is used during testing.

(4) If the sample ~~isdoes~~ not passed through a dryer during this verification test, measure the H₂O mole fraction, x_{H_2O} , of the humidified interference test gas as close as possible to ~~the inlet of the analyzer inlet~~. For example, You may measure dewpoint, T_{dew} , and absolute pressure, p_{total} , to calculate x_{H_2O} . Verify that the H₂O content meets the requirement in paragraph (d)(2) of this section. If the sample ~~is-passesd~~ through a dryer during this verification test, either measure dewpoint, T_{dew} , and absolute pressure, p_{total} , to calculate x_{H_2O} or use good engineering judgment to estimate the value of x_{H_2O} ~~you must verify that the H₂O content of the humidified test gas downstream of the vessel meets the requirement in paragraph (d)(2) of this section based on either direct measurement of the H₂O content (e.g.,~~

dewpoint and pressure) or an estimate based on the vessel pressure and temperature. Use good engineering judgment to estimate the H₂O content. For example, you may use previous direct measurements of H₂O content at certain vessel pressures and temperatures to estimate x_{H_2O} verify the vessel's level of saturation.

(5) If the verification procedure does not include a sample dryer is not used in this verification test, use good engineering judgment to prevent condensation in the transfer lines, fittings, or valves from between the point where of x_{H_2O} measurement and is measured to the analyzer. We recommend that you design your system so that the wall temperatures in those transfer lines, fittings, and valves from the point where x_{H_2O} is measured to the analyzer are at least 5 °C above the local sample gas dewpoint.

(6) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(7) While Operate the analyzer to measures the sample's NH₃ concentration and; record results its output for 30 seconds. Calculate the arithmetic mean of this these data to determine the interference value. When performed with all the interference species gases simultaneously, this is the combined interference.

(8) The analyzer meets the interference verification if the result of paragraph (d)(7) of this section meets the tolerance in paragraph (c) of this section.

(9) You may instead perform also run interference verification procedures separately for individual interference species. The interference verification specified in paragraph (c) of this section applies based on the sum of the interference values from separate interference species. If the concentration of the any interference species used are is higher than the maximum levels expected during testing, you may scale down each observed interference value (the arithmetic mean of 30 second data described in paragraph (d)(7) of this section) by multiplying the observed interference value by the ratio of the maximum expected concentration value to the concentration in the span gas actual value used during this procedure. You may run separate H₂O interference concentrations of H₂O (down to 0.025 mol/mol H₂O content) that are lower than the maximum levels expected during testing, but you must scale up the observed H₂O interference value by multiplying the observed interference value by the ratio of the maximum expected H₂O concentration value to the concentration in the span gas actual value used during this procedure. The sum of the scaled interference values must meet the tolerance for combined interference as specified in paragraph (c) of this section.

§ 1065.378 NO₂-to-NO converter conversion verification.

(a) *Scope and frequency.* If you use an analyzer that measures only NO to determine NO_x, you must use an NO₂-to-NO converter upstream of the analyzer. Perform this verification after installing the converter, after major maintenance and within 35 days before an emission test. This verification must be repeated at this frequency to verify that the catalytic activity of the NO₂-to-NO converter has not deteriorated.

(b) *Measurement principles.* An NO₂-to-NO converter allows an analyzer that measures only NO to determine total NO_x by converting the NO₂ in exhaust to NO.

(c) *System requirements.* An NO₂-to-NO converter must allow for measuring at least 95 % of the total NO₂ at the maximum expected concentration of NO₂.

(d) *Procedure.* Use the following procedure to verify the performance of a NO₂-to-NO converter:

(1) *Instrument setup.* Follow the analyzer and NO₂-to-NO converter manufacturers' start-up and operating instructions. Adjust the analyzer and converter as needed to optimize performance.

(2) *Equipment setup.* Connect an ozonator's inlet to a zero-air or oxygen source and connect its outlet to one port of a three-way tee fitting. Connect an NO span gas to another port, and connect the NO₂-to-NO converter inlet to the last port.

(3) *Adjustments and data collection.* Perform this check as follows:

(i) Set ozonator air off, turn ozonator power off, and set the analyzer to NO mode. Allow for stabilization, accounting only for transport delays and instrument response.

(ii) Use an NO concentration that is representative of the peak total NO_x concentration expected during testing. The NO₂ content of the gas mixture shall be less than 5 % of the NO concentration. Record the concentration of NO by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as x_{NOref} .

(iii) Turn on the ozonator O₂ supply and adjust the O₂ flow rate so the NO indicated by the analyzer is about 10 percent less than x_{NOref} . Record the concentration of NO by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as $x_{\text{NO+O2mix}}$.

(iv) Switch the ozonator on and adjust the ozone generation rate so the NO measured by the analyzer is 20 percent of x_{NOref} or a value which would simulate the maximum concentration of NO₂ expected during testing, while maintaining at least 10 percent unreacted NO. This ensures that the ozonator is generating NO₂ at the maximum concentration expected during testing. Record the concentration of NO by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as x_{NOmeas} .

(v) Switch the NO_x analyzer to NO_x mode and measure total NO_x. Record the concentration of NO_x by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as x_{NOxmeas} .

(vi) Switch off the ozonator but maintain gas flow through the system. The NO_x analyzer will indicate the NO_x in the NO + O₂ mixture. Record the concentration of NO_x by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as $x_{\text{NOx+O2mix}}$.

(vii) Turn off the ozonator O₂ supply. The NO_x analyzer will indicate the NO_x in the original NO-in-N₂ mixture. Record the concentration of NO_x by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as x_{NOxref} . This value should be no more than 5 percent above the x_{NOref} value.

(4) *Performance evaluation.* Calculate the efficiency of the NO_x converter by substituting the concentrations obtained into the following equation:

$$\text{efficiency} = \left(1 + \frac{x_{\text{NOxmeas}} - x_{\text{NOx+O2mix}}}{x_{\text{NO+O2mix}} - x_{\text{NOmeas}}} \right) \cdot 100 \%$$

(5) If the result is less than 95 %, repair or replace the NO₂-to-NO converter.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO_x sampling system and your emission calculations procedures, the converter always affects your brake-specific NO_x emission results by less than 0.5 % of the applicable NO_x standard.

(2) You may use a converter that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

[\(3\) You may request to verify converter conversion efficiency using an NO₂ concentration whose value is representative of the peak total NO₂ concentration expected during testing, in place of the procedure in paragraph \(d\) of this section, with our approval.](#)

PM MEASUREMENTS

§ 1065.390 PM balance verifications and weighing process verification.

(a) *Scope and frequency.* This section describes three verifications.

(1) Independent verification of PM balance performance within 370 days before weighing any filter.

(2) Zero and span the balance within 12 h before weighing any filter.

(3) Verify that the mass determination of reference filters before and after a filter weighing session are less than a specified tolerance.

(b) *Independent verification.* Have the balance manufacturer (or a representative approved by the balance manufacturer) verify the balance performance within 370 days of testing. Balances have internal weights that compensate for drift due to environmental changes. These internal weights must be verified as part of this independent verification with external, certified calibration weights that meet the specifications in § 1065.790.

(c) *Zeroing and spanning.* You must verify balance performance by zeroing and spanning it with at least one calibration weight. Also, any external weights you use must meet the specifications in § 1065.790. Any weights internal to the PM balance used for this verification must be verified as described in paragraph (b) of this section.

(1) Use a manual procedure in which you zero the balance and span the balance with at least one calibration weight. If you normally use mean values by repeating the weighing process to improve the accuracy and precision of PM measurements, use the same process to verify balance performance.

(2) You may use an automated procedure to verify balance performance. For example most balances have internal weights for automatically verifying balance performance.

(d) *Reference sample weighing.* Verify all mass readings during a weighing session by weighing reference PM sample media (e.g. filters) before and after a weighing session. A weighing session may be as short as desired, but no longer than 80 hours, and may include both pre-test and post-test mass readings. We recommend that weighing sessions be eight hours or less. Successive mass determinations of each reference PM sample media (e.g., filter) must return the same value within $\pm 10 \mu\text{g}$ or $\pm 10 \%$ of the net PM mass expected at the standard (if known), whichever is higher. If successive reference PM sample media (e.g. filter) weighing events fail this criterion, invalidate all individual test media (e.g., filter) mass readings occurring between the successive reference media (e.g., filter) mass determinations. You may reweigh these media (e.g. filter) in another weighing session. If you invalidate a pre-test media (e.g. filter) mass determination, that test interval is void. Perform this verification as follows:

(1) Keep at least two samples of unused PM sample media (e.g., filters) in the PM-stabilization environment. Use these as references. If you collect PM with filters, select unused filters of the same material and size for use as references. You may periodically replace references, using good engineering judgment.

(2) Stabilize references in the PM stabilization environment. Consider references stabilized if they have been in the PM-stabilization environment for a minimum of 30 min, and the PM-stabilization environment has been within the specifications of § 1065.190(d) for at least the preceding 60 min.

(3) Exercise the balance several times with a reference sample. We recommend weighing ten samples without recording the values.

(4) Zero and span the balance. Using good engineering judgment, place a test mass such as a calibration weight on the balance, then remove it. After spanning, confirm that the balance returns to a zero reading within the normal stabilization time.

(5) Weigh each of the reference media (e.g. filters) and record their masses. We recommend using substitution weighing as described in § 1065.590(j). If you normally use mean values by repeating the weighing process to improve the accuracy and precision of the reference media (e.g. filter) mass, you must use mean values of sample media (e.g. filter) masses.

(6) Record the balance environment dewpoint, ambient temperature, and atmospheric pressure.

(7) Use the recorded ambient conditions to correct results for buoyancy as described in § 1065.690. Record the buoyancy-corrected mass of each of the references.

(8) Subtract each reference media's (e.g. filter's) buoyancy-corrected reference mass from its previously measured and recorded buoyancy-corrected mass.

(9) If any of the reference filters' observed mass changes by more than that allowed under this paragraph, you must invalidate all PM mass determinations made since the last successful reference media (e.g. filter) mass validation. You may discard reference PM media (e.g. filters) if only one of the filter's mass changes by more than the allowable amount and you can positively identify a special cause for that filter's mass change that would not have affected other in-process filters. Thus, the validation can be considered a success. In this case, you do not have to include the contaminated reference media when determining compliance with paragraph (d)(10) of this section, but the affected reference filter must be immediately discarded and replaced prior to the next weighing session.

(10) If any of the reference masses change by more than that allowed under this paragraph (d), invalidate all PM results that were determined between the two times that the reference masses were determined. If you discarded reference PM sample media according to paragraph (d)(9) of this section, you must still have at least one reference mass difference that meets the criteria in this paragraph (d). Otherwise, you must invalidate all PM results that were determined between the two times that the reference media (e.g. filters) masses were determined.

§ 1065.395 Inertial PM balance verifications.

This section describes how to verify the performance of an inertial PM balance.

(a) *Independent verification.* Have the balance manufacturer (or a representative approved by the balance manufacturer) verify the inertial balance performance within 370 days before testing.

(b) *Other verifications.* Perform other verifications using good engineering judgment and instrument manufacturer recommendations.

Subpart E—Engine Selection, Preparation, and Maintenance

§ 1065.401 Test engine selection.

While all engine configurations within a certified engine family must comply with the applicable standards in the standard-setting part, you need not test each configuration for certification.

- (a) Select an engine configuration within the engine family for testing, as follows:
 - (1) Test the engine that we specify, whether we issue general guidance or give you specific instructions.
 - (2) If we do not tell you which engine to test, follow any instructions in the standard-setting part.
 - (3) If we do not tell you which engine to test and the standard-setting part does not include specifications for selecting test engines, use good engineering judgment to select the engine configuration within the engine family that is most likely to exceed an emission standard.
- (b) In the absence of other information, the following characteristics are appropriate to consider when selecting the engine to test:
 - (1) Maximum fueling rates.
 - (2) Maximum loads.
 - (3) Maximum in-use speeds.
 - (4) Highest sales volume.
- (c) For our testing, we may select any engine configuration within the engine family.

§ 1065.405 Test engine preparation and maintenance.

This part 1065 describes how to test engines for a variety of purposes, including certification testing, production-line testing, and in-use testing. Depending on which type of testing is being conducted, different preparation and maintenance requirements apply for the test engine.

- (a) If you are testing an emission-data engine for certification, make sure it is built to represent production engines, consistent with paragraph (f) of this section.
 - (1) This includes governors that you normally install on production engines. Production engines should also be tested with their installed governors. If your engine is equipped with multiple user-selectable governor types and if the governor does not manipulate the emission control system (i.e., the governor only modulates an “operator demand” signal such as commanded fuel rate, torque, or power), choose the governor type that allows the test cell to most accurately follow the duty cycle. If the governor manipulates the emission control system, treat it as an adjustable parameter. If you do not install governors on production engines, simulate a governor that is representative of a governor that others will install on your production engines.
 - (2) In certain circumstances, you may incorporate test cell components to simulate an in-use configuration, consistent with good engineering judgment. For example, §§ 1065.122 and 1065.125 allow the use of test cell components to represent engine cooling and intake air systems.
 - (3) The provisions in § 1065.110(e) also apply to emission-data engines for certification.
 - (4) For engines using SCR, use any size DEF tank and fuel tank. We may require you to give us a production-type DEF tank, including any associated sensors, for our testing.
- (b) We may set adjustable parameters to any value in the valid range, and you are responsible for controlling emissions over the full valid range. For each adjustable parameter, if the standard-setting part has no unique requirements and if we have not specified a value, use good engineering judgment to select the most common setting. If information on the most common

setting is not available, select the setting representing the engine's original shipped configuration. If information on the most common and original settings is not available, set the adjustable parameter in the middle of the valid range.

(c) Testing generally occurs only after the test engine has undergone a stabilization step (or in-use operation). If the engine has not already been stabilized, run the test engine, with all emission control systems operating, long enough to stabilize emission levels. Note that you must generally use the same stabilization procedures for emission-data engines for which you apply the same deterioration factors so low-hour emission-data engines are consistent with the low-hour engine used to develop the deterioration factor.

(1) Unless otherwise specified in the standard-setting part, you may consider emission levels stable without measurement after 50 h of operation. If the engine needs less operation to stabilize emission levels, record your reasons and the methods for doing this, and give us these records if we ask for them. If the engine will be tested for certification as a low-hour engine, see the standard-setting part for limits on testing engines to establish low-hour emission levels.

(2) You may stabilize emissions from a catalytic exhaust aftertreatment device by operating it on a different engine, consistent with good engineering judgment. Note that good engineering judgment requires that you consider both the purpose of the test and how your stabilization method will affect the development and application of deterioration factors. For example, this method of stabilization is generally not appropriate for production engines. We may also allow you to stabilize emissions from a catalytic exhaust aftertreatment device by operating it on an engine-exhaust simulator.

(d) Record any maintenance, modifications, parts changes, diagnostic or emissions testing and document the need for each event. You must provide this information if we request it.

(e) For accumulating operating hours on your test engines, select engine operation that represents normal in-use operation for the engine family.

(f) If your engine will be used in a vehicle equipped with a canister for storing evaporative hydrocarbons for eventual combustion in the engine and the test sequence involves a cold-start or hot-start duty cycle, attach a canister to the engine before running an emission test. You may omit using an evaporative canister for any hot-stabilized duty cycles. You may request to omit using an evaporative canister during testing if you can show that it would not affect your ability to show compliance with the applicable emission standards. You may operate the engine without an installed canister for service accumulation. Prior to an emission test, use the following steps to precondition a canister and attach it to your engine:

(1) Use a canister and plumbing arrangement that represents the in-use configuration of the largest capacity canister in all expected applications.

(2) Precondition the canister as described in 40 CFR 86.132-96(j).

(3) Connect the canister's purge port to the engine.

(4) Plug the canister port that is normally connected to the fuel tank.

(g) This paragraph (g) defines the components that are considered to be part of the engine for laboratory testing. See § 1065.110 for provisions related to system boundaries with respect to work inputs and outputs.

(1) This paragraph (g)(1) describes certain criteria for considering a component to be part of the test engine. The criteria are intended to apply broadly, such that a component would generally be considered part of the engine in cases of uncertainty. Except as specified in paragraph (g)(2) of this section, an engine-related component meeting both the following

criteria is considered to be part of the test engine for purposes of testing and for stabilizing emission levels, preconditioning, and measuring emission levels:

(i) The component directly affects the functioning of the engine, is related to controlling emissions, or transmits engine power. This would include engine cooling systems, engine controls, and transmissions.

(ii) The component is covered by the applicable certificate of conformity. For example, this criterion would typically exclude radiators not described in an application for certification.

(2) This paragraph (g)(2) applies for engine-related components that meet the criteria of paragraph (g)(1) of this section, but that are part of the laboratory setup or are used for other engines. Such components are considered to be part of the test engine for preconditioning, but not for engine stabilization. For example, if you test your engines using the same laboratory exhaust tubing for all tests, there would be no restrictions on the number of test hours that could be accumulated with the tubing, but it would need to be preconditioned separately for each engine.

§ 1065.410 Maintenance limits for stabilized test engines.

(a) After you stabilize the test engine's emission levels, you may do maintenance as allowed by the standard-setting part. However, you may not do any maintenance based on emission measurements from the test engine (i.e., unscheduled maintenance).

(b) For any critical emission-related maintenance—other than what we specifically allow in the standard-setting part—you must completely test an engine for emissions before and after doing any maintenance that might affect emissions, unless we waive this requirement.

(c) If you inspect an engine, keep a record of the inspection and update your application for certification to document any changes that result. You may use any kind of equipment, instrument, or tool that is available at dealerships and other service outlets to identify malfunctioning components or perform maintenance. You may inspect using electronic tools or internal engine systems to monitor engine performance, but only if the information is readable without specialized equipment.

(d) You may repair defective parts from a test engine if they are unrelated to emission control. You must ask us to approve repairs that might affect the engine's emission controls. If we determine that a part failure, system malfunction, or associated repair makes the engine's emission controls unrepresentative of production engines, you may not use it as an emission-data engine. Also, if your test engine has a major mechanical failure that requires you to take it apart, you may no longer use it as an emission-data engine.

§ 1065.415 Durability demonstration.

If the standard-setting part requires durability testing, you must accumulate service in a way that represents how you expect the engine to operate in use. You may accumulate service hours using an accelerated schedule, such as through continuous operation or by using duty cycles that are more aggressive than in-use operation, subject to any pre-approval requirements established in the applicable standard-setting part.

(a) *Maintenance*. The following limits apply to the maintenance that we allow you to do on an emission-data engine:

(1) You may perform scheduled maintenance that you recommend to operators, but only if it is consistent with the standard-setting part's restrictions.

(2) You may perform additional maintenance only as specified in § 1065.410 or allowed by the standard-setting part.

(b) *Emission measurements.* Perform emission tests following the provisions of the standard setting part and this part, as applicable. Perform emission tests to determine deterioration factors consistent with good engineering judgment. Evenly space any tests between the first and last test points throughout the durability period, unless we approve otherwise.

Subpart F—Performing an Emission Test Over Specified Duty Cycles

§ 1065.501 Overview.

(a) Use the procedures detailed in this subpart to measure engine emissions over a specified duty cycle. Refer to subpart J of this part for field test procedures that describe how to measure emissions during in-use engine operation. Refer to subpart L of this part for measurement procedures for testing related to standards other than brake-specific emission standards. This section describes how to--

(1) Map your engine, if applicable, by recording specified speed and torque data, as measured from the engine's primary output shaft.

(2) Transform normalized duty cycles into reference duty cycles for your engine by using an engine map.

(3) Prepare your engine, equipment, and measurement instruments for an emission test.

(4) Perform pre-test procedures to verify proper operation of certain equipment and analyzers.

(5) Record pre-test data.

(6) Start or restart the engine and sampling systems.

(7) Sample emissions throughout the duty cycle.

(8) Record post-test data.

(9) Perform post-test procedures to verify proper operation of certain equipment and analyzers.

(10) Weigh PM samples.

(b) Unless we specify otherwise, you may control the regeneration timing of infrequently regenerated aftertreatment devices such as diesel particulate filters using good engineering judgment. You may control the regeneration timing using a sequence of engine operating conditions or you may initiate regeneration with an external regeneration switch or other command. This provision also allows you to ensure that a regeneration event does not occur during an emission test.

(c) An emission test generally consists of measuring emissions and other parameters while an engine follows one or more duty cycles that are specified in the standard-setting part. There are two general types of duty cycles:

(1) *Transient cycles.* Transient duty cycles are typically specified in the standard-setting part as a second-by-second sequence of speed commands and normalized torque (or power) commands. Operate an engine over a transient cycle such that the speed and torque of the engine's primary output shaft follows the target values. Proportionally sample emissions and other parameters and use the calculations in subpart G of this part to calculate emissions. Start a transient test according to the standard-setting part, as follows:

- (i) A cold-start transient cycle where you start to measure emissions just before starting an engine that has not been warmed up.
- (ii) A hot-start transient cycle where you start to measure emissions just before starting a warmed-up engine.
- (iii) A hot running transient cycle where you start to measure emissions after an engine is started, warmed up, and running.

(2) *Steady-state cycles.* Steady-state duty cycles are typically specified in the standard-setting part as a list of discrete operating points (modes or notches), where each operating point has one value of a normalized speed command and one value of a normalized torque (or power) command. Ramped-modal cycles for steady-state testing also list test times for each mode and transition times between modes where speed and torque are linearly ramped between modes, even for cycles with % power. Start a steady-state cycle as a hot running test, where you start to measure emissions after an engine is started, warmed up and running. Run a steady-state duty cycle as a discrete-mode cycle or a ramped-modal cycle, as follows:

(i) *Discrete-mode cycles.* Before emission sampling, stabilize an engine at the first discrete mode of the duty cycle specified in the standard-setting part. Sample emissions and other parameters for that mode in the same manner as a transient cycle, with the exception that reference speed and torque values are constant. Record data for that mode, transition to the next mode, and then stabilize the engine at the next mode. Continue to sample each mode discretely as a separate test interval and calculate composite brake-specific emission results according to § 1065.650(g)(2).

(A) Use good engineering judgment to determine the time required to stabilize the engine. You may make this determination before starting the test based on prior experience, or you may make this determination in real time based on automated stability criteria. If needed, you may continue to operate the engine after reaching stability to get laboratory equipment ready for sampling.

(B) Collect PM on separate PM sample media for each mode.

(C) The minimum sample time is 60 seconds. We recommend that you sample both gaseous and PM emissions over the same test interval. If you sample gaseous and PM emissions over different test intervals, there must be no change in engine operation between the two test intervals. These two test intervals may completely or partially overlap, they may run consecutively, or they may be separated in time.

(ii) *Ramped-modal cycles.* Perform ramped-modal cycles similar to the way you would perform transient cycles, except that ramped-modal cycles involve mostly steady-state engine operation. Generate a ramped-modal duty cycle as a sequence of second-by-second (1 Hz) reference speed and torque points. Run the ramped-modal duty cycle in the same manner as a transient cycle and use the 1 Hz reference speed and torque values to validate the cycle, even for cycles with % power. Proportionally sample emissions and other parameters during the cycle and use the calculations in subpart G of this part to calculate emissions.

(d) Other subparts in this part identify how to select and prepare an engine for testing (subpart E), how to perform the required engine service accumulation (subpart E), and how to calculate emission results (subpart G).

(e) Subpart J of this part describes how to perform field testing.

§ 1065.510 Engine mapping.

(a) *Applicability, scope, and frequency.* An engine map is a data set that consists of a series of paired data points that represent the maximum brake torque versus engine speed, measured at the engine's primary output shaft. Map your engine if the standard-setting part requires engine mapping to generate a duty cycle for your engine configuration. Map your engine while it is connected to a dynamometer or other device that can absorb work output from the engine's primary output shaft according to § 1065.110. Configure any auxiliary work inputs and outputs such as hybrid, turbo-compounding, or thermoelectric systems to represent their in-use configurations, and use the same configuration for emission testing. See [Figure 1 to § 1065.210](#). This may involve configuring initial states of charge and rates and times of auxiliary-work inputs and outputs. We recommend that you contact the EPA Program Officer before testing to determine how you should configure any auxiliary-work inputs and outputs. If your engine has an auxiliary emission control device to reduce torque output that may activate during engine mapping, turn it off before mapping. Use the most recent engine map to transform a normalized duty cycle from the standard-setting part to a reference duty cycle specific to your engine. Normalized duty cycles are specified in the standard-setting part. You may update an engine map at any time by repeating the engine-mapping procedure. You must map or re-map an engine before a test if any of the following apply:

- (1) If you have not performed an initial engine map.
- (2) If the atmospheric pressure near the engine's air inlet is not within ± 5 kPa of the atmospheric pressure recorded at the time of the last engine map.
- (3) If the engine or emission-control system has undergone changes that might affect maximum torque performance. This includes changing the configuration of auxiliary work inputs and outputs.
- (4) If you capture an incomplete map on your first attempt or you do not complete a map within the specified time tolerance. You may repeat mapping as often as necessary to capture a complete map within the specified time.

(b) *Mapping variable-speed engines.* Map variable-speed engines using the procedure in this paragraph (b). Note that under § 1065.10(c) we may allow or require you to use "other procedures" if the specified procedure results in unrepresentative testing or if your engine cannot be tested using the specified procedure. If the engine has a user-adjustable idle speed setpoint, you may set it to its minimum adjustable value for this mapping procedure and the resulting map may be used for any test, regardless of where it is set for running each test except that the warm idle speed(s) must be determined based on where it is set for running each test.

- (1) Record the atmospheric pressure.
- (2) Warm up the engine by operating it. We recommend operating the engine at any speed and at approximately 75 % of its expected maximum power. Continue the warm-up until the engine coolant, block, [lubricating oil](#), or head absolute temperature is within ± 2 % of its mean value for at least 2 min or until the engine thermostat controls engine temperature.
- (3) Operate the engine at its warm idle speed as follows:
 - (i) For engines with a low-speed governor, set the operator demand to minimum, use the dynamometer or other loading device to target a torque of zero or the lowest idle load that you will use for cycle generation on the engine's primary output shaft, and allow the engine to govern the speed. If the idle load is a function of engine speeds (e.g., the optional declared power from paragraph (f)(6) of this section), calculate the target torque

in real-time. Measure this warm idle speed; we recommend recording at least 30 values of speed and using the mean of those values. If you identify multiple warm idle loads under paragraph (f)(4), (f)(5)(iii), or (f)(6) of this section, measure the warm idle speed at the lowest torque level for this paragraph (b)(3). Measure the other warm idle speeds as described in paragraph (b)(7) of this section.

(ii) For engines without a low-speed governor, operate the engine at warm idle speed from paragraph (f)(2) of this section and zero torque or the lowest warm idle torque that you will use for cycle generation on the engine's primary output shaft. You may use the dynamometer to target a control either torque or speed of zero on the engine's primary output shaft, and manipulate the operator demand to control the other parameter the speed to target the manufacturer-declared value for the lowest engine speed possible with minimum load (also known as manufacturer-declared warm idle speed). You may alternatively use the dynamometer to target control the manufacturer-declared warm idle speed and manipulate the operator demand to control the torque on the engine's primary output shaft to zero.

~~(iii) For variable-speed engines with or without a low-speed governor, if a nonzero idle torque is representative of in-use operation, you may use the dynamometer or operator demand to target the manufacturer-declared idle torque instead of targeting zero torque as specified in paragraphs (b)(3)(i) and (ii) of this section. Control speed as specified in paragraph (b)(3)(i) or (ii) of this section, as applicable. If you use this option for engines with a low-speed governor to measure the warm idle speed with the manufacturer-declared torque at this step, you may use this as the warm idle speed for cycle generation as specified in paragraph (b)(6) of this section. However, if you identify multiple warm idle torques under paragraph (f)(4)(i) of this section, measure the warm idle speed at only one torque level for this paragraph (b)(3).~~

(4) Operate the engine at the minimum mapped speed. A minimum mapped speed equal to (95 ± 1) % of its warm idle speed determined in paragraph (b)(3) of this section may be used for any engine or test. A higher minimum mapped speed may be used if all the duty cycles that the engine is subject to have a minimum reference speed higher than the warm idle speed determined in paragraph (b)(3) of this section. In this case you may use a minimum mapped speed equal to (95 ± 1) % of the lowest minimum reference speed in all the duty cycles the engine is subject to. Set operator demand to maximum and control engine speed at this minimum mapped speed for at least 15 seconds. Set operator demand to maximum and control engine speed at (95 ± 1) % of its warm idle speed determined in paragraph (b)(3)(i) of this section for at least 15 seconds.

(5) Perform a continuous or discrete engine map as described in paragraphs (b)(5)(i) or (ii) of this section. A continuous engine map may be used for any engine. A discrete engine map may be used for engines subject only to steady-state duty cycles. Use linear interpolation between the series of points generated by either of these maps to determine intermediate torque values. Use the series of points generated by either of these maps to generate the power map as described in paragraph (e) of this section.

(i) For continuous engine mapping, begin recording mean feedback speed and torque at 1 Hz or more frequently and increase speed at a constant rate such that it takes (4 to 6) min to sweep from the minimum mapped speed described in paragraphs (b)(4) of this section to the check point speed described in paragraph (b)(5)(iii) of this section. Use good engineering judgment to determine when to stop recording data to ensure that the sweep

is complete. In most cases, this means that you can stop the sweep at any point after the power falls to 50 % of the maximum value.

(ii) For discrete engine mapping, select at least 20 evenly spaced setpoints from the minimum mapped speed described in paragraph (b)(4) of this section to the check point speed described in paragraph (b)(5)(iii) of this section. At each setpoint, stabilize speed and allow torque to stabilize. We recommend that you stabilize an engine for at least 15 seconds at each setpoint and record the mean feedback speed and torque of the last (4 to 6) seconds. Record the mean speed and torque at each setpoint.

(iii) The check point speed of the map is the highest speed above maximum power at which 50 % of maximum power occurs. If this speed is unsafe or unachievable (e.g., for ungoverned engines or engines that do not operate at that point), use good engineering judgment to map up to the maximum safe speed or maximum achievable speed. For discrete mapping, if the engine cannot be mapped to the check point speed, make sure the map includes at least 20 points from 95 % of warm idle to the maximum mapped speed. For continuous mapping, if the engine cannot be mapped to the check point speed, verify that the sweep time from 95 % of warm idle to the maximum mapped speed is (4 to 6) min.

(iv) Note that under § 1065.10(c)(1) we may allow you to disregard portions of the map when selecting maximum test speed if the specified procedure would result in a duty cycle that does not represent in-use operation.

(6) Determine warm high-idle speed for engines with a high-speed governor. You may skip this if the engine is not subject to transient testing with a duty cycle that includes reference speed values above 100 %. You may use a manufacturer-declared warm high-idle speed if the engine is electronically governed. For engines with a high-speed governor that regulates speed by disabling and enabling fuel or ignition at two manufacturer-specified speeds, declare the middle of this specified speed range as the warm high-idle speed. You may alternatively measure warm high-idle speed using the following procedure:

(i) Run an operating point targeting zero torque.

(A) Set operator demand to maximum and use the dynamometer to target zero torque on the engine's primary output shaft.

(B) Wait for the engine governor and dynamometer to stabilize. We recommend that you stabilize for at least 15 seconds.

(C) Record 1 Hz means of the feedback speed and torque for at least 30 seconds. You may record means at a higher frequency as long as there are no gaps in the recorded data. For engines with a high-speed governor that regulates speed by disabling and enabling fuel or ignition, you may need to extend this stabilization period to include at least one disabling event at the higher speed and one enabling event at the lower speed.

(D) Determine if the feedback speed is stable over the recording period. The feedback speed is considered stable if all the recorded 1 Hz means are within ± 2 % of the mean feedback speed over the recording period. If the feedback speed is not stable because of the dynamometer, void the results and repeat measurements after making any necessary corrections. You may void and repeat the entire map sequence, or you may void and replace only the results for establishing warm high-idle speed; use good engineering judgment to warm-up the engine before repeating measurements.

- (E) If the feedback speed is stable, use the mean feedback speed over the recording period as the measured speed for this operating point.
- (F) If the feedback speed is not stable because of the engine, determine the mean as the value representing the midpoint between the observed maximum and minimum recorded feedback speed.
- (G) If the mean feedback torque over the recording period is within $(0 \pm 1) \%$ of $T_{\max \text{ mapped}}$, use the measured speed for this operating point as the warm high-idle speed. Otherwise, continue testing as described in paragraph (b)(6)(ii) of this section.
- (ii) Run a second operating point targeting a positive torque. Follow the same procedure in paragraphs (b)(6)(i)(A) through (F) of this section, except that the dynamometer is set to target a torque equal to the mean feedback torque over the recording period from the previous operating point plus 20 % of $T_{\max \text{ mapped}}$.
- (iii) Use the mean feedback speed and torque values from paragraphs (b)(6)(i) and (ii) of this section to determine the warm high-idle speed. If the two recorded speed values are the same, use that value as the warm high-idle-speed. Otherwise, use a linear equation passing through these two speed-torque points and extrapolate to solve for the speed at zero torque and use this speed intercept value as the warm high-idle speed.
- (iv) You may use a manufacturer-declared T_{\max} instead of the measured $T_{\max \text{ mapped}}$. If you do this, you may also measure the warm high-idle speed as described in this paragraph (b)(6) before running the operating point and speed sweeps specified in paragraphs (b)(4) and (5) of this section.
- (7) This paragraph (b)(7) describes how to collect additional data to determine warm idle speed(s) for cycle generation if your engine has a low-speed governor. You may omit this paragraph (b)(7) if you use the option to declare a warm idle speed in paragraph (f)(3)(iv) of this section, or if you identify only one idle load and one user-adjustable idle speed setpoint under paragraph (b)(3)(i) of this section. Collect additional data to determine warm idle speed(s) using one of the following options:
- For engines with a low speed governor
- (i) For each idle load (e.g., idle with the transmission in neutral and drive) you identify under paragraph (f)(4), (f)(5)(iii), or (f)(6) of this section, operate the engine at each idle load and measure the warm idle speed at each idle load as described in paragraph (b)(3)(i) of this section. The warm idle operating point run in paragraph (b)(3)(i) of this section may be skipped and the measured warm idle speed from paragraph (b)(3)(i) of this section may be used for cycle generation for cycles where the user-adjustable idle speed setpoint is the same. If a nonzero idle torque is representative of in-use operation, operate the engine at warm idle with the manufacturer-declared idle torque. Set the operator demand to minimum, use the dynamometer to target the declared idle torque, and allow the engine to govern the speed. Note that this option requires you to know all the idle loads in all the cycles that will be generated with this map at the time the map is run.
- (ii) You may map the idle governor at multiple ~~load torque~~ levels and use this map to determine the ~~measured~~ warm idle speed(s) at ~~the declared~~ any idle load within the range of this map ~~torque(s)~~. For cases where the idle torque is a function of engine speeds (e.g., if CITT is specified as a function of speed or if the optional declared power in paragraph (f)(6) of this section applies) we recommend that the warm idle speed be determined using a closed form solution assuming speed and torque vary linearly between points in

this map. If an iterative method is used, continue to iterate until the value is within ± 0.0001 % of the previous value.

(8) This paragraph (b)(8) describes how to collect additional data to determine warm idle speed(s) for cycle generation if your engine has a low-speed governor and a user-adjustable idle speed setpoint and you need to generate cycles for tests with a different setpoint from the setpoint used in this mapping procedure. You may omit this paragraph (b)(8) if you use the option to declare a warm idle speed in paragraph (f)(3)(iv) of this section. Collect additional data using paragraph (b)(7) of this section to determine the warm idle speed for each setpoint for use in generating cycles. Record the warm idle speed and torque for each setpoint.

(c) *Negative torque mapping.* If your engine is subject to a reference duty cycle that specifies negative torque values (i.e., engine motoring), generate a motoring torque curve by any of the following procedures:

(1) Multiply the positive torques from your map by -40 %. Use linear interpolation to determine intermediate values.

(2) Map the amount of negative torque required to motor the engine by repeating paragraph (b) of this section with minimum operator demand, as applicable. You may start the negative torque map at either the minimum or maximum speed from paragraph (b) of this section.

(3) Determine the amount of negative torque required to motor the engine at the following two points near the ends of the engine's speed range. Operate the engine at these two points at minimum operator demand. Use linear interpolation to determine intermediate values.

(i) *Low speed point.* For engines without a low-speed governor, determine the amount of negative torque at warm idle speed. For engines with a low-speed governor, motor the engine above warm idle speed so the governor is inactive and determine the amount of negative torque at that speed.

(ii) *High speed point.* For engines without a high-speed governor, determine the amount of negative torque at the maximum safe speed or the maximum representative speed. For engines with a high-speed governor, determine the amount of negative torque at a speed at or above n_{hi} per § 1065.610(c)(2).

(4) For engines with an electric hybrid system, map the negative torque required to motor the engine and absorb any power delivered from the RESS by repeating paragraph (g)(2) of this section with minimum operator demand, stopping the sweep to discharge the RESS when the absolute instantaneous power measured from the RESS drops below the expected maximum absolute power from the RESS by more than 2 % of total system maximum power (including engine motoring and RESS power) as determined from mapping the negative torque.

(5) For engines with an electric hybrid system, map the negative torque required to motor the engine by repeating paragraph (b) of this section with minimum operator demand and a fully charged RESS or with the hybrid system disabled, such that it doesn't affect the motoring torque. You may start the negative torque map at either the minimum or maximum speed from paragraph (b) of this section.

(d) *Mapping constant-speed engines.* Map constant-speed engines using the procedure in this paragraph (d). When testing without a motoring dynamometer (e.g., eddy-current or water-brake dynamometer or any device that is already installed on a vehicle, equipment, or vessel) operate these devices over the no-load operating points in the procedure as close to no-load as possible.

(1) Record the atmospheric pressure.

(2) Warm up the engine by operating it. We recommend operating the engine at approximately 75 % of the engine's expected maximum power. Continue the warm-up until

the engine coolant, block, or head absolute temperature is within ± 2 % of its mean value for at least 2 min or until the engine thermostat controls engine temperature.

(3) You may operate the engine with a production constant-speed governor or simulate a constant-speed governor by controlling engine speed with an operator demand control system described in § 1065.110. Use either isochronous or speed-droop governor operation, as appropriate.

(4) With the governor or simulated governor controlling speed using operator demand, operate the engine at the no-load, or minimum achievable load, governed speed (at high speed, not low idle) for at least 15 seconds.

(5) Perform one of the following:

(i) For constant-speed engines subject only to steady-state testing, you may perform an engine map by using a series of discrete torques. Select at least five evenly spaced torque setpoints from no-load to 80 % of the manufacturer-declared test torque or to a torque derived from your published maximum power level if the declared test torque is unavailable. Starting at the 80 % torque point, select setpoints in 2.5 % or smaller intervals, stopping at the endpoint torque. The endpoint torque is defined as the first discrete mapped torque value greater than the torque at maximum observed power where the engine outputs 90 % of the maximum observed power; or the torque when engine stall has been determined using good engineering judgment (i.e., sudden deceleration of engine speed while adding torque). You may continue mapping at higher torque setpoints. At each setpoint, allow torque and speed to stabilize. Record the mean feedback speed and torque at each setpoint. From this series of mean feedback speed and torque values, use linear interpolation to determine intermediate values. Use this series of mean feedback speeds and torques to generate the power map as described in paragraph (e) of this section.

(ii) For any constant-speed engine, you may perform an engine map with a continuous torque sweep by continuing to record the mean feedback speed and torque at 1 Hz or more frequently. Use the dynamometer to increase torque. Increase the reference torque at a constant rate from no-load to the endpoint torque as defined in paragraph (d)(5)(i) of this section. You may continue mapping at higher torque setpoints. Unless the standard-setting part specifies otherwise, target a torque sweep rate equal to the manufacturer-declared test torque (or a torque derived from your published power level if the declared test torque is not known) divided by 180 seconds. Stop recording after you complete the sweep. Verify that the average torque sweep rate over the entire map is within ± 7 % of the target torque sweep rate. Use linear interpolation to determine intermediate values from this series of mean feedback speed and torque values. Use this series of mean feedback speeds and torques to generate the power map as described in paragraph (e) of this section.

(iii) For any isochronous governed (~~0 %~~no speed droop) constant-speed engine, you may map the engine with two points as described in this paragraph (d)(5)(iii). After stabilizing at the no-load, or minimum achievable load, governed speed in paragraph (d)(4) of this section, record the mean feedback speed and torque. Continue to operate the engine with the governor or simulated governor controlling engine speed using operator demand, and control the dynamometer to target a speed of 99.5 % of the recorded mean no-load governed speed. Allow speed and torque to stabilize. Record the mean feedback speed and torque. Record the target speed. The absolute value of the speed error (the mean

feedback speed minus the target speed) must be no greater than 0.1 % of the recorded mean no-load governed speed. From this series of two mean feedback speed and torque values, use linear interpolation to determine intermediate values. Use this series of two mean feedback speeds and torques to generate a power map as described in paragraph (e) of this section. Note that the measured maximum test torque as determined in § 1065.610(b)(1) will be the mean feedback torque recorded on the second point.

(e) *Power mapping.* For all engines, create a power-versus-speed map by transforming torque and speed values to corresponding power values. Use the mean values from the recorded map data. Do not use any interpolated values. Multiply each torque by its corresponding speed and apply the appropriate conversion factors to arrive at units of power (kW). Interpolate intermediate power values between these power values, which were calculated from the recorded map data.

(f) *Measured and declared ~~test-speeds, and-torques, and power.~~* You must select ~~test-speeds, and~~ *torques, and power* for *engine mapping and for* cycle generation as required in this paragraph (f). “Measured” values are either directly measured during the engine mapping process or they are determined from the engine map. “Declared” values are specified by the manufacturer. When both measured and declared values are available, you may use declared test speeds and torques instead of measured speeds and torques if they meet the criteria in this paragraph (f). Otherwise, you must use measured speeds and torques derived from the engine map.

(1) *Measured speeds and torques.* Determine the applicable speeds and torques for the duty cycles you will run:

(i) Measured maximum test speed for variable-speed engines according to § 1065.610.

(ii) Measured maximum test torque for constant-speed engines according to § 1065.610.

(iii) Measured “A”, “B”, and “C” speeds for variable-speed engines according to § 1065.610.

(iv) Measured intermediate speed for variable-speed engines according to § 1065.610.

(v) For variable-speed engines with a low-speed governor, measure warm idle speed(s) according to ~~§ 1065.510~~ *paragraph (b) of this section* and use this *(these)* speed(s) for cycle generation in § 1065.512. For engines with no low-speed governor, instead use the manufacturer-declared warm idle speed *from paragraph (f)(2) of this section.*

(2) *Required declared speeds.* You must declare the lowest engine speed possible with minimum load (i.e., manufacturer-declared warm idle speed). This is applicable only to variable-speed engines with no low-speed governor. For engines with no low-speed governor, the declared warm idle speed is used for cycle generation in § 1065.512. Declare this speed in a way that is representative of in-use operation. For example, if your engine is typically connected to an automatic transmission or a hydrostatic transmission, declare this speed at the idle speed at which your engine operates when the transmission is engaged.

(3) *Optional declared speeds.* You may use declared speeds instead of measured speeds as follows:

(i) You may use a declared value for maximum test speed for variable-speed engines if it is within (97.5 to 102.5) % of the corresponding measured value. You may use a higher declared speed if the length of the “vector” at the declared speed is within 2 % of the length of the “vector” at the measured value. The term vector refers to the square root of the sum of normalized engine speed squared and the normalized full-load power (at that speed) squared, consistent with the calculations in § 1065.610.

(ii) You may use a declared value for intermediate, “A”, “B”, or “C” speeds for steady-state tests if the declared value is within (97.5 to 102.5) % of the corresponding measured value.

(iii) For electronically governed variable-speed engines, you may use a declared warm high-idle speed for calculating the alternate maximum test speed as specified in § 1065.610.

(iv) For electronically governed variable-speed engines with an isochronous low-speed governor (i.e., no speed droop), you may declare that the warm idle speed is equal to the idle speed setpoint and use it for cycle generation instead of warm idle speed(s) determined from the data collected during the engine mapping procedure in paragraph (b) of this section. When generating cycles with multiple idle torque values, you may use this idle speed setpoint for all idle points. If the idle torque is a function of speed (e.g., CITT is specified as a function of speed or if the optional declared power in paragraph (f)(6) of this section applies) use the setpoint to calculate the idle torque(s) for cycle generation. If the engine has a user-adjustable idle speed setpoint, generate the cycle using the idle speed setpoint that will be set when the engine is run for that cycle.

(4) *Required declared torques.* ~~If a nonzero idle or minimum torque is representative of in-use operation, you must declare the appropriate torque as follows:~~

~~(i) For variable-speed engines, declare a warm idle torque that is representative of in-use operation. For example, if your engine is typically connected to an automatic transmission or a hydrostatic transmission, declare the torque that occurs at the idle speed at which your engine operates when the transmission is engaged. Use this value for cycle generation. You may use multiple warm idle torques and associated idle speeds in cycle generation for representative testing. For example, for cycles that start the engine and begin with idle, you may start a cycle in idle with the transmission in neutral with zero torque and later switch to a different idle with the transmission in drive with the Curb-Idle Transmission Torque (CITT). For variable-speed engines intended primarily for propulsion of a vehicle with an automatic transmission where that engine is subject to a transient duty cycle with idle operation, you must declare a Curb-Idle Transmission Torque (CITT). We recommend that you specify CITT as a function of idle speed for engines with adjustable warm idle or enhanced-idle. You may specify a CITT based on typical applications at the mean of the range of idle speeds you specify at stabilized temperature conditions. See the required deviations for cycle generation in § 1065.610(d)(3) for how the required declared CITT and the optional declared torque in paragraph (f)(5)(iii) of this section and the optional declared power in paragraph (f)(6) of this section are used in cycle generation.~~

~~(ii) For constant-speed engines, declare a warm minimum torque that is representative of in-use operation. For example, if your engine is typically connected to a machine that does not operate below a certain minimum torque, declare this torque and use it for cycle generation.~~

(5) *Optional declared torques.* You may use declared torque instead of measured torque as follows:

(i) For variable-speed engines you may declare a maximum torque over the engine operating range. You may use the declared value for measuring warm high-idle speed as specified in this section.

(ii) For constant-speed engines you may declare a maximum test torque. You may use the declared value for cycle generation if it is within (95 to 100) % of the measured value.

~~(iii) For variable-speed engines, if a nonzero idle load is representative of in-use operation, you may declare a nonzero torque for idle operation that represents is representative of in-use operation. For example, if your engine is connected to a hydrostatic transmission with and it has a minimum torque even when all the driven hydraulic actuators and motors are stationary and the engine is at idle, then you may use this minimum torque as the declared value minimum torque. As another example, if your engine is connected to a vehicle or machine and it has vehicle or machine with accessories, then you may use a this declared torque corresponding to operation with those accessories. You may specify a combination of torque and power as described If you specify a torque in this paragraph (f)(5)(iii) and a power in paragraph (f)(6) of this section, declare values so that their sum is representative of in-use operation and use the sum for cycle generation. Use this option when the idle loads (e.g., vehicle accessory loads) are best represented as a constant torque on the primary output shaft. You may use multiple warm idle loads and associated idle speeds in cycle generation for representative testing. As an example, see the required deviations for cycle generation in § 1065.610(d)(3) for improved simulation of idle points for engines intended primarily for propulsion of a vehicle with an automatic or manual transmission where that engine is subject to a transient duty cycle with idle operation.~~

~~(iv) For constant-speed engines, if a nonzero minimum torque is representative of in-use operation, you may declare a warm minimum torque that represents is representative of in-use operation. For example, if your engine is typically connected to a machine that does not operate below a certain minimum torque, you may use this minimum torque as the declared value declare this torque and use it for cycle generation.~~

~~(6) *Optional declared power.* For variable-speed engines, if a nonzero idle load is representative of in-use operation, you may declare a nonzero power for idle operation that is representative of represents in-use operation. If you specify a torque in paragraph (f)(5)(iii) of this section and a power in this paragraph (f)(6), the combination of declared values so that their sum is representative of must represent in-use operation and you must use the combination sum for cycle generation. Use the combination of declared values this option when the idle loads (i.e., vehicle accessory loads) are best represented as a constant power.~~

(g) *Mapping variable-speed engines with an electric hybrid system.* Map variable-speed engines that include electric hybrid systems as described in this paragraph (g). You may ask to apply these provisions to other types of hybrid engines, consistent with good engineering judgment. However, do not use this procedure for engines used in hybrid vehicles where the hybrid system is certified as part of the vehicle rather than the engine. Follow the steps for mapping a variable-speed engine as given in paragraph (b)(5) of this section except as noted in this paragraph (g). You must generate one engine map with the hybrid system inactive as described in paragraph (g)(1) of this section, and a separate map with the hybrid system active as described in paragraph (g)(2) of this section. See the standard-setting part to determine how to use these maps. The map with the system inactive is typically used to generate steady-state duty cycles, but may also be used to generate transient cycles, such as those that do not involve engine motoring. This hybrid-inactive map is also used for generating the hybrid-active map. The hybrid-active map is typically used to generate transient duty cycles that involve engine motoring.

(1) Prepare the engine for mapping by either deactivating the hybrid system or by operating the engine as specified in paragraph (b)(4) of this section and remaining at this condition until the rechargeable energy storage system (RESS) is depleted. Once the hybrid has been

disabled or the RESS is depleted, perform an engine map as specified in paragraph (b)(5) of this section. If the RESS was depleted instead of deactivated, ensure that instantaneous power from the RESS remains less than 2 % of the instantaneous measured power from the engine (or engine-hybrid system) at all engine speeds.

(2) The purpose of the mapping procedure in this paragraph (g) is to determine the maximum torque available at each speed, such as what might occur during transient operation with a fully charged RESS. Use one of the following methods to generate a hybrid-active map:

(i) Perform an engine map by using a series of continuous sweeps to cover the engine's full range of operating speeds. Prepare the engine for hybrid-active mapping by ensuring that the RESS state of charge is representative of normal operation. Perform the sweep as specified in paragraph (b)(5)(i) of this section, but stop the sweep to charge the RESS when the power measured from the RESS drops below the expected maximum power from the RESS by more than 2 % of total system power (including engine and RESS power). Unless good engineering judgment indicates otherwise, assume that the expected maximum power from the RESS is equal to the measured RESS power at the start of the sweep segment. For example, if the 3-second rolling average of total engine-RESS power is 200 kW and the power from the RESS at the beginning of the sweep segment is 50 kW, once the power from the RESS reaches 46 kW, stop the sweep to charge the RESS. Note that this assumption is not valid where the hybrid motor is torque-limited. Calculate total system power as a 3-second rolling average of instantaneous total system power. After each charging event, stabilize the engine for 15 seconds at the speed at which you ended the previous segment with operator demand set to maximum before continuing the sweep from that speed. Repeat the cycle of charging, mapping, and recharging until you have completed the engine map. You may shut down the system or include other operation between segments to be consistent with the intent of this paragraph (g)(2)(i). For example, for systems in which continuous charging and discharging can overheat batteries to an extent that affects performance, you may operate the engine at zero power from the RESS for enough time after the system is recharged to allow the batteries to cool. Use good engineering judgment to smooth the torque curve to eliminate discontinuities between map intervals.

(ii) Perform an engine map by using discrete speeds. Select map setpoints at intervals defined by the ranges of engine speed being mapped. From 95 % of warm idle speed to 90 % of the expected maximum test speed, select setpoints that result in a minimum of 13 equally spaced speed setpoints. From 90 % to 110 % of expected maximum test speed, select setpoints in equally spaced intervals that are nominally 2 % of expected maximum test speed. Above 110 % of expected maximum test speed, select setpoints based on the same speed intervals used for mapping from 95 % warm idle speed to 90 % maximum test speed. You may stop mapping at the highest speed above maximum power at which 50 % of maximum power occurs. We refer to the speed at 50 % power as the check point speed as described in paragraph (b)(5)(iii) of this section. Stabilize engine speed at each setpoint, targeting a torque value at 70 % of peak torque at that speed without hybrid-assist. Make sure the engine is fully warmed up and the RESS state of charge is within the normal operating range. Snap the operator demand to maximum, operate the engine there for at least 10 seconds, and record the 3-second rolling average feedback speed and torque at 1 Hz or higher. Record the peak 3-second average torque and 3-second average speed at that point. Use linear interpolation to determine intermediate speeds and torques.

Follow § 1065.610(a) to calculate the maximum test speed. Verify that the measured maximum test speed falls in the range from 92 to 108 % of the estimated maximum test speed. If the measured maximum test speed does not fall in this range, repeat the map using the measured value of maximum test speed.

(h) *Other mapping procedures.* You may use other mapping procedures if you believe the procedures specified in this section are unsafe or unrepresentative for your engine. Any alternate techniques you use must satisfy the intent of the specified mapping procedures, which is to determine the maximum available torque at all engine speeds that occur during a duty cycle. Identify any deviations from this section's mapping procedures when you submit data to us.

§ 1065.512 Duty cycle generation.

(a) Generate duty cycles according to this section if the standard-setting part requires engine mapping to generate a duty cycle for your engine configuration. The standard-setting part generally defines applicable duty cycles in a normalized format. A normalized duty cycle generally consists of a sequence of paired values for speed and torque or for speed and power.

(b) Transform normalized values of speed, torque, and power using the following conventions:

(1) *Engine speed for variable-speed engines.* For variable-speed engines, normalized speed may be expressed as a percentage between warm idle speed, f_{idle} , and maximum test speed, f_{ntest} , or speed may be expressed by referring to a defined speed by name, such as "warm idle," "intermediate speed," or "A," "B," or "C" speed. Section 1065.610 describes how to transform these normalized values into a sequence of reference speeds, f_{href} . Running duty cycles with negative or small normalized speed values near warm idle speed may cause low-speed idle governors to activate and the engine torque to exceed the reference torque even though the operator demand is at a minimum. In such cases, we recommend controlling the dynamometer so it gives priority to follow the reference torque instead of the reference speed and let the engine govern the speed. Note that the cycle-validation criteria in § 1065.514 allow an engine to govern itself. This allowance permits you to test engines with enhanced-idle devices and, and to simulate the effects of transmissions such as automatic transmissions, and for engines with speed derate intended to limit exhaust mass flowrate.

(i) For example, an enhanced-idle device might be an idle speed value that is normally commanded only under cold-start conditions to quickly warm up the engine and aftertreatment devices. In this case, negative and very low normalized speeds will generate reference speeds below this higher enhanced-idle speed. Control the dynamometer so it gives priority to follow the reference torque, controlling the operator demand so it gives priority to follow reference speed and let the engine govern the speed when the operator demand is at minimum.

You may do either any of the following when using enhanced-idle devices:

~~(i) Control the dynamometer so it gives priority to follow the reference torque, controlling the operator demand so it gives priority to follow reference speed and let the engine govern the speed when the operator demand is at minimum.~~

(iiiA) While running an engine where the ECM broadcasts an enhanced-idle speed that is above the denormalized speed, use the broadcast speed as the reference speed. Use these new reference points for duty-cycle validation. This does not affect how you determine denormalized reference torque in paragraph (b)(2) of this section.

(iiiB) If an ECM broadcast signal is not available, perform one or more practice cycles to determine the enhanced-idle speed as a function of cycle time. Generate the reference

cycle as you normally would but replace any reference speed that is lower than the enhanced-idle speed with the enhanced-idle speed. This does not affect how you determine denormalized reference torque in paragraph (b)(2) of this section.

~~(ii) For example, an engine with power derate intended to limit exhaust mass flowrate might include controls that reduce engine speed under cold start conditions, resulting in reduced exhaust flow that assists other aftertreatment thermal management technologies (e.g., electric heater). In this case, normalized speeds will generate reference speeds above this engine speed derate. Control the dynamometer so it gives priority to follow the reference speed, controlling the operator demand so it gives priority to follow reference torque. You may do one of the following, as specified, when using engine derate devices:~~

~~(A) While running an engine where the ECM broadcasts engine derate speed that is below the denormalized speed, use the broadcast speed as the reference speed. Use these new reference points for duty cycle validation. This does not affect how you determine denormalized reference torque in paragraph (b)(2) of this section.~~

~~(B) If an ECM broadcast signal is not available, perform one or more practice cycles to determine the engine derate speed as a function of cycle time. Generate the reference cycle as you normally would but replace any reference speed that is greater than the engine derate speed with the engine derate speed. This does not affect how you determine denormalized reference torque in paragraph (b)(2) of this section.~~

(2) *Engine torque for variable-speed engines.* For variable-speed engines, normalized torque is expressed as a percentage of the mapped torque at the corresponding reference speed. Section 1065.610 describes how to transform normalized torques into a sequence of reference torques, T_{ref} . Section 1065.610 also describes special requirements for modifying transient duty cycles for variable-speed engines intended primarily for propulsion of a vehicle with an automatic or manual transmission. Section 1065.610 also describes under what conditions you may command T_{ref} greater than the reference torque you calculated from a normalized duty cycle, which permits you to command T_{ref} values that are limited by a declared minimum torque. For any negative torque commands, command minimum operator demand and use the dynamometer to control engine speed to the reference speed, but if reference speed is so low that the idle governor activates, we recommend using the dynamometer to control torque to zero, CITT, or a declared minimum torque as appropriate. Note that you may omit power and torque points during motoring from the cycle-validation criteria in § 1065.514. Also, use the maximum mapped torque at the minimum mapped speed as the maximum torque for any reference speed at or below the minimum mapped speed.

(3) *Engine torque for constant-speed engines.* For constant-speed engines, normalized torque is expressed as a percentage of maximum test torque, T_{test} . Section 1065.610 describes how to transform normalized torques into a sequence of reference torques, T_{ref} . Section 1065.610 also describes under what conditions you may command T_{ref} greater than the reference torque you calculated from the normalized duty cycle. This provision permits you to command T_{ref} values that are limited by a declared minimum torque.

(4) *Engine power.* For all engines, normalized power is expressed as a percentage of mapped power at maximum test speed, f_{ntest} , unless otherwise specified by the standard-setting part. Section 1065.610 describes how to transform these normalized values into a sequence of reference powers, P_{ref} . Convert these reference powers to corresponding torques for operator demand and dynamometer control. Use the reference speed associated with each reference power point for this conversion. As with cycles specified with % torque, issue torque

commands more frequently and linearly interpolate between these reference torque values generated from cycles with % power.

(5) *Ramped-modal cycles*. For ramped-modal cycles, generate reference speed and torque values at 1 Hz and use this sequence of points to run the cycle and validate it in the same manner as with a transient cycle. During the transition between modes, linearly ramp the denormalized reference speed and torque values between modes to generate reference points at 1 Hz. Do not linearly ramp the normalized reference torque values between modes and then denormalize them. Do not linearly ramp normalized or denormalized reference power points. These cases will produce nonlinear torque ramps in the denormalized reference torques. If the speed and torque ramp runs through a point above the engine's torque curve, continue to command the reference torques and allow the operator demand to go to maximum. Note that you may omit power and either torque or speed points from the cycle-validation criteria under these conditions as specified in § 1065.514.

- (c) For variable-speed engines, command reference speeds and torques sequentially to perform a duty cycle. Issue speed and torque commands at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles (i.e., discrete-mode and ramped-modal). Linearly interpolate between the 1 Hz reference values specified in the standard-setting part to determine more frequently issued reference speeds and torques. During an emission test, record the feedback speeds and torques at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles. For transient cycles, you may record the feedback speeds and torques at lower frequencies (as low as 1 Hz) if you record the average value over the time interval between recorded values. Calculate the average values based on feedback values updated at a frequency of at least 5 Hz. Use these recorded values to calculate cycle-validation statistics and total work.
- (d) For constant-speed engines, operate the engine with the same production governor you used to map the engine in § 1065.510 or simulate the in-use operation of a governor the same way you simulated it to map the engine in § 1065.510. Command reference torque values sequentially to perform a duty cycle. Issue torque commands at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles (i.e., discrete-mode, ramped-modal). Linearly interpolate between the 1 Hz reference values specified in the standard-setting part to determine more frequently issued reference torque values. During an emission test, record the feedback speeds and torques at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles. For transient cycles, you may record the feedback speeds and torques at lower frequencies (as low as 1 Hz) if you record the average value over the time interval between recorded values. Calculate the average values based on feedback values updated at a frequency of at least 5 Hz. Use these recorded values to calculate cycle-validation statistics and total work.
- (e) You may perform practice duty cycles with the test engine to optimize operator demand and dynamometer controls to meet the cycle-validation criteria specified in § 1065.514.

§ 1065.514 Cycle-validation criteria for operation over specified duty cycles.

Validate the execution of your duty cycle according to this section unless the standard-setting part specifies otherwise. This section describes how to determine if the engine's operation during the test adequately matched the reference duty cycle. This section applies only to speed, torque, and power from the engine's primary output shaft. Other work inputs and outputs are not subject to cycle-validation criteria. You must compare the original reference duty cycle points generated as described in § 1065.512 to the corresponding feedback values recorded during the test. You may compare reference duty cycle points recorded during the test to the corresponding feedback

values recorded during the test as long as the recorded reference values match the original points generated in § 1065.512. The number of points in the validation regression are based on the number of points in the original reference duty cycle generated in § 1065.512. For example if the original cycle has 1199 reference points at 1 Hz, then the regression will have up to 1199 pairs of reference and feedback values at the corresponding moments in the test. The feedback speed and torque signals may be filtered – either in real-time while the test is run or afterward in the analysis program. Any filtering that is used on the feedback signals used for cycle validation must also be used for calculating work. Feedback signals for control loops may use different filtering.

(a) *Testing performed by EPA.* Our tests must meet the specifications of paragraph (f) of this section, unless we determine that failing to meet the specifications is related to engine performance rather than to shortcomings of the dynamometer or other laboratory equipment.

(b) *Testing performed by manufacturers.* Emission tests that meet the specifications of paragraph (f) of this section satisfy the standard-setting part's requirements for duty cycles. You may ask to use a dynamometer or other laboratory equipment that cannot meet those specifications. We will approve your request as long as using the alternate equipment does not adversely affect your ability to show compliance with the applicable emission standards.

(c) *Time-alignment.* Because time lag between feedback values and the reference values may bias cycle-validation results, you may advance or delay the entire sequence of feedback engine speed and torque pairs to synchronize them with the reference sequence. If you advance or delay feedback signals for cycle validation, you must make the same adjustment for calculating work. You may use linear interpolation between successive recorded feedback signals to time shift an amount that is a fraction of the recording period.

(d) *Omitting additional points.* Besides engine cranking, you may omit additional points from cycle-validation statistics as described in the following table:

TABLE 1 TO PARAGRAPH (D) OF § 1065.514—PERMISSIBLE CRITERIA FOR OMITTING POINTS FROM DUTY-CYCLE REGRESSION STATISTICS

For reference duty cycles that are specified in terms of speed and torque (f_{nref} , T_{ref})		
When operator demand is at its...	you may omit...	if...
minimum	power and torque	$T_{ref} < 0\%$ (motoring).
minimum	power and speed	$f_{nref} = 0\%$ (idle speed) and $T_{ref} = 0\%$ (idle torque) and $T_{ref} - (2\% \cdot T_{max\ mapped}) < T < T_{ref} + (2\% \cdot T_{max\ mapped})$.
minimum	power and speed	$f_{nref} < \text{enhanced-idle speed}^a$ and $T_{ref} > 0\%$.
minimum	power and either torque or speed	$f_n > f_{nref}$ or $T > T_{ref}$ but not if $f_n > (f_{nref} \cdot 102\%)$ and $T > T_{ref} + (2\% \cdot T_{max\ mapped})$.
maximum	power and either torque or speed	$f_n < f_{nref}$ or $T < T_{ref}$ but not if $f_n < (f_{nref} \cdot 98\%)$ and $T < T_{ref} - (2\% \cdot T_{max\ mapped})$.
For reference duty cycles that are specified in terms of speed and power (f_{nref} , P_{ref})		
When operator demand is at its...	you may omit...	if...
minimum	power and torque	$P_{ref} < 0\%$ (motoring).
minimum	power and speed	$f_{nref} = 0\%$ (idle speed) and $P_{ref} = 0\%$ (idle power) and $P_{ref} - (2\% \cdot P_{max\ mapped}) < P < P_{ref} + (2\% \cdot P_{max\ mapped})$.
minimum	power and either torque or speed	$f_n > f_{nref}$ or $P > P_{ref}$ but not if $f_n > (f_{nref} \cdot 102\%)$ and $P > P_{ref} + (2\% \cdot P_{max\ mapped})$.
maximum	power and either torque or speed	$f_n < f_{nref}$ or $P < P_{ref}$ but not if $f_n < (f_{nref} \cdot 98\%)$ and $P < P_{ref} - (2\% \cdot P_{max\ mapped})$.

^aDetermine enhanced-idle speed from ECM broadcast or a practice cycle.

(e) *Statistical parameters.* Use the remaining points to calculate regression statistics for a floating intercept as described in § 1065.602. Round calculated regression statistics to the same number of significant digits as the criteria to which they are compared. Refer to Table 2 of this section for the default criteria and refer to the standard-setting part to determine if there are other criteria for your engine. Calculate the following regression statistics:

- (1) Slopes for feedback speed, a_{1fn} , feedback torque, a_{1T} , and feedback power a_{1P} .
- (2) Intercepts for feedback speed, a_{0fn} , feedback torque, a_{0T} , and feedback power a_{0P} .
- (3) Standard error of the estimate for feedback speed, SEE_{fn} , feedback torque, SEE_T , and feedback power SEE_P .
- (4) Coefficients of determination for feedback speed, r_{fn}^2 , feedback torque, r_T^2 , and feedback power r_P^2 .

(f) *Cycle-validation criteria.* Unless the standard-setting part specifies otherwise, use the following criteria to validate a duty cycle:

- (1) For variable-speed engines, apply all the statistical criteria in Table 2 of this section.
- (2) For constant-speed engines, apply only the statistical criteria for torque in Table 2 of this section.
- (3) For discrete-mode steady-state testing, apply cycle-validation criteria by treating the sampling periods from the series of test modes as a continuous sampling period, analogous to ramped-modal testing and apply statistical criteria as described in paragraph (f)(1) (2) of this section. Note that if the gaseous and particulate test intervals are different periods of time, separate validations are required for the gaseous and particulate test intervals. Table 2 follows:

TABLE 2 OF § 1065.514—DEFAULT STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES

Parameter	Speed	Torque	Power
Slope, a_1	$0.950 \leq a_1 \leq 1.030$	$0.830 \leq a_1 \leq 1.030$	$0.830 \leq a_1 \leq 1.030$.
Absolute value of intercept, $ a_0 $	$\leq 10\%$ of warm idle	$\leq 2\%$ of maximum mapped torque	$\leq 2\%$ of maximum mapped power.
Standard error of the estimate, SEE	$\leq 5\%$ of maximum test speed	$\leq 10\%$ of maximum mapped torque	$\leq 10\%$ of maximum mapped power.
Coefficient of determination, r^2	≥ 0.970	≥ 0.850	≥ 0.910 .

§ 1065.516 Sample system decontamination and preconditioning.

This section describes how to manage the impact of sampling system contamination on emission measurements. Use good engineering judgment to determine if you should decontaminate and precondition your sampling system. Contamination occurs when a regulated pollutant accumulates in the sample system in a high enough concentration to cause release during emission tests. Hydrocarbons and PM are generally the only regulated pollutants that contaminate sample systems. Note that although this section focuses on avoiding excessive contamination of sampling systems, you must also use good engineering judgment to avoid loss of sample to a sampling system that is too clean. The goal of decontamination is not to perfectly clean the sampling system, but rather to achieve equilibrium between the sampling system and the exhaust so emission components are neither lost to nor entrained from the sampling system.

(a) You may perform contamination checks as follows to determine if decontamination is needed:

- (1) For dilute exhaust sampling systems, measure hydrocarbon and PM emissions by sampling with the CVS dilution air turned on, without an engine connected to it.
- (2) For raw analyzers and systems that collect PM samples from raw exhaust, measure hydrocarbon and PM emissions by sampling purified air or nitrogen.
- (3) When calculating zero emission levels, apply all applicable corrections, including initial THC contamination and diluted (CVS) exhaust background corrections.
- (4) Sampling systems are considered contaminated if either of the following conditions applies:
 - (i) The hydrocarbon emission level exceeds 2 % of the flow-weighted mean concentration expected at the HC standard.
 - (ii) The PM emission level exceeds 5 % of the level expected at the standard and exceeds 20 μg on a 47 mm PTFE membrane filter.

(b) To precondition or decontaminate sampling systems, use the following recommended procedure or select a different procedure using good engineering judgment:

- (1) Start the engine and use good engineering judgment to operate it at a condition that generates high exhaust temperatures at the sample probe inlet.
- (2) Operate any dilution systems at their expected flow rates. Prevent aqueous condensation in the dilution systems.
- (3) Operate any PM sampling systems at their expected flow rates.
- (4) Sample PM for at least 10 min using any sample media. You may change sample media at any time during this process and you may discard them without weighing them.

(5) You may purge any gaseous sampling systems that do not require decontamination during this procedure.

(6) You may conduct calibrations or verifications on any idle equipment or analyzers during this procedure.

(c) If your sampling system is still contaminated following the procedures specified in paragraph (b) of this section, you may use more aggressive procedures to decontaminate the sampling system, as long as the decontamination does not cause the sampling system to be cleaner than an equilibrium condition such that artificially low emission measurements may result.

§ 1065.518 Engine preconditioning.

(a) This section applies for engines where measured emissions are affected by prior operation, such as with a diesel engine that relies on urea-based selective catalytic reduction. Note that § 1065.520(e) allows you to run practice duty cycles before the emission test; this section recommends how to do this for the purpose of preconditioning the engine. Follow the standard-setting part if it specifies a different engine preconditioning procedure.

(b) The intent of engine preconditioning is to manage the representativeness of emissions and emission controls over the duty cycle and to reduce bias.

(c) This paragraph (c) specifies the engine preconditioning procedures for different types of duty cycles. You must identify the amount of preconditioning before starting to precondition. You must run the predefined amount of preconditioning. You may measure emissions during preconditioning. You may not abort an emission test sequence based on emissions measured during preconditioning. For confirmatory testing, you may ask us to run more preconditioning cycles than we specify in this paragraph (c); we will agree to this only if you show that additional preconditioning cycles are required to meet the intent of paragraph (b) of this section, for example, due to the effect of DPF regeneration on NH₃ storage in the SCR catalyst. Perform preconditioning as follows, noting that the specific cycles for preconditioning are the same ones that apply for emission testing:

(1) *Cold-start transient cycle.* Precondition the engine by running at least one hot-start transient cycle. We will precondition your engine by running two hot-start transient cycles. Immediately after completing each preconditioning cycle, shut down the engine and complete the engine-off soak period. Immediately after completing the last preconditioning cycle, shut down the engine and begin the cold soak as described in § 1065.530(a)(1).

(2) *Hot-start transient cycle.* Precondition the engine by running at least one hot-start transient cycle. We will precondition your engine by running two hot-start transient cycles. Immediately after completing each preconditioning cycle, shut down the engine, then start the next cycle (including the emission test) as soon as practical. For any repeat cycles, start the next cycle within 60 seconds after completing the last preconditioning cycle (this is optional for manufacturer testing).

(3) *Hot-running transient cycle.* Precondition the engine by running at least one hot-running transient cycle. We will precondition your engine by running two hot-running transient cycles. Do not shut down the engine between cycles. Immediately after completing each preconditioning cycle, start the next cycle (including the emission test) as soon as practical. For any repeat cycles, start the next cycle within 60 seconds after completing the last preconditioning cycle (this is optional for manufacturer testing). See § 1065.530(a)(1)(iii) for additional instructions if the cycle begins and ends under different operating conditions.

(4) *Discrete-mode cycle for steady-state testing.* Precondition the engine at the same operating condition as the next test mode, unless the standard-setting part specifies otherwise. We will precondition your engine by running it for at least five minutes before sampling.

(5) *Ramped-modal cycle for steady-state testing.* Precondition the engine by running at least the second half of the ramped-modal cycle, based on the number of test modes. For example, for the five-mode cycle specified in 40 CFR 1039.505(b)(1), the second half of the cycle consists of modes three through five. We will precondition your engine by running one complete ramped-modal cycle. Do not shut down the engine between cycles. Immediately after completing each preconditioning cycle, start the next cycle (including the emission test) as soon as practical. For any repeat cycles, start the next cycle within 60 seconds after completing the last preconditioning cycle. See § 1065.530(a)(1)(iii) for additional instructions if the cycle begins and ends under different operating conditions.

(d) You may conduct calibrations or verifications on any idle equipment or analyzers during engine preconditioning.

§ 1065.520 Pre-test verification procedures and pre-test data collection.

(a) For tests in which you measure PM emissions, follow the procedures for PM sample preconditioning and tare weighing according to § 1065.590.

(b) Unless the standard-setting part specifies different tolerances, verify at some point before the test that ambient conditions are within the tolerances specified in this paragraph (b). For purposes of this paragraph (b), “before the test” means any time from a point just prior to engine starting (excluding engine restarts) to the point at which emission sampling begins.

(1) Ambient temperature of (20 to 30) °C. See § 1065.530(j) for circumstances under which ambient temperatures must remain within this range during the test.

(2) Atmospheric pressure of (80.000 to 103.325) kPa and within ± 5 kPa of the value recorded at the time of the last engine map. You are not required to verify atmospheric pressure prior to a hot start test interval for testing that also includes a cold start.

(3) Dilution air conditions as specified in § 1065.140, except in cases where you preheat your CVS before a cold start test. We recommend verifying dilution air conditions just prior to the start of each test interval.

(c) You may test engines at any intake-air humidity, and we may test engines at any intake-air humidity.

(d) Verify that auxiliary-work inputs and outputs are configured as they were during engine mapping, as described in § 1065.510(a).

(e) You may perform a final calibration of the speed, torque, and proportional-flow control systems, which may include performing practice duty cycles (or portions of duty cycles). This may be done in conjunction with the preconditioning in § 1065.518.

(f) If your testing requires a chemical balance, then before the start of emissions testing select the chemical balance method and the gaseous emission measurement equipment required for testing. Select the chemical balance method depending on the fuels used during testing:

(1) When using only carbon-containing fuels, use the carbon-based chemical balance procedure in § 1065.655.

(2) When using only fuels other than carbon-containing fuels, use the hydrogen-based chemical balance procedure in § 1065.656.

(3) When using constant mixtures of carbon-containing fuels and fuels other than carbon-containing fuels, use the following chemical balance methods and gaseous emission measurement equipment:

(i) If the hydrogen-to-carbon ratio, α , of the fuel mixture is less than or equal to 6, then use the carbon-based chemical balance procedure in § 1065.655.

(ii) Otherwise, use the hydrogen-based chemical balance procedure in § 1065.656.

(4) When using variable mixtures of carbon-containing fuels and fuels other than carbon-containing fuels, if the mean hydrogen-to-carbon ratio of the fuel mixture, α , is expected to be greater than 6 for a test interval, you must use the hydrogen-based chemical balance procedure in § 1065.656 for that test interval⁵. Otherwise, you may use the carbon-based chemical balance procedure in § 1065.655.

(fg) If your testing requires measuring hydrocarbon emissions, vVerify the amount of nonmethane hydrocarbon contamination in the exhaust and background HC sampling systems within 8 hours before the start of the first test interval of each duty-cycle sequence for laboratory tests. You may verify the contamination of a background HC sampling system by reading the last bag fill and purge using zero gas. For any NMHC measurement system that involves separately measuring CH₄ and subtracting it from a THC measurement or for any CH₄ measurement system that uses an NMC, verify the amount of THC contamination using only the THC analyzer response. There is no need to operate any separate CH₄ analyzer for this verification; however, you may measure and correct for THC contamination in the CH₄ sample path for the cases where NMHC is determined by subtracting CH₄ from THC or, where CH₄ is determined, using an NMC as configured in § 1065.365(d), (e), and (f); and using the calculations in § 1065.660(b)(2). Perform this verification as follows:

(1) Select the HC analyzer range for measuring the flow-weighted mean concentration expected at the HC standard.

(2) Zero the HC analyzer at the analyzer zero or sample port. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O₂ expected during testing.

(3) Span the HC analyzer using span gas introduced at the analyzer span or sample port. Span on a carbon number basis of one (C₁). For example, if you use a C₃H₈ span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol.

(4) Overflow zero gas at the HC probe inlet or into a tee near the probe outlet.

(5) Measure the THC concentration in the sampling and background systems as follows:

(i) For continuous sampling, record the mean THC concentration as overflow zero gas flows.

(ii) For batch sampling, fill the sample medium (e.g., bag) and record its mean THC concentration.

(iii) For the background system, record the mean THC concentration of the last fill and purge.

(6) Record this value as the initial THC concentration, $x_{\text{THC}[\text{THC-FID}]_{\text{init}}}$, and use it to correct measured values as described in § 1065.660.

(7) You may correct the measured initial THC concentration for drift as follows:

(i) For batch and continuous HC analyzers, after determining the initial THC concentration, flow zero gas to the analyzer zero or sample port. When the analyzer reading is stable, record the mean analyzer value.

(ii) Flow span gas to the analyzer span or sample port. When the analyzer reading is stable, record the mean analyzer value.

(iii) Use mean analyzer values from paragraphs (fg)(2), (fg)(3), (fg)(7)(i), and (fg)(7)(ii) of this section to correct the initial THC concentration recorded in paragraph (fg)(6) of this section for drift, as described in § 1065.550.

(8) If any of the $x_{\text{THC}}[\text{THC-FID}]_{\text{init}}$ values exceed the greatest of the following values, determine the source of the contamination and take corrective action, such as purging the system during an additional preconditioning cycle or replacing contaminated portions:

(i) 2 % of the flow-weighted mean concentration expected at the HC (THC or NMHC) standard.

(ii) 2 % of the flow-weighted mean concentration of HC (THC or NMHC) measured during testing.

(iii) 2 $\mu\text{mol/mol}$.

(9) If corrective action does not resolve the deficiency, you may request to use the contaminated system as an alternate procedure under § 1065.10.

§ 1065.525 Engine starting, restarting, and shutdown.

(a) For test intervals that require emission sampling during engine starting, start the engine using one of the following methods:

(1) Start the engine as recommended in the owners manual using a production starter motor or air-start system and either an adequately charged battery, a suitable power supply, or a suitable compressed air source.

(2) Use the dynamometer to start the engine. To do this, motor the engine within ± 25 % of its typical in-use cranking speed. Stop cranking within 1 second of starting the engine.

(3) In the case of hybrid engines, activate the system such that the engine will start when its control algorithms determine that the engine should provide power instead of or in addition to power from the RESS. Unless we specify otherwise, engine starting throughout this part generally refers to this step of activating the system on hybrid engines, whether or not that causes the engine to start running.

(b) If the engine does not start after 15 seconds of cranking, stop cranking and determine why the engine failed to start, unless the owners manual or the service-repair manual describes the longer cranking time as normal.

(c) Respond to engine stalling with the following steps:

(1) If the engine stalls during warm-up before emission sampling begins, restart the engine and continue warm-up.

(2) If the engine stalls during preconditioning before emission sampling begins, restart the engine and restart the preconditioning sequence.

(3) Void the entire test if the engine stalls at any time after emission sampling begins, except as described in § 1065.526. If you do not void the entire test, you must void the individual test mode or test interval in which the engine stalls.

(d) Shut down the engine according to the manufacturer's specifications.

§ 1065.526 Repeating of void modes or test intervals.

(a) Test modes and test intervals can be voided because of instrument malfunction, engine stalling, emissions exceeding instrument ranges, and other unexpected deviations from the

specified procedures. This section specifies circumstances for which a test mode or test interval can be repeated without repeating the entire test.

(b) This section is intended to result in replicate test modes and test intervals that are identical to what would have occurred if the cause of the voiding had not occurred. It does not allow you to repeat test modes or test intervals in any circumstances that would be inconsistent with good engineering judgment. For example, the procedures specified here for repeating a mode or interval may not apply for certain engines that include hybrid energy storage features or emission controls that involve physical or chemical storage of pollutants. This section applies for circumstances in which emission concentrations exceed the analyzer range only if it is due to operator error or analyzer malfunction. It does not apply for circumstances in which the emission concentrations exceed the range because they were higher than expected.

(c) If one of the modes of a discrete-mode duty cycle is voided while running the duty cycle as provided in this section, you may void the results for that individual mode and continue the duty cycle as follows:

(1) If the engine has stalled or been shut down, restart the engine.

(2) Use good engineering judgment to restart the duty cycle using the appropriate steps in § 1065.530(b).

(3) Stabilize the engine by operating it at the mode at which the duty cycle was interrupted and continue with the duty cycle as specified in the standard-setting part.

(d) If an individual mode of a discrete-mode duty cycle sequence is voided after running the full duty cycle, you may void results for that mode and repeat testing for that mode as follows:

(1) Use good engineering judgment to restart the test sequence using the appropriate steps in § 1065.530(b).

(2) Stabilize the engine by operating it at that mode.

(3) Sample emissions over an appropriate test interval.

(4) If you sampled gaseous and PM emissions over separate test intervals for a voided mode, you must void both test intervals and repeat sampling of both gaseous and PM emissions for that mode.

(e) If a transient or ramped-modal cycle test interval is voided as provided in this section, you may repeat the test interval as follows:

(1) Use good engineering judgment to restart (as applicable) and precondition the engine to the same condition as would apply for normal testing. This may require you to complete the voided test interval. For example, you may generally repeat a hot-start test of a heavy-duty highway engine after completing the voided hot-start test and allowing the engine to soak for 20 minutes.

(2) Complete the remainder of the test according to the provisions in this subpart.

(f) Keep records from the voided test mode or test interval in the same manner as required for unvoided tests.

§ 1065.530 Emission test sequence.

(a) Time the start of testing as follows:

(1) Perform one of the following if you precondition the engine as described in § 1065.518:

(i) For cold-start duty cycles, shut down the engine. Unless the standard-setting part specifies that you may only perform a natural engine cooldown, you may perform a forced engine cooldown. Use good engineering judgment to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to

remove heat from coolant through the engine cooling system, and to remove heat from any exhaust aftertreatment systems. In the case of a forced aftertreatment cooldown, good engineering judgment would indicate that you not start flowing cooling air until the aftertreatment system has cooled below its catalytic activation temperature. For platinum-group metal catalysts, this temperature is about 200 °C. Once the aftertreatment system has naturally cooled below its catalytic activation temperature, good engineering judgment would indicate that you use clean air with a temperature of at least 15 °C, and direct the air through the aftertreatment system in the normal direction of exhaust flow. Do not use any cooling procedure that results in unrepresentative emissions (see § 1065.10(c)(1)). You may start a cold-start duty cycle when the temperatures of an engine's lubricant, coolant, and aftertreatment systems are all between (20 and 30) °C.

(ii) For hot-start emission measurements, shut down the engine immediately after completing the last preconditioning cycle. For any repeat cycles, start the hot-start transient emission test within 60 seconds after completing the last preconditioning cycle (this is optional for manufacturer testing).

(iii) For testing that involves hot-stabilized emission measurements, such as any steady-state testing with a ramped-modal cycle, start the hot-stabilized emission test within 60 seconds after completing the last preconditioning cycle (the time between cycles is optional for manufacturer testing). If the hot-stabilized cycle begins and ends with different operating conditions, add a linear transition period of 20 seconds between hot-stabilized cycles where you linearly ramp the (denormalized) reference speed and torque values over the transition period. See § 1065.501(c)(2)(i) for discrete-mode cycles.

(2) If you do not precondition the engine as described in § 1065.518, perform one of the following:

(i) For cold-start duty cycles, prepare the engine according to paragraph (a)(1)(i) of this section.

(ii) For hot-start duty cycles, first operate the engine at any speed above peak-torque speed and at (65 to 85) % of maximum mapped power until either the engine coolant, block, [lubricating oil](#), or head absolute temperature is within ± 2 % of its mean value for at least 2 min or until the engine thermostat controls engine temperature. Shut down the engine. Start the duty cycle within 20 min of engine shutdown.

(iii) For testing that involves hot-stabilized emission measurements, bring the engine either to warm idle or the first operating point of the duty cycle. Start the test within 10 min of achieving temperature stability. Determine temperature stability as the point at which the engine thermostat controls engine temperature or as the point at which measured operating temperature has stayed within ± 2 % of the mean value for at least 2 min based on the following parameters:

(A) Engine coolant, ~~or~~ block, [lubricating oil](#), or head absolute temperatures for water-cooled engines.

(B) Oil sump absolute temperature for air-cooled engines with an oil sump.

(C) Cylinder head absolute temperature or exhaust gas temperature for air-cooled engines with no oil sump.

(b) Take the following steps before emission sampling begins:

(1) For batch sampling, connect clean storage media, such as evacuated bags or tare-weighted filters.

(2) Start all measurement instruments according to the instrument manufacturer's instructions and using good engineering judgment.

(3) Start dilution systems, sample pumps, cooling fans, and the data-collection system.

(4) Pre-heat or pre-cool heat exchangers in the sampling system to within their operating temperature tolerances for a test interval.

(5) Allow heated or cooled components such as sample lines, filters, chillers, and pumps to stabilize at their operating temperatures.

(6) Verify that there are no significant vacuum-side leaks according to § 1065.345.

(7) Adjust the sample flow rates to desired levels, using bypass flow, if desired.

(8) Zero or re-zero any electronic integrating devices, before the start of any test interval.

(9) Select gas analyzer ranges. You may automatically or manually switch gas analyzer ranges during a test interval only if switching is performed by changing the span over which the digital resolution of the instrument is applied. During a test interval you may not switch the gains of an analyzer's analog operational amplifier(s).

(10) Zero and span all continuous analyzers using NIST-traceable gases that meet the specifications of § 1065.750. Span FID analyzers on a carbon number basis of one (1), C₁. For example, if you use a C₃H₈ span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol. Span FID analyzers consistent with the determination of their respective response factors, *RF*, and penetration fractions, *PF*, according to § 1065.365.

(11) We recommend that you verify gas analyzer responses after zeroing and spanning by sampling a calibration gas that has a concentration near one-half of the span gas concentration. Based on the results and good engineering judgment, you may decide whether or not to re-zero, re-span, or re-calibrate a gas analyzer before starting a test interval.

(12) Drain any accumulated condensate from the intake air system before starting a duty cycle, as described in § 1065.125(e)(1). If engine and aftertreatment preconditioning cycles are run before the duty cycle, treat the preconditioning cycles and any associated soak period as part of the duty cycle for the purpose of opening drains and draining condensate. Note that you must close any intake air condensate drains that are not representative of those normally open during in-use operation.

(c) Start and run each test interval as described in this paragraph (c). The procedure varies depending on whether the test interval is part of a discrete-mode cycle, and whether the test interval includes engine starting. Note that the standard-setting part may apply different requirements for running test intervals. For example, 40 CFR part 1033 specifies a different way to perform discrete-mode testing.

(1) For steady-state discrete-mode duty cycles, start the duty cycle with the engine warmed-up and running as described in § 1065.501(c)(2)(i). Run each mode in the sequence specified in the standard-setting part. This will require controlling engine speed, engine load, or other operator demand settings as specified in the standard-setting part. Simultaneously start any electronic integrating devices, continuous data recording, and batch sampling. We recommend that you stabilize the engine for at least 5 minutes for each mode. Once sampling begins, sample continuously for at least 1 minute. Note that longer sample times may be needed for accurately measuring very low emission levels.

(2) For transient and steady-state ramped-modal duty cycles that do not include engine starting, start the test interval with the engine running as soon as practical after completing

engine preconditioning. Simultaneously start any electronic integrating devices, continuous data recording, batch sampling, and execution of the duty cycle.

(3) If engine starting is part of the test interval, simultaneously start any electronic integrating devices, continuous data recording, and batch sampling before attempting to start the engine. Initiate the sequence of points in the duty cycle when the engine starts.

(4) For batch sampling systems, you may advance or delay the start and end of sampling at the beginning and end of the test interval to improve the accuracy of the batch sample, consistent with good engineering judgment.

(d) At the end of each test interval, continue to operate all sampling and dilution systems to allow the sampling system's response time to elapse. Then stop all sampling and recording, including the recording of background samples. Finally, stop any integrating devices and indicate the end of the duty cycle in the recorded data.

(e) Shut down the engine if you have completed testing or if it is part of the duty cycle.

(f) If testing involves another duty cycle after a soak period with the engine off, start a timer when the engine shuts down, and repeat the steps in paragraphs (b) through (e) of this section as needed.

(g) Take the following steps after emission sampling is complete:

(1) For any proportional batch sample, such as a bag sample or PM sample, verify that proportional sampling was maintained according to § 1065.545. Void any samples that did not maintain proportional sampling according to § 1065.545.

(2) Place any used PM samples into covered or sealed containers and return them to the PM-stabilization environment. Follow the PM sample post-conditioning and total weighing procedures in § 1065.595.

(3) As soon as practical after the duty cycle is complete, or during the soak period if practical, perform the following:

(i) Zero and span all batch gas analyzers no later than 30 minutes after the duty cycle is complete, or during the soak period if practical.

(ii) Analyze any conventional gaseous batch samples no later than 30 minutes after the duty cycle is complete, or during the soak period if practical.

(iii) Analyze background samples no later than 60 minutes after the duty cycle is complete.

(iv) Analyze non-conventional gaseous batch samples, such as ethanol (NMHCE) as soon as practical using good engineering judgment.

(4) After quantifying exhaust gases, verify drift as follows:

(i) For batch and continuous gas analyzers, record the mean analyzer value after stabilizing a zero gas to the analyzer. Stabilization may include time to purge the analyzer of any sample gas, plus any additional time to account for analyzer response.

(ii) Record the mean analyzer value after stabilizing the span gas to the analyzer. Stabilization may include time to purge the analyzer of any sample gas, plus any additional time to account for analyzer response.

(iii) Use these data to validate and correct for drift as described in § 1065.550.

(5) If you perform the optional carbon balance error verification, verify carbon balance error as specified in the standard-setting part and § 1065.543. Calculate and report the three carbon balance error quantities for each test interval; carbon mass absolute error for a test interval, ϵ_{aC} , carbon mass rate absolute error for a test interval, ϵ_{aCrate} , and carbon mass relative error for a test interval, ϵ_{rC} . For duty cycles with multiple test intervals, you may calculate and

report the composite carbon mass relative error, ϵ_{rCcomp} , for the whole duty cycle. If you report ϵ_{rCcomp} , you must still calculate and report ϵ_{aC} , ϵ_{aCrate} , and ϵ_{rC} for each test interval.

(h) Unless the standard-setting part specifies otherwise, determine whether or not the test meets the cycle-validation criteria in § 1065.514.

(1) If the criteria void the test, you may retest using the same denormalized duty cycle, or you may re-map the engine, denormalize the reference duty cycle based on the new map and retest the engine using the new denormalized duty cycle.

(2) If the criteria void the test for a constant-speed engine only during commands of maximum test torque, you may do the following:

(i) Determine the first and last feedback speeds at which maximum test torque was commanded.

(ii) If the last speed is greater than or equal to 90 % of the first speed, the test is void. You may retest using the same denormalized duty cycle, or you may re-map the engine, denormalize the reference duty cycle based on the new map and retest the engine using the new denormalized duty cycle.

(iii) If the last speed is less than 90 % of the first speed, reduce maximum test torque by 5 %, and proceed as follows:

(A) Denormalize the entire duty cycle based on the reduced maximum test torque according to § 1065.512.

(B) Retest the engine using the denormalized test cycle that is based on the reduced maximum test torque.

(C) If your engine still fails the cycle criteria, reduce the maximum test torque by another 5 % of the original maximum test torque.

(D) If your engine fails after repeating this procedure four times, such that your engine still fails after you have reduced the maximum test torque by 20 % of the original maximum test torque, notify us and we will consider specifying a more appropriate duty cycle for your engine under the provisions of § 1065.10(c).

(i) [Reserved]

(j) Measure and record ambient temperature, pressure, and humidity, as appropriate. For testing the following engines, you must record ambient temperature continuously to verify that it remains within the pre-test temperature range as specified in § 1065.520(b):

(1) Air-cooled engines.

(2) Engines equipped with auxiliary emission control devices that sense and respond to ambient temperature.

(3) Any other engine for which good engineering judgment indicates this is necessary to remain consistent with § 1065.10(c)(1).

§ 1065.543 Carbon balance error verification.

(a) This optional carbon balance error verification compares independently calculated quantities of carbon flowing into and out of an engine system. The engine system includes aftertreatment devices as applicable. Calculating carbon intake considers carbon-carrying streams flowing into the system, including intake air, fuel, and optionally DEF or other fluids. Carbon flow out of the system comes from exhaust emission calculations. Note that this verification is not valid if you calculate exhaust molar flow rate using fuel rate and chemical balance as described in § 1065.655(f)(3) because carbon flows into and out of the system are not independent. Use good engineering judgment to ensure that carbon mass in and carbon mass out data signals align.

(b) Perform the carbon balance error verification after emission sampling is complete for a test sequence as described in § 1065.530(g)(5). Testing must include measured values as needed to determine intake air, fuel flow, and carbon-related gaseous exhaust emissions. You may optionally account for the flow of carbon-carrying fluids other than intake air and fuel into the system. Perform carbon balance error verification as follows:

(1) Calculate carbon balance error quantities as described in § 1065.643. The three quantities for individual test intervals are carbon mass absolute error, ϵ_{aC} , carbon mass rate absolute error, ϵ_{aCrate} , and carbon mass relative error, ϵ_{rC} . Determine ϵ_{aC} , ϵ_{aCrate} , and ϵ_{rC} for all test intervals. You may determine composite carbon mass relative error, ϵ_{rCcomp} , as a fourth quantity that optionally applies for duty cycles with multiple test intervals.

(2) You meet the carbon balance error verification for a test sequence if all test intervals pass the test-interval criteria. A test interval passes if at least one of the absolute values of the three carbon balance error quantities for test intervals, ϵ_{aC} , ϵ_{aCrate} , and ϵ_{rC} , is at or below its respective limit value in paragraphs (b)(2)(i) through (iii) of this section. You meet the carbon balance error verification for a duty cycle with multiple test intervals if the duty cycle passes the duty-cycle criterion. A duty cycle passes if the absolute value of the composite carbon mass relative error quantity, ϵ_{rCcomp} , is at or below the limit value in paragraph (b)(2)(iii) of this section. Unless specified otherwise in the standard-setting part, if verification fails for a test sequence, you may repeat the entire test sequence or repeat individual test intervals as described in § 1065.526.

(i) Calculate the carbon mass absolute error limit, $L_{\epsilon_{aC}}$, in grams to three decimal places for comparison to the absolute value of ϵ_{aC} , using the following equation:

$$L_{\epsilon_{aC}} = c \cdot P_{max}$$

Eq. 1065.543-1

Where:

c = power-specific carbon mass absolute error coefficient = 0.007 g/kW.

P_{max} = maximum power from the engine map generated according to § 1065.510. If measured P_{max} is not available, use a manufacturer-declared value for P_{max} .

Example:

$$c = 0.007 \text{ g/kW}$$

$$P_{max} = 230.0 \text{ kW}$$

$$L_{\epsilon_{aC}} = 0.007 \cdot 230.0$$

$$L_{\epsilon_{aC}} = 1.610 \text{ g}$$

(ii) Calculate the carbon mass rate absolute error limit, $L_{\epsilon_{aCrate}}$, in grams per hour to three decimal places for comparison to the absolute value of ϵ_{aCrate} , using the following equation:

$$L_{\epsilon_{aCrate}} = d \cdot P_{max}$$

Eq. 1065.543-2

Where:

d = power-specific carbon mass rate absolute error coefficient = 0.31 g/(kW·hr).

P_{max} = maximum power from the engine map generated according to § 1065.510. If measured P_{max} is not available, use a manufacturer-declared value for P_{max} .

Example:

$$d = 0.31 \text{ g/(kW}\cdot\text{hr)}$$

$$P_{\max} = 230.0 \text{ kW}$$

$$L_{\epsilon_{\text{aCrate}}} = 0.31 \cdot 230.0$$

$$L_{\epsilon_{\text{aCrate}}} = 71.300 \text{ g/hr}$$

(iii) The carbon mass relative error limit, $L_{\epsilon_{\text{rC}}}$, is 0.020 for comparison to the absolute value of ϵ_{rC} , and to the absolute value of ϵ_{rCcomp} .

(c) A failed carbon balance error verification might indicate one or more problems requiring corrective action, as follows:

TABLE 1 OF § 1065.543—TROUBLESHOOTING GUIDE FOR CARBON BALANCE ERROR VERIFICATION

Area of Concern	Problem	Recommended Corrective Action
Gas analyzer system	Incorrect analyzer calibration	Calibrate NDIR and THC analyzers.
	Incorrect time alignment between flow and concentration data	Determine transformation time, t_{50} , for continuous gas analyzers and time-align flow and concentration data as described in § 1065.650(c)(2)(i).
	Problems with the sample system	Inspect sample system components such as sample lines, filters, chillers, and pumps for leaks, operating temperature, and contamination.
Fuel flow measurement	Zero shift of fuel flow rate meter	Perform an in-situ zero adjustment.
	Change in fuel flow meter calibration	Calibrate the fuel flow meter as described in § 1065.320.
	Incorrect time alignment of fuel flow data	Verify alignment of carbon mass in and carbon mass out data streams.
	Short sampling periods	For test intervals with varying duration, such as discrete-mode steady-state duty cycles, make the test intervals longer to improve accuracy when measuring low fuel flow rates.
	Fluctuations in the fuel conditioning system	Improve stability of the fuel temperature and pressure conditioning system to improve accuracy when measuring low fuel flow rates.
Dilute testing using a CVS system	Leaks	Inspect exhaust system and CVS tunnel, connections, and fasteners. Repair or replace components as needed. A leak in the exhaust transfer tube to the CVS may result in negative values for carbon balance error.
	Poor mixing	Perform the verification related to mixing in § 1065.341(f).
	Change in CVS calibration	Calibrate the CVS flow meter as described in § 1065.340.
	Flow meter entrance effects	Inspect the CVS tunnel to determine whether entrance effects from the piping configuration upstream of the flow meter adversely affect flow measurement.
	Other problems with the CVS or sampling verification hardware or software	Inspect hardware and software for the CVS system and CVS verification system for discrepancies.
Raw testing using intake air flow measurement or direct exhaust flow measurement	Leaks	Inspect intake air and exhaust systems, connections, fasteners. Repair or replace components as needed.
	Zero shift of intake air flow rate meter	Perform an in-situ zero adjustment.
	Change in intake air flow meter calibration	Calibrate the intake air flow meter as described in § 1065.325.
	Zero shift of exhaust flow rate meter	Perform an in-situ zero adjustment.
	Change in exhaust flow meter calibration	Calibrate the exhaust flow meter as described in § 1065.330.
	Flow meter entrance effects	Inspect intake air and exhaust systems to determine whether entrance effects from the piping configuration upstream and downstream of the intake air flow meter or the exhaust flow meter adversely affect flow measurement.
	Other problems with the intake air flow and exhaust flow measurement hardware or software	Look for discrepancies in the hardware and software for measuring intake air flow and exhaust flow.
	Poor mixing	Ensure that all streams are well mixed.
Accuracy of fluid properties	Inaccurate fluid properties	If defaults are used, use measured values. If measured values are used, verify fluid property determination.

§ 1065.545 Verification of proportional flow control for batch sampling.

For any proportional batch sample such as a bag or PM filter, demonstrate that proportional sampling was maintained using one of the following, noting that you may omit up to 5 % of the total number of data points as outliers:

- (a) For any pair of sample and total flow rates, use continuous recorded data or 1 Hz means. Total flow rate means the raw exhaust flow rate for raw exhaust sampling and the dilute exhaust flow rate for CVS sampling. For each test interval, determine the standard error of the estimate, *SEE*, of the sample flow rate versus the total flow rate as described in § 1065.602, forcing the intercept to zero. Determine the mean sample flow rate over each test interval as described in § 1065.602. For each test interval, demonstrate that *SEE* is at or below 3.5 % of the mean sample flow rate.
- (b) For any pair of sample and total flow rates, use continuous recorded data or 1 Hz means. Total flow rate means the raw exhaust flow rate for raw exhaust sampling and the dilute exhaust flow rate for CVS sampling. For each test interval, demonstrate that each flow rate is constant within ± 2.5 % of its respective mean or target flow rate. You may use the following options instead of recording the respective flow rate of each type of meter:
 - (1) *Critical-flow venturi option*. For critical-flow venturis, you may use recorded venturi-inlet conditions or their 1 Hz means. Demonstrate that the flow density at the venturi inlet was constant within ± 2.5 % of the mean or target density over each test interval. For a CVS critical-flow venturi, you may demonstrate this by showing that the absolute temperature at the venturi inlet was constant within ± 4 % of the mean or target absolute temperature over each test interval.
 - (2) *Positive-displacement pump option*. You may use recorded pump-inlet conditions or their 1 Hz means. Demonstrate that the flow density at the pump inlet was constant within ± 2.5 % of the mean or target density over each test interval. For a CVS pump, you may demonstrate this by showing that the absolute temperature at the pump inlet was constant within ± 2 % of the mean or target absolute temperature over each test interval.
- (c) Using good engineering judgment, demonstrate with an engineering analysis that the proportional-flow control system inherently ensures proportional sampling under all circumstances expected during testing. For example, you might use CFVs for both sample flow and total dilute exhaust (CVS) flow and demonstrate that they always have the same inlet pressures and temperatures and that they always operate under critical-flow conditions.

§ 1065.546 Verification of minimum dilution ratio for PM batch sampling.

Use continuous flows and/or tracer gas concentrations for transient and ramped-modal cycles to verify the minimum dilution ratios for PM batch sampling as specified in § 1065.140(e)(2) over the test interval. You may use mode-average values instead of continuous measurements for discrete mode steady-state duty cycles. Determine the minimum primary and minimum overall dilution ratios using one of the following methods (you may use a different method for each stage of dilution):

- (a) Determine minimum dilution ratio based on molar flow data. This involves determination of at least two of the following three quantities: raw exhaust flow (or previously diluted flow), dilution air flow, and dilute exhaust flow. You may determine the raw exhaust flow rate based on the measured intake air or fuel flow rate and the raw exhaust chemical balance terms as given in § 1065.655(f). You may determine the raw exhaust flow rate based on the measured intake air

and dilute exhaust molar flow rates and the dilute exhaust chemical balance terms as given in § 1065.655(g). You may alternatively estimate the molar raw exhaust flow rate based on intake air, fuel rate measurements, and fuel properties, consistent with good engineering judgment.

(b) Determine minimum dilution ratio based on tracer gas (e.g., CO₂) concentrations in the raw (or previously diluted) and dilute exhaust corrected for any removed water.

(c) Use good engineering judgment to develop your own method of determining dilution ratios.

§ 1065.550 Gas analyzer range verification and drift verification.

(a) *Range verification.* If an analyzer operated above 100 % of its range at any time during the test, perform the following steps:

(1) For batch sampling, re-analyze the sample using the lowest analyzer range that results in a maximum instrument response below 100 %. Report the result from the lowest range from which the analyzer operates below 100 % of its range.

(2) For continuous sampling, repeat the entire test using the next higher analyzer range. If the analyzer again operates above 100 % of its range, repeat the test using the next higher range.

Continue to repeat the test until the analyzer always operates at less than 100 % of its range.

(b) *Drift verification.* Gas analyzer drift verification is required for all gaseous exhaust constituents for which an emission standard applies. It is also required for CO₂, H₂, O₂, H₂O, and NH₃, if required by the applicable chemical balance, even if there ~~is-are~~ no CO₂-emission standards. It is not required for other gaseous exhaust constituents for which only a reporting requirement applies (such as CH₄ and N₂O).

(1) Verify drift using one of the following methods:

(i) For regulated exhaust constituents determined from the mass of a single component, perform drift verification based on the regulated constituent. For example, when NO_x mass is determined with a dry sample measured with a CLD and the removed water is corrected based on measured CO₂, CO, THC, and NO_x concentrations, you must verify the calculated NO_x value.

(ii) For regulated exhaust constituents determined from the masses of multiple subcomponents, perform the drift verification based on either the regulated constituent or all the mass subcomponents. For example, when NO_x is measured with separate NO and NO₂ analyzers, you must verify either the NO_x value or both the NO and NO₂ values.

(iii) For regulated exhaust constituents determined from the concentrations of multiple gaseous emission subcomponents prior to performing mass calculations, perform drift verification on the regulated constituent. You may not verify the concentration subcomponents (e.g., THC and CH₄ for NMHC) separately. For example, for NMHC measurements, perform drift verification on NMHC; do not verify THC and CH₄ separately.

(2) Drift verification requires two sets of emission calculations. For each set of calculations, include all the constituents in the drift verification. Calculate one set using the data before drift correction and calculate the other set after correcting all the data for drift according to § 1065.672. Note that for purposes of drift verification, you must leave unaltered any negative emission results over a given test interval (i.e., do not set them to zero). These unaltered results are used when verifying either test interval results or composite brake-specific emissions over the entire duty cycle for drift. For each constituent to be verified, both sets of calculations must include the following:

(i) Calculated mass (or mass rate) emission values over each test interval.

- (ii) If you are verifying each test interval based on brake-specific values, calculate brake-specific emission values over each test interval.
 - (iii) If you are verifying over the entire duty cycle, calculate composite brake-specific emission values.
- (3) The duty cycle is verified for drift if you satisfy the following criteria:
- (i) For each regulated gaseous exhaust constituent, you must satisfy one of the following:
 - (A) For each test interval of the duty cycle, the difference between the uncorrected and the corrected brake-specific emission values of the regulated constituent must be within ± 4 % of the uncorrected value or the applicable emissions standard, whichever is greater. Alternatively, the difference between the uncorrected and the corrected emission mass (or mass rate) values of the regulated constituent must be within ± 4 % of the uncorrected value or the composite work (or power) multiplied by the applicable emissions standard, whichever is greater. For purposes of verifying each test interval, you may use either the reference or actual composite work (or power).
 - (B) For each test interval of the duty cycle and for each mass subcomponent of the regulated constituent, the difference between the uncorrected and the corrected brake-specific emission values must be within ± 4 % of the uncorrected value. Alternatively, the difference between the uncorrected and the corrected emissions mass (or mass rate) values must be within ± 4 % of the uncorrected value.
 - (C) For the entire duty cycle, the difference between the uncorrected and the corrected composite brake-specific emission values of the regulated constituent must be within ± 4 % of the uncorrected value or applicable emission standard, whichever is greater.
 - (D) For the entire duty cycle and for each subcomponent of the regulated constituent, the difference between the uncorrected and the corrected composite brake-specific emission values must be within ± 4 % of the uncorrected value.
 - (ii) Where no emission standard applies for CO₂, H₂, O₂, H₂O, and NH₃, you must satisfy one of the following:
 - (A) For each test interval of the duty cycle, the difference between the uncorrected and the corrected brake-specific CO₂, H₂, O₂, H₂O, or NH₃ values must be within ± 4 % of the uncorrected value; or the difference between the uncorrected and the corrected CO₂, H₂, O₂, H₂O, or NH₃ mass (or mass rate) values must be within ± 4 % of the uncorrected value.
 - (B) For the entire duty cycle, the difference between the uncorrected and the corrected composite brake-specific CO₂, H₂, O₂, H₂O, or NH₃ values must be within ± 4 % of the uncorrected value.
- (4) If the test is not verified for drift as described in paragraph (b)(1) of this section, you may consider the test results for the duty cycle to be valid only if, using good engineering judgment, the observed drift does not affect your ability to demonstrate compliance with the applicable emission standards. For example, if the drift-corrected value is less than the standard by at least two times the absolute difference between the uncorrected and corrected values, you may consider the data to be verified for demonstrating compliance with the applicable standard.

§ 1065.590 PM sampling media (e.g., filters) preconditioning and tare weighing.

Before an emission test, take the following steps to prepare PM sampling media (e.g., filters) and equipment for PM measurements:

- (a) Make sure the balance and PM-stabilization environments meet the periodic verifications in § 1065.390.
- (b) Visually inspect unused sample media (e.g., filters) for defects and discard defective media.
- (c) To handle PM sampling media (e.g., filters), use electrically grounded tweezers or a grounding strap, as described in § 1065.190.
- (d) Place unused sample media (e.g., filters) in one or more containers that are open to the PM-stabilization environment. If you are using filters, you may place them in the bottom half of a filter cassette.
- (e) Stabilize sample media (e.g., filters) in the PM-stabilization environment. Consider an unused sample medium stabilized as long as it has been in the PM-stabilization environment for a minimum of 30 min, during which the PM-stabilization environment has been within the specifications of § 1065.190.
- (f) Weigh the sample media (e.g., filters) automatically or manually, as follows:
 - (1) For automatic weighing, follow the automation system manufacturer's instructions to prepare samples for weighing. This may include placing the samples in a special container.
 - (2) Use good engineering judgment to determine if substitution weighing is necessary to show that an engine meets the applicable standard. You may follow the substitution weighing procedure in paragraph (j) of this section, or you may develop your own procedure.
- (g) Correct the measured mass of each sample medium (e.g., filter) for buoyancy as described in § 1065.690. These buoyancy-corrected values are subsequently subtracted from the post-test mass of the corresponding sample media (e.g., filters) and collected PM to determine the mass of PM emitted during the test.
- (h) You may repeat measurements to determine the mean mass of each sample medium (e.g., filter). Use good engineering judgment to exclude outliers from the calculation of mean mass values.
- (i) If you use filters as sample media, load unused filters that have been tare-weighed into clean filter cassettes and place the loaded cassettes in a clean, covered or sealed container before removing them from the stabilization environment for transport to the test site for sampling. We recommend that you keep filter cassettes clean by periodically washing or wiping them with a compatible solvent applied using a lint-free cloth. Depending upon your cassette material, ethanol (C₂H₅OH) might be an acceptable solvent. Your cleaning frequency will depend on your engine's level of PM and HC emissions.
- (j) Substitution weighing involves measurement of a reference weight before and after each weighing of the PM sampling medium (e.g., the filter). While substitution weighing requires more measurements, it corrects for a balance's zero-drift and it relies on balance linearity only over a small range. This is most advantageous when quantifying net PM masses that are less than 0.1 % of the sample medium's mass. However, it may not be advantageous when net PM masses exceed 1 % of the sample medium's mass. If you utilize substitution weighing, it must be used for both pre-test and post-test weighing. The same substitution weight must be used for both pre-test and post-test weighing. Correct the mass of the substitution weight for buoyancy if the density of the substitution weight is less than 2.0 g/cm³. The following steps are an example of substitution weighing:

- (1) Use electrically grounded tweezers or a grounding strap, as described in § 1065.190.
- (2) Use a static neutralizer as described in § 1065.190 to minimize static electric charge on any object before it is placed on the balance pan.
- (3) Select and weigh a substitution weight that meets the requirements for calibration weights found in § 1065.790. The substitution weight must also have the same density as the weight you use to span the microbalance, and be similar in mass to an unused sample medium (e.g., filter). A 47 mm PTFE membrane filter will typically have a mass in the range of 80 to 100 mg.
- (4) Record the stable balance reading, then remove the substitution weight.
- (5) Weigh an unused sample medium (e.g., a new filter), record the stable balance reading and record the balance environment's dewpoint, ambient temperature, and atmospheric pressure.
- (6) Reweigh the substitution weight and record the stable balance reading.
- (7) Calculate the arithmetic mean of the two substitution-weight readings that you recorded immediately before and after weighing the unused sample. Subtract that mean value from the unused sample reading, then add the true mass of the substitution weight as stated on the substitution-weight certificate. Record this result. This is the unused sample's tare weight without correcting for buoyancy.
- (8) Repeat these substitution-weighing steps for the remainder of your unused sample media.
- (9) Once weighing is completed, follow the instructions given in paragraphs (g) through (i) of this section.

§ 1065.595 PM sample post-conditioning and total weighing.

After testing is complete, return the sample media (e.g., filters) to the weighing and PM-stabilization environments.

- (a) Make sure the weighing and PM-stabilization environments meet the ambient condition specifications in § 1065.190(e)(1). If those specifications are not met, leave the test sample media (e.g., filters) covered until proper conditions have been met.
- (b) In the PM-stabilization environment, remove PM samples from sealed containers. If you use filters, you may remove them from their cassettes before or after stabilization. We recommend always removing the top portion of the cassette before stabilization. When you remove a filter from a cassette, separate the top half of the cassette from the bottom half using a cassette separator designed for this purpose.
- (c) To handle PM samples, use electrically grounded tweezers or a grounding strap, as described in § 1065.190.
- (d) Visually inspect the sampling media (e.g., filters) and collected particulate. If either the sample media (e.g. filters) or particulate sample appear to have been compromised, or the particulate matter contacts any surface other than the filter, the sample may not be used to determine particulate emissions. In the case of contact with another surface, clean the affected surface before continuing.
- (e) To stabilize PM samples, place them in one or more containers that are open to the PM-stabilization environment, as described in § 1065.190. If you expect that a sample medium's (e.g., filter's) total surface concentration of PM will be less than 400 µg, assuming a 38 mm diameter filter stain area, expose the filter to a PM-stabilization environment meeting the specifications of § 1065.190 for at least 30 minutes before weighing. If you expect a higher PM concentration or do not know what PM concentration to expect, expose the filter to the

stabilization environment for at least 60 minutes before weighing. Note that 400 µg on sample media (e.g., filters) is an approximate net mass of 0.07 g/kW·hr for a hot-start test with compression-ignition engines tested according to 40 CFR part 86, subpart N, or 50 mg/mile for light-duty vehicles tested according to 40 CFR part 86, subpart B.

(f) Repeat the procedures in § 1065.590(f) through (i) to determine post-test mass of the sample media (e.g., filters).

(g) Subtract each buoyancy-corrected tare mass of the sample medium (e.g., filter) from its respective buoyancy-corrected mass. The result is the net PM mass, m_{PM} . Use m_{PM} in emission calculations in § 1065.650.

Subpart G—Calculations and Data Requirements

§ 1065.601 Overview.

(a) This subpart describes how to—

(1) Use the signals recorded before, during, and after an emission test to calculate brake-specific emissions of each regulated pollutant.

(2) Perform calculations for calibrations and performance checks.

(3) Determine statistical values.

(b) You may use data from multiple systems to calculate test results for a single emission test, consistent with good engineering judgment. You may also make multiple measurements from a single batch sample, such as multiple weighings of a PM filter or multiple readings from a bag sample. Although you may use an average of multiple measurements from a single test, you may not use test results from multiple emission tests to report emissions.

(1) We allow weighted means where appropriate.

(2) You may discard statistical outliers, but you must report all results.

(3) For emission measurements related to durability testing, we may allow you to exclude certain test points other than statistical outliers relative to compliance with emission standards, consistent with good engineering judgment and normal measurement variability; however, you must include these results when calculating the deterioration factor. This would allow you to use durability data from an engine that has an intermediate test result above the standard that cannot be discarded as a statistical outlier, as long as good engineering judgment indicates that the test result does not represent the engine's actual emission level. Note that good engineering judgment would preclude you from excluding endpoints. Also, if normal measurement variability causes emission results below zero, include the negative result in calculating the deterioration factor to avoid an upward bias. These provisions related to durability testing are intended to address very stringent standards where measurement variability is large relative to the emission standard.

(c) You may use any of the following calculations instead of the calculations specified in this subpart G:

(1) Mass-based emission calculations prescribed by the International Organization for Standardization (ISO), according to ISO 8178, except the following:

(i) ISO 8178-~~14~~ Section ~~9.1.6~~~~14.4~~, NO_x Correction for Humidity and Temperature. See § 1065.670 for approved methods for humidity corrections.

(ii) ~~ISO 8178-1 Section 15.1, Particulate Correction Factor for Humidity~~~~[Reserved]~~.

(2) Other calculations that you show are equivalent to within ±0.1 % of the brake-specific emission results determined using the calculations specified in this subpart G.

§ 1065.602 Statistics.

(a) *Overview.* This section contains equations and example calculations for statistics that are specified in this part. In this section we use the letter "y" to denote a generic measured quantity, the superscript over-bar "–" to denote an arithmetic mean, and the subscript "ref" to denote the reference quantity being measured.

(b) *Arithmetic mean.* Calculate an arithmetic mean, \bar{y} , as follows:

$$\bar{y} = \frac{\sum_{i=1}^N y_i}{N}$$

Eq. 1065.602-1

Example:

$$N = 3$$

$$y_1 = 10.60$$

$$y_2 = 11.91$$

$$y_N = y_3 = 11.09$$

$$\bar{y} = \frac{10.60 + 11.91 + 11.09}{3}$$

$$\bar{y} = 11.20$$

(c) *Standard deviation.* Calculate the standard deviation for a non-biased (e.g., $N-1$) sample, σ , as follows:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^N (y_i - \bar{y})^2}{(N - 1)}}$$

Eq. 1065.602-2

Example:

$$N = 3$$

$$y_1 = 10.60$$

$$y_2 = 11.91$$

$$y_N = y_3 = 11.09$$

$$\bar{y} = 11.20$$

$$\sigma_y = \sqrt{\frac{(10.60 - 11.2)^2 + (11.91 - 11.2)^2 + (11.09 - 11.2)^2}{2}}$$

$$\sigma_y = 0.6619$$

(d) *Root mean square.* Calculate a root mean square, rms_y , as follows:

$$rms_y = \sqrt{\frac{1}{N} \sum_{i=1}^N y_i^2}$$

Eq. 1065.602-3

Example:

$$N = 3$$

$$y_1 = 10.60$$

$$y_2 = 11.91$$

$$y_N = y_3 = 11.09$$

$$rms_y = \sqrt{\frac{10.60^2 + 11.91^2 + 11.09^2}{3}}$$

$$rms_y = 11.21$$

(e) *Accuracy*. Determine accuracy as described in this paragraph (e). Make multiple measurements of a standard quantity to create a set of observed values, y_i , and compare each observed value to the known value of the standard quantity. The standard quantity may have a single known value, such as a gas standard, or a set of known values of negligible range, such as a known applied pressure produced by a calibration device during repeated applications. The known value of the standard quantity is represented by y_{refi} . If you use a standard quantity with a single value, y_{refi} would be constant. Calculate an accuracy value as follows:

$$accuracy = \left| \frac{1}{N} \sum_{i=1}^N (y_i - y_{refi}) \right|$$

Eq. 1065.602-4

Example:

$$y_{ref} = 1800.0$$

$$N = 3$$

$$y_1 = 1806.4$$

$$y_2 = 1803.1$$

$$y_3 = 1798.9$$

$$accuracy = \left| \frac{1}{3} ((1806.4 - 1800.0) + (1803.1 - 1800.0) + (1798.9 - 1800.0)) \right|$$

$$accuracy = \left| \frac{1}{3} ((6.4) + (3.1) + (-1.1)) \right|$$

$$accuracy = 2.8$$

(f) *t-test*. Determine if your data passes a *t-test* by using the following equations and tables:

(1) For an unpaired *t-test*, calculate the *t* statistic and its number of degrees of freedom, ν , as follows:

$$t = \frac{|\bar{y}_{ref} - \bar{y}|}{\sqrt{\frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N}}}$$

Eq. 1065.602-5

$$v = \frac{\left(\frac{\sigma_{\text{ref}}^2}{N_{\text{ref}}} + \frac{\sigma_y^2}{N}\right)^2}{\frac{\left(\frac{\sigma_{\text{ref}}^2}{N_{\text{ref}}}\right)^2}{N_{\text{ref}} - 1} + \frac{\left(\frac{\sigma_y^2}{N}\right)^2}{N - 1}}$$

Eq. 1065.602-6

Example:

$$\bar{y}_{\text{ref}} = 1205.3$$

$$\bar{y} = 1123.8$$

$$\sigma_{\text{ref}} = 9.399$$

$$\sigma_y = 10.583$$

$$N_{\text{ref}} = 11$$

$$N = 7$$

$$t = \frac{|1205.3 - 1123.8|}{\sqrt{\frac{9.399^2}{11} + \frac{10.583^2}{7}}}$$

$$t = 16.63$$

$$\sigma_{\text{ref}} = 9.399$$

$$\sigma_y = 10.583$$

$$N_{\text{ref}} = 11$$

$$N = 7$$

$$v = \frac{\left(\frac{9.399^2}{11} + \frac{10.583^2}{7}\right)^2}{\frac{\left(\frac{9.399^2}{11}\right)^2}{11 - 1} + \frac{\left(\frac{10.583^2}{7}\right)^2}{7 - 1}}$$

$$v = 11.76$$

(2) For a paired t -test, calculate the t statistic and its number of freedom, v , as follows, noting that the ε_i are the errors (e.g., differences) between each pair of $y_{\text{ref}i}$ and y_i :

$$t = \frac{|\bar{\varepsilon}| \cdot \sqrt{N}}{\sigma_{\varepsilon}}$$

Eq. 1065.602-7

Example 1:

$$\bar{\varepsilon} = -0.12580$$

$$N = 16$$

$$\sigma_{\varepsilon} = 0.04837$$

$$t = \frac{|-0.12580| \cdot \sqrt{16}}{0.04837}$$

$$t = 10.403$$

$$v = N - 1$$

Example 2:

$$N = 16$$

$$v = 16 - 1$$

$$v = 15$$

(3) Use Table 1 of this section to compare t to the t_{crit} values tabulated versus the number of degrees of freedom. If t is less than t_{crit} , then t passes the t -test. The Microsoft Excel software has a TINV function that returns results equivalent results and may be used in place of Table 1, which follows:

TABLE 1 OF § 1065.602–
CRITICAL T VALUES VERSUS NUMBER OF DEGREES OF FREEDOM, v^a

v	Confidence	
	90 %	95 %
1	6.314	12.706
2	2.920	4.303
3	2.353	3.182
4	2.132	2.776
5	2.015	2.571
6	1.943	2.447
7	1.895	2.365
8	1.860	2.306
9	1.833	2.262
10	1.812	2.228
11	1.796	2.201
12	1.782	2.179
13	1.771	2.160
14	1.761	2.145
15	1.753	2.131
16	1.746	2.120
18	1.734	2.101
20	1.725	2.086
22	1.717	2.074
24	1.711	2.064
26	1.706	2.056
28	1.701	2.048
30	1.697	2.042
35	1.690	2.030
40	1.684	2.021
50	1.676	2.009
70	1.667	1.994
100	1.660	1.984
1000+	1.645	1.960

^aUse linear interpolation to establish values not shown here.

(g) F -test. Calculate the F statistic as follows:

$$F_y = \frac{\sigma_y^2}{\sigma_{\text{ref}}^2}$$

Eq. 1065.602-8

Example:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^N (y_i - \bar{y})^2}{(N - 1)}} = 10.583$$

$$\sigma_{\text{ref}} = \sqrt{\frac{\sum_{i=1}^{N_{\text{ref}}} (y_{\text{ref}i} - \bar{y}_{\text{ref}})^2}{(N_{\text{ref}} - 1)}} = 9.399$$

$$F = \frac{10.583^2}{9.399^2}$$

$$F = 1.268$$

(1) For a 90 % confidence F-test, use the following table to compare F to the $F_{\text{crit}90}$ values tabulated versus $(N-1)$ and $(N_{\text{ref}}-1)$. If F is less than $F_{\text{crit}90}$, then F passes the F -test at 90 % confidence.

TABLE 2 OF § 1065.602—CRITICAL F VALUES, $F_{\text{CRIT}90}$, VERSUS $N-1$ AND $N_{\text{REF}}-1$ AT 90 % CONFIDENCE

$N-1$	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000+
$N_{\text{REF}}-1$																			
1	39.86	49.50	53.59	55.83	57.24	58.20	58.90	59.43	59.85	60.19	60.70	61.22	61.74	62.00	62.26	62.52	62.79	63.06	63.32
2	8.526	9.000	9.162	9.243	9.293	9.326	9.349	9.367	9.381	9.392	9.408	9.425	9.441	9.450	9.458	9.466	9.475	9.483	9.491
3	5.538	5.462	5.391	5.343	5.309	5.285	5.266	5.252	5.240	5.230	5.216	5.200	5.184	5.176	5.168	5.160	5.151	5.143	5.134
4	4.545	4.325	4.191	4.107	4.051	4.010	3.979	3.955	3.936	3.920	3.896	3.870	3.844	3.831	3.817	3.804	3.790	3.775	3.761
5	4.060	3.780	3.619	3.520	3.453	3.405	3.368	3.339	3.316	3.297	3.268	3.238	3.207	3.191	3.174	3.157	3.140	3.123	3.105
6	3.776	3.463	3.289	3.181	3.108	3.055	3.014	2.983	2.958	2.937	2.905	2.871	2.836	2.818	2.800	2.781	2.762	2.742	2.722
7	3.589	3.257	3.074	2.961	2.883	2.827	2.785	2.752	2.725	2.703	2.668	2.632	2.595	2.575	2.555	2.535	2.514	2.493	2.471
8	3.458	3.113	2.924	2.806	2.726	2.668	2.624	2.589	2.561	2.538	2.502	2.464	2.425	2.404	2.383	2.361	2.339	2.316	2.293
9	3.360	3.006	2.813	2.693	2.611	2.551	2.505	2.469	2.440	2.416	2.379	2.340	2.298	2.277	2.255	2.232	2.208	2.184	2.159
10	3.285	2.924	2.728	2.605	2.522	2.461	2.414	2.377	2.347	2.323	2.284	2.244	2.201	2.178	2.155	2.132	2.107	2.082	2.055
11	3.225	2.860	2.660	2.536	2.451	2.389	2.342	2.304	2.274	2.248	2.209	2.167	2.123	2.100	2.076	2.052	2.026	2.000	1.972
12	3.177	2.807	2.606	2.480	2.394	2.331	2.283	2.245	2.214	2.188	2.147	2.105	2.060	2.036	2.011	1.986	1.960	1.932	1.904
13	3.136	2.763	2.560	2.434	2.347	2.283	2.234	2.195	2.164	2.138	2.097	2.053	2.007	1.983	1.958	1.931	1.904	1.876	1.846
14	3.102	2.726	2.522	2.395	2.307	2.243	2.193	2.154	2.122	2.095	2.054	2.010	1.962	1.938	1.912	1.885	1.857	1.828	1.797
15	3.073	2.695	2.490	2.361	2.273	2.208	2.158	2.119	2.086	2.059	2.017	1.972	1.924	1.899	1.873	1.845	1.817	1.787	1.755
16	3.048	2.668	2.462	2.333	2.244	2.178	2.128	2.088	2.055	2.028	1.985	1.940	1.891	1.866	1.839	1.811	1.782	1.751	1.718
17	3.026	2.645	2.437	2.308	2.218	2.152	2.102	2.061	2.028	2.001	1.958	1.912	1.862	1.836	1.809	1.781	1.751	1.719	1.686
18	3.007	2.624	2.416	2.286	2.196	2.130	2.079	2.038	2.005	1.977	1.933	1.887	1.837	1.810	1.783	1.754	1.723	1.691	1.657
19	2.990	2.606	2.397	2.266	2.176	2.109	2.058	2.017	1.984	1.956	1.912	1.865	1.814	1.787	1.759	1.730	1.699	1.666	1.631
20	2.975	2.589	2.380	2.249	2.158	2.091	2.040	1.999	1.965	1.937	1.892	1.845	1.794	1.767	1.738	1.708	1.677	1.643	1.607
21	2.961	2.575	2.365	2.233	2.142	2.075	2.023	1.982	1.948	1.920	1.875	1.827	1.776	1.748	1.719	1.689	1.657	1.623	1.586
22	2.949	2.561	2.351	2.219	2.128	2.061	2.008	1.967	1.933	1.904	1.859	1.811	1.759	1.731	1.702	1.671	1.639	1.604	1.567
23	2.937	2.549	2.339	2.207	2.115	2.047	1.995	1.953	1.919	1.890	1.845	1.796	1.744	1.716	1.686	1.655	1.622	1.587	1.549
24	2.927	2.538	2.327	2.195	2.103	2.035	1.983	1.941	1.906	1.877	1.832	1.783	1.730	1.702	1.672	1.641	1.607	1.571	1.533
25	2.918	2.528	2.317	2.184	2.092	2.024	1.971	1.929	1.895	1.866	1.820	1.771	1.718	1.689	1.659	1.627	1.593	1.557	1.518
26	2.909	2.519	2.307	2.174	2.082	2.014	1.961	1.919	1.884	1.855	1.809	1.760	1.706	1.677	1.647	1.615	1.581	1.544	1.504
27	2.901	2.511	2.299	2.165	2.073	2.005	1.952	1.909	1.874	1.845	1.799	1.749	1.695	1.666	1.636	1.603	1.569	1.531	1.491
28	2.894	2.503	2.291	2.157	2.064	1.996	1.943	1.900	1.865	1.836	1.790	1.740	1.685	1.656	1.625	1.593	1.558	1.520	1.478
29	2.887	2.495	2.283	2.149	2.057	1.988	1.935	1.892	1.857	1.827	1.781	1.731	1.676	1.647	1.616	1.583	1.547	1.509	1.467
30	2.881	2.489	2.276	2.142	2.049	1.980	1.927	1.884	1.849	1.819	1.773	1.722	1.667	1.638	1.606	1.573	1.538	1.499	1.456
40	2.835	2.440	2.226	2.091	1.997	1.927	1.873	1.829	1.793	1.763	1.715	1.662	1.605	1.574	1.541	1.506	1.467	1.425	1.377
60	2.791	2.393	2.177	2.041	1.946	1.875	1.819	1.775	1.738	1.707	1.657	1.603	1.543	1.511	1.476	1.437	1.395	1.348	1.291
120	2.748	2.347	2.130	1.992	1.896	1.824	1.767	1.722	1.684	1.652	1.601	1.545	1.482	1.447	1.409	1.368	1.320	1.265	1.193

1000+	2.706	2.303	2.084	1.945	1.847	1.774	1.717	1.670	1.632	1.599	1.546	1.487	1.421	1.383	1.342	1.295	1.240	1.169	1.000
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(2) For a 95 % confidence F -test, use the following table to compare F to the $F_{\text{crit}95}$ values tabulated versus $(N-1)$ and $(N_{\text{ref}}-1)$. If F is less than $F_{\text{crit}95}$, then F passes the F -test at 95 % confidence.

TABLE 3 OF § 1065.602—CRITICAL F VALUES, $F_{\text{CRIT}95}$, VERSUS $N-1$ AND $N_{\text{REF}}-1$ AT 95 % CONFIDENCE

$N-1$	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000+
$N_{\text{REF}}-1$																			
1	161.4	199.5	215.7	224.5	230.1	233.9	236.7	238.8	240.5	241.8	243.9	245.9	248.0	249.0	250.1	251.1	252.2	253.2	254.3
2	18.51	19.00	19.16	19.24	19.29	19.33	19.35	19.37	19.38	19.39	19.41	19.42	19.44	19.45	19.46	19.47	19.47	19.48	19.49
3	10.12	9.552	9.277	9.117	9.014	8.941	8.887	8.845	8.812	8.786	8.745	8.703	8.660	8.639	8.617	8.594	8.572	8.549	8.526
4	7.709	6.944	6.591	6.388	6.256	6.163	6.094	6.041	5.999	5.964	5.912	5.858	5.803	5.774	5.746	5.717	5.688	5.658	5.628
5	6.608	5.786	5.410	5.192	5.050	4.950	4.876	4.818	4.773	4.735	4.678	4.619	4.558	4.527	4.496	4.464	4.431	4.399	4.365
6	5.987	5.143	4.757	4.534	4.387	4.284	4.207	4.147	4.099	4.060	4.000	3.938	3.874	3.842	3.808	3.774	3.740	3.705	3.669
7	5.591	4.737	4.347	4.120	3.972	3.866	3.787	3.726	3.677	3.637	3.575	3.511	3.445	3.411	3.376	3.340	3.304	3.267	3.230
8	5.318	4.459	4.066	3.838	3.688	3.581	3.501	3.438	3.388	3.347	3.284	3.218	3.150	3.115	3.079	3.043	3.005	2.967	2.928
9	5.117	4.257	3.863	3.633	3.482	3.374	3.293	3.230	3.179	3.137	3.073	3.006	2.937	2.901	2.864	2.826	2.787	2.748	2.707
10	4.965	4.103	3.708	3.478	3.326	3.217	3.136	3.072	3.020	2.978	2.913	2.845	2.774	2.737	2.700	2.661	2.621	2.580	2.538
11	4.844	3.982	3.587	3.357	3.204	3.095	3.012	2.948	2.896	2.854	2.788	2.719	2.646	2.609	2.571	2.531	2.490	2.448	2.405
12	4.747	3.885	3.490	3.259	3.106	2.996	2.913	2.849	2.796	2.753	2.687	2.617	2.544	2.506	2.466	2.426	2.384	2.341	2.296
13	4.667	3.806	3.411	3.179	3.025	2.915	2.832	2.767	2.714	2.671	2.604	2.533	2.459	2.420	2.380	2.339	2.297	2.252	2.206
14	4.600	3.739	3.344	3.112	2.958	2.848	2.764	2.699	2.646	2.602	2.534	2.463	2.388	2.349	2.308	2.266	2.223	2.178	2.131
15	4.543	3.682	3.287	3.056	2.901	2.791	2.707	2.641	2.588	2.544	2.475	2.403	2.328	2.288	2.247	2.204	2.160	2.114	2.066
16	4.494	3.634	3.239	3.007	2.852	2.741	2.657	2.591	2.538	2.494	2.425	2.352	2.276	2.235	2.194	2.151	2.106	2.059	2.010
17	4.451	3.592	3.197	2.965	2.810	2.699	2.614	2.548	2.494	2.450	2.381	2.308	2.230	2.190	2.148	2.104	2.058	2.011	1.960
18	4.414	3.555	3.160	2.928	2.773	2.661	2.577	2.510	2.456	2.412	2.342	2.269	2.191	2.150	2.107	2.063	2.017	1.968	1.917
19	4.381	3.522	3.127	2.895	2.740	2.628	2.544	2.477	2.423	2.378	2.308	2.234	2.156	2.114	2.071	2.026	1.980	1.930	1.878
20	4.351	3.493	3.098	2.866	2.711	2.599	2.514	2.447	2.393	2.348	2.278	2.203	2.124	2.083	2.039	1.994	1.946	1.896	1.843
21	4.325	3.467	3.073	2.840	2.685	2.573	2.488	2.421	2.366	2.321	2.250	2.176	2.096	2.054	2.010	1.965	1.917	1.866	1.812
22	4.301	3.443	3.049	2.817	2.661	2.549	2.464	2.397	2.342	2.297	2.226	2.151	2.071	2.028	1.984	1.938	1.889	1.838	1.783
23	4.279	3.422	3.028	2.796	2.640	2.528	2.442	2.375	2.320	2.275	2.204	2.128	2.048	2.005	1.961	1.914	1.865	1.813	1.757
24	4.260	3.403	3.009	2.776	2.621	2.508	2.423	2.355	2.300	2.255	2.183	2.108	2.027	1.984	1.939	1.892	1.842	1.790	1.733
25	4.242	3.385	2.991	2.759	2.603	2.490	2.405	2.337	2.282	2.237	2.165	2.089	2.008	1.964	1.919	1.872	1.822	1.768	1.711
26	4.225	3.369	2.975	2.743	2.587	2.474	2.388	2.321	2.266	2.220	2.148	2.072	1.990	1.946	1.901	1.853	1.803	1.749	1.691
27	4.210	3.354	2.960	2.728	2.572	2.459	2.373	2.305	2.250	2.204	2.132	2.056	1.974	1.930	1.884	1.836	1.785	1.731	1.672
28	4.196	3.340	2.947	2.714	2.558	2.445	2.359	2.291	2.236	2.190	2.118	2.041	1.959	1.915	1.869	1.820	1.769	1.714	1.654
29	4.183	3.328	2.934	2.701	2.545	2.432	2.346	2.278	2.223	2.177	2.105	2.028	1.945	1.901	1.854	1.806	1.754	1.698	1.638
30	4.171	3.316	2.922	2.690	2.534	2.421	2.334	2.266	2.211	2.165	2.092	2.015	1.932	1.887	1.841	1.792	1.740	1.684	1.622
40	4.085	3.232	2.839	2.606	2.450	2.336	2.249	2.180	2.124	2.077	2.004	1.925	1.839	1.793	1.744	1.693	1.637	1.577	1.509
60	4.001	3.150	2.758	2.525	2.368	2.254	2.167	2.097	2.040	1.993	1.917	1.836	1.748	1.700	1.649	1.594	1.534	1.467	1.389
120	3.920	3.072	2.680	2.447	2.290	2.175	2.087	2.016	1.959	1.911	1.834	1.751	1.659	1.608	1.554	1.495	1.429	1.352	1.254

1000+	3.842	2.996	2.605	2.372	2.214	2.099	2.010	1.938	1.880	1.831	1.752	1.666	1.571	1.517	1.459	1.394	1.318	1.221	1.000
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(h) *Slope*. Calculate a least-squares regression slope, a_{1y} , using one of the following two methods:

(1) If the intercept floats, i.e., is not forced through zero:

$$a_{1y} = \frac{\sum_{i=1}^N (y_i - \bar{y}) \cdot (y_{\text{ref}i} - \bar{y}_{\text{ref}})}{\sum_{i=1}^N (y_{\text{ref}i} - \bar{y}_{\text{ref}})^2}$$

Eq. 1065.602-9

Example:

$$N = 6000$$

$$y_1 = 2045.8$$

$$\bar{y} = 1050.1$$

$$y_{\text{ref}1} = 2045.0$$

$$\bar{y}_{\text{ref}} = 1055.3$$

$$a_{1y}$$

$$= \frac{(2045.8 - 1050.1) \cdot (2045.0 - 1055.3) + \dots + (y_{6000} - 1050.1) \cdot (y_{\text{ref}6000} - 1055.3)}{(2045.0 - 1055.3)^2 + \dots + (y_{\text{ref}6000} - 1055.3)^2}$$

$$a_{1y} = 1.0110$$

(2) If the intercept is forced through zero, such as for verifying proportional sampling:

$$a_{1y} = \frac{\sum_{i=1}^N y_i \cdot y_{\text{ref}i}}{\sum_{i=1}^N y_{\text{ref}i}^2}$$

Eq. 1065.602-10

Example:

$$N = 6000$$

$$y_1 = 2045.8$$

$$y_{\text{ref}1} = 2045.0$$

$$a_{1y} = \frac{2045.8 \cdot 2045.0 + \dots + y_{6000} \cdot y_{\text{ref}6000}}{2045.0^2 + \dots + y_{\text{ref}6000}^2}$$

$$a_{1y} = 1.0110$$

(i) *Intercept*. For a floating intercept, calculate a least-squares regression intercept, a_{0y} , as follows:

$$a_{0y} = \bar{y} - (a_{1y} \cdot \bar{y}_{\text{ref}})$$

Eq. 1065.602-11

Example:

$$\bar{y} = 1050.1$$

$$a_{1y} = 1.0110$$

$$\bar{y}_{\text{ref}} = 1055.3$$

$$a_{0y} = 1050.1 - (1.0110 \cdot 1055.3)$$

$$a_{0y} = -16.8083$$

(j) *Standard error of the estimate.* Calculate a standard error of the estimate, *SEE*, using one of the following two methods:

(1) For a floating intercept:

$$SEE_y = \sqrt{\frac{\sum_{i=1}^N (y_i - a_{0y} - (a_{1y} \cdot y_{refi}))^2}{N - 2}}$$

Eq. 1065.602-12

Example:

$$N = 6000$$

$$y_1 = 2045.8$$

$$a_{0y} = -16.8083$$

$$a_{1y} = 1.0110$$

$$y_{ref1} = 2045.0$$

$$SEE_y = \sqrt{\frac{(2045.8 - (-16.8083) - (1.0110 \cdot 2045.0))^2 + \dots + (y_{6000} - (-16.8083) - (1.0110 \cdot y_{ref6000}))^2}{6000 - 2}}$$

$$SEE_y = 5.348$$

(2) If the intercept is forced through zero, such as for verifying proportional sampling:

$$SEE_y = \sqrt{\frac{\sum_{i=1}^N (y_i - a_{1y} \cdot y_{refi})^2}{N - 1}}$$

Eq. 1065.602-13

Example:

$$N = 6000$$

$$y_1 = 2045.8$$

$$a_{1y} = 1.0110$$

$$y_{ref1} = 2045.0$$

$$SEE_y = \sqrt{\frac{(2045.8 - 1.0110 \cdot 2045.0)^2 + \dots + (y_{6000} - 1.0110 \cdot y_{ref6000})^2}{6000 - 1}}$$

$$SEE_y = 5.347$$

(k) *Coefficient of determination.* Calculate a coefficient of determination, r_y^2 , as follows:

$$r_y^2 = 1 - \frac{\sum_{i=1}^N (y_i - a_{0y} - (a_{1y} \cdot y_{refi}))^2}{\sum_{i=1}^N (y_i - \bar{y})^2}$$

Eq. 1065.602-14

Example:

$$N = 6000$$

$$y_1 = 2045.8$$

$$a_{0y} = -16.8083$$

$$a_{1y} = 1.0110$$

$$y_{\text{ref1}} = 2045.0$$

$$\bar{y} = 1480.5$$

$$r_y^2 = 1 - \frac{(2045.8 - (-16.8083)) - (1.0110 \times 2045.0))^2 + \dots (y_{6000} - (-16.8083) - (1.0110 \cdot y_{\text{ref6000}}))^2}{(2045.8 - 1480.5)^2 + \dots (y_{6000} - 1480.5)^2}$$

$$r_y^2 = 0.9859$$

(1) *Flow-weighted mean concentration.* In some sections of this part, you may need to calculate a flow-weighted mean concentration to determine the applicability of certain provisions. A flow-weighted mean is the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust molar flow rate, divided by the sum of the recorded flow rate values. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration because the CVS system itself flow-weights the bag concentration. You might already expect a certain flow-weighted mean concentration of an emission at its standard based on previous testing with similar engines or testing with similar equipment and instruments. If you need to estimate your expected flow-weighted mean concentration of an emission at its standard, we recommend using the following examples as a guide for how to estimate the flow-weighted mean concentration expected at the standard. Note that these examples are not exact and that they contain assumptions that are not always valid. Use good engineering judgment to determine if you can use similar assumptions.

(1) To estimate the flow-weighted mean raw exhaust NO_x concentration from a turbocharged heavy-duty compression-ignition engine at a NO_x standard of 2.5 g/(kW·hr), you may do the following:

(i) Based on your engine design, approximate a map of maximum torque versus speed and use it with the applicable normalized duty cycle in the standard-setting part to generate a reference duty cycle as described in § 1065.610. Calculate the total reference work, W_{ref} , as described in § 1065.650. Divide the reference work by the duty cycle's time interval, $\Delta t_{\text{duty cycle}}$, to determine mean reference power, \bar{P}_{ref} .

(ii) Based on your engine design, estimate maximum power, P_{max} , the design speed at maximum power, f_{inmax} , the design maximum intake manifold boost pressure, p_{inmax} , and temperature, T_{inmax} . Also, estimate a mean fraction of power that is lost due to friction and pumping, \bar{P}_{frict} . Use this information along with the engine displacement volume, V_{disp} , an approximate volumetric efficiency, η_v , and the number of engine strokes per power stroke (two-stroke or four-stroke), N_{stroke} , to estimate the maximum raw exhaust molar flow rate, \dot{n}_{exhmax} .

(iii) Use your estimated values as described in the following example calculation:

$$\bar{x}_{\text{exp}} = \frac{e_{\text{std}} \cdot W_{\text{ref}}}{M \cdot \dot{n}_{\text{exhmax}} \cdot \Delta t_{\text{duty cycle}} \cdot \left(\frac{\bar{P}_{\text{ref}} + (\bar{P}_{\text{frict}} \cdot P_{\text{max}})}{P_{\text{max}}} \right)}$$

Eq. 1065.602-15

$$\dot{n}_{\text{exhmax}} = \frac{p_{\text{max}} \cdot V_{\text{disp}} \cdot f_{\text{inmax}} \cdot \frac{2}{N_{\text{stroke}}} \cdot \eta_v}{R \cdot T_{\text{max}}}$$

Eq. 1065.602-16

Example:

$$e_{\text{NO}_x} = 2.5 \text{ g}/(\text{kW}\cdot\text{hr})$$

$$W_{\text{ref}} = 11.883 \text{ kW}\cdot\text{hr}$$

$$M_{\text{NO}_x} = 46.0055 \text{ g}/\text{mol} = 46.0055 \cdot 10^{-6} \text{ g}/\mu\text{mol}$$

$$\Delta t_{\text{duty cycle}} = 20 \text{ min} = 1200 \text{ s}$$

$$\bar{P}_{\text{ref}} = 35.65 \text{ kW}$$

$$\bar{P}_{\text{frict}} = 15 \%$$

$$P_{\text{max}} = 125 \text{ kW}$$

$$p_{\text{max}} = 300 \text{ kPa} = 300000 \text{ Pa}$$

$$V_{\text{disp}} = 3.0 \text{ l} = 0.0030 \text{ m}^3/\text{r}$$

$$f_{\text{nmax}} = 2800 \text{ r}/\text{min} = 46.67 \text{ r}/\text{s}$$

$$N_{\text{stroke}} = 4$$

$$\eta_V = 0.9$$

$$R = 8.314472 \text{ J}/(\text{mol}\cdot\text{K})$$

$$T_{\text{max}} = 348.15 \text{ K}$$

$$\dot{n}_{\text{exhmax}} = \frac{300000 \cdot 0.0030 \cdot 46.67 \cdot \frac{2}{4} \cdot 0.9}{8.314472 \cdot 348.15}$$

$$\dot{n}_{\text{exhmax}} = 6.53 \text{ mol}/\text{s}$$

$$\bar{x}_{\text{exp}} = \frac{2.5 \cdot 11.883}{46.0055 \cdot 10^{-6} \cdot 6.53 \cdot 1200 \cdot \left(\frac{35.65 + (0.15 \cdot 125)}{125} \right)}$$

$$\bar{x}_{\text{exp}} = 189.4 \mu\text{mol}/\text{mol}$$

(2) To estimate the flow-weighted mean NMHC concentration in a CVS from a naturally aspirated nonroad spark-ignition engine at an NMHC standard of 0.5 g/(kW·hr), you may do the following:

(i) Based on your engine design, approximate a map of maximum torque versus speed and use it with the applicable normalized duty cycle in the standard-setting part to generate a reference duty cycle as described in § 1065.610. Calculate the total reference work, W_{ref} , as described in § 1065.650.

(ii) Multiply your CVS total molar flow rate by the time interval of the duty cycle, $\Delta t_{\text{duty cycle}}$. The result is the total diluted exhaust flow of the n_{dexh} .

(iii) Use your estimated values as described in the following example calculation:

$$\bar{x}_{\text{NMHC}} = \frac{e_{\text{std}} \cdot W_{\text{ref}}}{M \cdot \dot{n}_{\text{dexh}} \cdot \Delta t_{\text{duty cycle}}}$$

Eq. 1065.602-17

Example:

$$e_{\text{NMHC}} = 1.5 \text{ g}/(\text{kW}\cdot\text{hr})$$

$$W_{\text{ref}} = 5.389 \text{ kW}\cdot\text{hr}$$

$$M_{\text{NMHC}} = 13.875389 \text{ g}/\text{mol} = 13.875389 \cdot 10^{-6} \text{ g}/\mu\text{mol}$$

$$\dot{n}_{\text{dexh}} = 6.021 \text{ mol}/\text{s}$$

$$\Delta t_{\text{duty cycle}} = 30 \text{ min} = 1800 \text{ s}$$

$$\bar{x}_{\text{NMHC}} = \frac{1.5 \cdot 5.389}{13.875389 \cdot 10^{-6} \cdot 6.021 \cdot 1800}$$

$$\bar{x}_{\text{NMHC}} = 53.8 \mu\text{mol/mol}$$

(m) Median. Determine median, M , as described in this paragraph (m). Arrange the data points in the data set in increasing order where the smallest value is ranked 1, the second-smallest value is ranked 2, etc.

(1) For even numbers of data points:

(i) Determine the rank of the data point whose value is used to determine the median as follows:

$$i = \frac{N}{2}$$

Where:

i = an indexing variable that represents the rank of the data point whose value is used to determine the median.

N = the number of data points in the set.

Example:

$$N = 4$$

$$y_1 = 41.515$$

$$y_2 = 41.780$$

$$y_3 = 41.861$$

$$y_4 = 41.902$$

$$i = \frac{4}{2}$$

$$i = 2$$

(ii) Determine the median as the average of the data point i and the data point $i + 1$ as follows:

$$M = \frac{y_i + y_{i+1}}{2}$$

Example:

$$y_2 = 41.780$$

$$y_3 = 41.861$$

$$M = \frac{41.780 + 41.861}{2}$$

$$M = 41.821$$

(2) For odd numbers of data points, determine the rank of the data point whose value is the median and the corresponding median value as follows:

$$i = \frac{N + 1}{2}$$

Where:

i = an indexing variable that represents the rank of the data point whose value is the median.

N = the number of data points in the set.

Example:

$$N = 3$$

$$y_1 = 41.515$$

$$y_2 = 41.780$$

$$y_3 = 41.861$$

$$i = \frac{3 + 1}{2}$$

$$i = 2$$

$$M = 41.780$$

§ 1065.610 Duty cycle generation.

This section describes how to generate duty cycles that are specific to your engine, based on the normalized duty cycles in the standard-setting part. During an emission test, use a duty cycle that is specific to your engine to command engine speed, torque, and power, as applicable, using an engine dynamometer and an engine operator demand. Paragraphs (a) and (b) of this section describe how to “normalize” your engine’s map to determine the maximum test speed or torque for your engine. The rest of this section describes how to use these values to “denormalize” the duty cycles in the standard-setting parts, which are all published on a normalized basis. Thus, the term “normalized” in paragraphs (a) and (b) of this section refers to different values than it does in the rest of the section.

(a) *Maximum test speed, f_{ntest} .* For variable-speed engines, determine f_{ntest} from the torque and power maps, generated according to § 1065.510, as follows:

(1) Determine a measured value for f_{ntest} as follows:

(i) Determine maximum power, P_{max} , from the engine map generated according to § 1065.510 and calculate the value for power equal to 98 % of P_{max} .

(ii) Determine the lowest and highest engine speeds corresponding to 98 % of P_{max} , using linear interpolation, and no extrapolation, as appropriate.

(iii) Determine the engine speed corresponding to maximum power, f_{nPmax} , by calculating the average of the two speed values from paragraph (a)(1)(ii) of this section. If there is only one speed where power is equal to 98 % of P_{max} , take f_{nPmax} as the speed at which P_{max} occurs.

(iv) Transform the map into a normalized power-versus-speed map by dividing power terms by P_{max} and dividing speed terms by f_{nPmax} . Use the following equation to calculate a quantity representing the sum of squares from the normalized map:

$$\text{Sum of squares} = f_{nnormi}^2 + P_{normi}^2$$

Eq. 1065.610-1

Where:

i = an indexing variable that represents one recorded value of an engine map.

f_{nnormi} = an engine speed normalized by dividing it by f_{nPmax} .

P_{normi} = an engine power normalized by dividing it by P_{max} .

(v) Determine the maximum value for the sum of the squares from the map and multiply that value by 0.98.

(vi) Determine the lowest and highest engine speeds corresponding to the value calculated in paragraph (a)(1)(v) of this section, using linear interpolation as appropriate.

Calculate f_{ntest} as the average of these two speed values. If there is only one speed corresponding to the value calculated in paragraph (a)(1)(v) of this section, take f_{ntest} as the speed where the maximum of the sum of the squares occurs.

(vii) The following example illustrates a calculation of f_{ntest} :

$$P_{max} = 230.0$$

$$(f_{n1} = 2360, P_1 = 222.5, f_{nnorm1} = 1.002, P_{norm1} = 0.9675)$$

$$(f_{n2} = 2364, P_2 = 226.8, f_{nnorm2} = 1.004, P_{norm2} = 0.9859)$$

$$(f_{n3} = 2369, P_3 = 228.6, f_{nnorm3} = 1.006, P_{norm3} = 0.9940)$$

$$(f_{n4} = 2374, P_4 = 218.7, f_{nnorm4} = 1.008, P_{norm4} = 0.9508)$$

$$\text{Sum of squares} = (1.002^2 + 0.9675^2) = 1.94$$

$$\text{Sum of squares} = (1.004^2 + 0.9859^2) = 1.98$$

$$\text{Sum of squares} = (1.006^2 + 0.9940^2) = 2.00$$

$$\text{Sum of squares} = (1.008^2 + 0.9508^2) = 1.92$$

$$f_{ntest} = \frac{\left((2360 + (2364 - 2360) \cdot \frac{0.98 \cdot 2.0 - 1.94}{1.98 - 1.94}) + (2369 + (2374 - 2369) \cdot \frac{0.98 \cdot 2.0 - 2.0}{1.92 - 2.0}) \right)}{2}$$

$$= \frac{2362.0 + 2371.5}{2} = 2366.8 \frac{\text{r}}{\text{min}}$$

$$f_{npmax} = \frac{\left((2360 + (2364 - 2360) \cdot \frac{0.98 \cdot 230.0 - 222.5}{226.8 - 222.5}) + (2369 + (2374 - 2369) \cdot \frac{0.98 \cdot 230.0 - 228.6}{218.7 - 228.6}) \right)}{2}$$

$$= \frac{2362.7 + 2370.6}{2} = 2366.7 \frac{\text{r}}{\text{min}}$$

(2) For engines with a high-speed governor that will be subject to a reference duty cycle that specifies normalized speeds greater than 100 %, calculate an alternate maximum test speed, $f_{ntest,alt}$, as specified in this paragraph (a)(2). If $f_{ntest,alt}$ is less than the measured maximum test speed, f_{ntest} , determined in paragraph (a)(1) of this section, replace f_{ntest} with $f_{ntest,alt}$. In this case, $f_{ntest,alt}$ becomes the “maximum test speed” for that engine for all duty cycles. Note that § 1065.510 allows you to apply an optional declared maximum test speed to the final measured maximum test speed determined as an outcome of the comparison between f_{ntest} , and $f_{ntest,alt}$ in this paragraph (a)(2). Determine $f_{ntest,alt}$ as follows:

$$f_{ntest,alt} = \frac{f_{nhi,idle} - f_{nidle}}{\% speed_{max}} + f_{nidle}$$

Eq. 1065.610-2

Where:

$f_{ntest,alt}$ = alternate maximum test speed

$f_{nhi,idle}$ = warm high-idle speed

f_{nidle} = warm idle speed

$\% speed_{max}$ = maximum normalized speed from duty cycle

Example:

$f_{nhi,idle} = 2200 \text{ r/min}$

$f_{nidle} = 800 \text{ r/min}$

$\% speed_{max} = 105 \%$ (Nonroad CI Transient Cycle) = 1.05

$$f_{ntest,alt} = \frac{2200 - 800}{1.05} + 800$$

$$f_{ntest,alt} = 2133 \text{ r/min}$$

(3) Transform normalized speeds to reference speeds according to paragraph (c) of this section by using the measured maximum test speed determined according to paragraphs (a)(1) and (2) of this section—or use your declared maximum test speed, as allowed in § 1065.510.

(b) *Maximum test torque, T_{test} .* For constant-speed engines, determine T_{test} from the torque and power-versus-speed maps, generated according to § 1065.510, as follows:

(1) For constant speed engines mapped using the methods in § 1065.510(d)(5)(i) or (ii), determine a measured value for T_{test} as follows:

(i) Determine maximum power, P_{max} , from the engine map generated according to § 1065.510 and calculate the value for power equal to 98 % of P_{max} .

(ii) Determine the lowest and highest engine speeds corresponding to 98 % of P_{max} , using linear interpolation, and no extrapolation, as appropriate.

(iii) Determine the engine speed corresponding to maximum power, $f_{nP_{max}}$, by calculating the average of the two speed values from paragraph (a)(1)(ii) of this section. If there is only one speed where power is equal to 98 % of P_{max} , take $f_{nP_{max}}$ as the speed at which P_{max} occurs.

(iv) Transform the map into a normalized power-versus-speed map by dividing power terms by P_{max} and dividing speed terms by $f_{nP_{max}}$. Use Eq. 1065.610-1 to calculate a quantity representing the sum of squares from the normalized map.

(v) Determine the maximum value for the sum of the squares from the map and multiply that value by 0.98.

(vi) Determine the lowest and highest engine speeds corresponding to the value calculated in paragraph (a)(1)(v) of this section, using linear interpolation as appropriate. Calculate f_{ntest} as the average of these two speed values. If there is only one speed corresponding to the value calculated in paragraph (a)(1)(v) of this section, take f_{ntest} as the speed where the maximum of the sum of the squares occurs.

(vii) The measured T_{test} is the mapped torque at f_{ntest} .

(2) For constant speed engines using the two-point mapping method in § 1065.510(d)(5)(iii), you may follow paragraph (a)(1) of this section to determine the measured T_{test} , or you may use the measured torque of the second point as the measured T_{test} directly.

(3) Transform normalized torques to reference torques according to paragraph (d) of this section by using the measured maximum test torque determined according to paragraph (b)(1) or (2) of this section—or use your declared maximum test torque, as allowed in § 1065.510.

(c) *Generating reference speed values from normalized duty cycle speeds.* Transform normalized speed values to reference values as follows:

(1) *% speed.* If your normalized duty cycle specifies % speed values, use your warm idle speed and your maximum test speed to transform the duty cycle, as follows:

$$f_{nref} = \% \text{ speed} \cdot (f_{ntest} - f_{nidle}) + f_{nidle}$$

Eq. 1065.610-3

Example:

$$\% \text{ speed} = 85 \% = 0.85$$

$$f_{ntest} = 2364 \text{ r/min}$$

$$f_{nidle} = 650 \text{ r/min}$$

$$f_{nref} = 0.85 \cdot (2364 - 650) + 650$$

$$f_{nref} = 2107 \text{ r/min}$$

(2) *A, B, C, and D speeds.* If your normalized duty cycle specifies speeds as A, B, C, or D values, use your power-versus-speed curve to determine the lowest speed below maximum power at which 50 % of maximum power occurs. Denote this value as n_{lo} . Take n_{lo} to be warm idle speed if all power points at speeds below the maximum power speed are higher than 50 % of maximum power. Also determine the highest speed above maximum power at which 70 % of maximum power occurs. Denote this value as n_{hi} . If all power points at speeds above the maximum power speed are higher than 70 % of maximum power, take n_{hi} to be the declared maximum safe engine speed or the declared maximum representative engine speed, whichever is lower. Use n_{hi} and n_{lo} to calculate reference values for A, B, C, or D speeds as follows:

$$f_{nrefA} = 0.25 \cdot (n_{hi} - n_{lo}) + n_{lo}$$

$$\text{Eq. 1065.610-4}$$

$$f_{nrefB} = 0.50 \cdot (n_{hi} - n_{lo}) + n_{lo}$$

$$\text{Eq. 1065.610-5}$$

$$f_{nrefC} = 0.75 \cdot (n_{hi} - n_{lo}) + n_{lo}$$

$$\text{Eq. 1065.610-6}$$

$$f_{nrefD} = 0.15 \cdot (n_{hi} - n_{lo}) + n_{lo}$$

$$\text{Eq. 1065.610-7}$$

Example:

$$n_{lo} = 1005 \text{ r/min}$$

$$n_{hi} = 2385 \text{ r/min}$$

$$f_{nrefA} = 0.25 \cdot (2385 - 1005) + 1005$$

$$f_{nrefB} = 0.50 \cdot (2385 - 1005) + 1005$$

$$f_{nrefC} = 0.75 \cdot (2385 - 1005) + 1005$$

$$f_{nrefD} = 0.15 \cdot (2385 - 1005) + 1005$$

$$f_{nrefA} = 1350 \text{ r/min}$$

$$f_{nrefB} = 1695 \text{ r/min}$$

$$f_{nrefC} = 2040 \text{ r/min}$$

$$f_{nrefD} = 1212 \text{ r/min}$$

(3) *Intermediate speed.* Based on the map, determine maximum torque, T_{max} , and the corresponding speed, f_{nTmax} , calculated as the average of the lowest and highest speeds at which torque is equal to 98 % of T_{max} . Use linear interpolation between points to determine the speeds where torque is equal to 98 % of T_{max} . Identify your reference intermediate speed as one of the following values:

(i) f_{nTmax} if it is between (60 and 75) % of maximum test speed.

(ii) 60 % of maximum test speed if $f_{nT_{max}}$ is less than 60 % of maximum test speed.

(iii) 75 % of maximum test speed if $f_{nT_{max}}$ is greater than 75 % of maximum test speed.

(d) *Generating reference torques from normalized duty-cycle torques.* Transform normalized torques to reference torques using your map of maximum torque versus speed.

(1) *Reference torque for variable-speed engines.* For a given speed point, multiply the corresponding % torque by the maximum torque at that speed, according to your map. If your engine is subject to a reference duty cycle that specifies negative torque values (i.e., engine motoring), use negative torque for those motoring points (i.e., the motoring torque). If you map negative torque as allowed under § 1065.510(c)(2) and the low-speed governor activates, resulting in positive torques, you may replace those positive motoring mapped torques with negative values between zero and the largest negative motoring torque. For both maximum and motoring torque maps, linearly interpolate mapped torque values to determine torque between mapped speeds. If the reference speed is below the minimum mapped speed (i.e., 95 % of idle speed or 95 % of lowest required speed, whichever is higher), use the mapped torque at the minimum mapped speed as the reference torque. The result is the reference torque for each speed point.

(2) *Reference torque for constant-speed engines.* Multiply a % torque value by your maximum test torque. The result is the reference torque for each point.

(3) *Required deviations.* We require the following deviations for variable-speed engines intended primarily for propulsion of a vehicle with an automatic or manual transmission where that engine is subject to a transient duty cycle that specifies points with normalized reference speed of 0 % and normalized reference torque of 0 % (i.e., with idle points) operation. These deviations are intended to produce a more representative transient duty cycle for these applications. For steady-state duty cycles or transient duty cycles with no idle operation, the requirements in this paragraph (d)(3) do not apply. Idle points for steady-state duty cycles of such engines are to be run at conditions simulating neutral or park on the transmission. For manual transmissions, set CITT to zero, which results in warm-idle-in-drive speed and torque values being the same as warm-idle-in-neutral values. For the case of a manual transmission where the optional declared idle torque in § 1065.510(f)(5)(iii) and the optional declared power in § 1065.510(f)(6) are not declared (i.e., idle torque is zero), the required deviations in this paragraph (d)(3) have no impact and may be skipped. You may develop different procedures for adjusting CITT as a function of speed, consistent with good engineering judgment.

(i) Determine the warm-idle-in-drive speed and torque values with the transmission in drive from the data collected during the engine mapping procedure in § 1065.510. The warm-idle-in-drive torque is the sum of CITT and the torques representing loads from vehicle accessories. For example, the sum of the required declared CITT in § 1065.510(f)(4), any optional declared torque in § 1065.510(f)(5)(iii), and the torque on the primary output shaft from any optional declared power in § 1065.510(f)(6).

(ii) Determine the warm-idle-in-neutral speed and torque values with the transmission in neutral from the data collected during the engine mapping procedure in § 1065.510. The warm-idle-in-neutral torque is the sum of any optional declared torque in § 1065.510(f)(5)(iii) and the torque on the primary output shaft from any optional declared power in § 1065.510(f)(6) (i.e., the sum of the torques representing loads from vehicle accessories).

(iii) Zero-percent speed for denormalization of non-idle points is the warm-warm-idle-in-drive speed ~~measured according to § 1065.510(b)(6) with CITT applied, i.e., measured warm idle speed in drive.~~

(iv) For motoring points, make no changes.

(v) If the cycle begins with an idle segment (i.e., a set of one or more contiguous idle points) ~~(zero percent speed, and zero percent torque)~~, set the reference speed and torque values to the warm-idle-in-neutral values ~~leave the reference torques set to zero~~ for this initial ~~contiguous idle~~ segment. This is to represent ~~free~~ idle operation with the transmission in neutral or park at the start of the transient duty cycle, after the engine is started. If the initial idle segment is longer than 24 seconds, change the reference speed and torque values for the remaining idle points in the initial ~~contiguous~~ idle segment to the warm-idle-in-drive values ~~CITT~~ (i.e., change idle points corresponding to 25 seconds to the end of the initial idle segment to warm-idle-in-drive ~~CITT~~). This is to represent manually shifting the transmission to drive.

(vi) For all other idle ~~points~~ segments, change set the reference speed and torque values to the warm-idle-in-drive values ~~CITT~~. This is to represent the transmission operating in drive.

(vii) If the engine is intended primarily for automatic transmissions with a Neutral-When-Stationary feature that automatically shifts the transmission to neutral after the vehicle is stopped for a designated time and automatically shifts back to drive when the operator increases demand (i.e., pushes the accelerator pedal), reprocess all idle segments. Change the reference speed and torque values ~~back values to from the warm-idle-in-drive values to the warm-idle-in-neutral values zero~~ for idle points in drive after the designated time.

(viii) For all nonidle nonmotoring points with normalized speed at or below zero percent and reference torque from zero to the warm-idle-in-drive torque value ~~CITT~~, set the reference torque to the warm-idle-in-drive torque value ~~CITT~~. This is to ~~provide smoother torque references below idle speed~~ represent the transmission operating in drive.

(ix) For consecutive nonidle nonmotoring points ~~with reference torques from zero to CITT~~ that immediately follow and precede idle points ~~segments, with reference torque values from zero to the warm-idle-in-drive torque value~~, change their reference torques to the warm-idle-in-drive torque value ~~CITT~~. This is to ~~provide smooth torque transition out of idle operation~~ represent the transmission operating in drive. ~~This does not apply if the Neutral-When-Stationary feature is used and the transmission has shifted to neutral.~~

(x) For consecutive nonidle nonmotoring points ~~with reference torque from zero to CITT~~ that immediately follow and precede any point(s) that were modified in paragraph (d)(3)(viii) of this section, with reference torque values from zero to the warm-idle-in-drive torque value ~~idle points~~, change their reference torques to the warm-idle-in-drive torque value ~~CITT~~. This is to provide smooth torque transition around these points ~~to idle operation~~.

(4) *Permissible deviations for any engine.* If your engine does not operate below a certain minimum torque under normal in-use conditions, you may use a declared minimum torque as the reference value instead of any value denormalized to be less than the declared value. For example, if your engine is connected to a hydrostatic transmission and it has a minimum torque even when all the driven hydraulic actuators and motors are stationary and the engine is at idle, then you may use this declared minimum torque as a reference torque value instead

of any reference torque value generated under paragraph (d)(1) or (2) of this section that is between zero and this declared minimum torque.

(e) *Generating reference power values from normalized duty cycle powers.* Transform normalized power values to reference speed and power values using your map of maximum power versus speed.

(1) First transform normalized speed values into reference speed values. For a given speed point, multiply the corresponding % power by the mapped power at maximum test speed, f_{ntest} , unless specified otherwise by the standard-setting part. The result is the reference power for each speed point, P_{ref} . Convert these reference powers to corresponding torques for operator demand and dynamometer control and for duty cycle validation per 1065.514. Use the reference speed associated with each reference power point for this conversion. As with cycles specified with % torque, linearly interpolate between these reference torque values generated from cycles with % power.

(2) Permissible deviations for any engine. If your engine does not operate below a certain power under normal in-use conditions, you may use a declared minimum power as the reference value instead of any value denormalized to be less than the declared value. For example, if your engine is directly connected to a propeller, it may have a minimum power called idle power. In this case, you may use this declared minimum power as a reference power value instead of any reference power value generated per paragraph (e)(1) of this section that is from zero to this declared minimum power.

§ 1065.630 Local acceleration of gravity.

(a) The acceleration of Earth's gravity, a_g , varies depending on the test location. Determine a_g at your location by entering latitude, longitude, and elevation data into the U.S. National Oceanographic and Atmospheric Administration's surface gravity prediction Web site at https://geodesy.noaa.gov/cgi-bin/grav_pdx.prl.

(b) If the Web site specified in paragraph (a) of this section is unavailable, or the test location is outside of the continental United States, you may calculate a_g for your latitude as follows:

$$a_g = 9.7803267715 \cdot [1 + 5.2790414 \cdot 10^{-3} \cdot \sin^2(\Theta) + 2.32718 \cdot 10^{-5} \cdot \sin^4(\Theta) + 1.262 \cdot 10^{-7} \cdot \sin^6(\Theta) + 7 \cdot 10^{-10} \cdot \sin^8(\Theta)]$$

Eq. 1065.630-1

Where:

Θ = Degrees north or south latitude.

Example:

$$\Theta = 45^\circ$$

$$a_g = 9.7803267715 \cdot (1 + 5.2790414 \cdot 10^{-3} \cdot \sin^2(45) + 2.32718 \cdot 10^{-5} \cdot \sin^4(45) + 1.262 \cdot 10^{-7} \cdot \sin^6(45) + 7 \cdot 10^{-10} \cdot \sin^8(45))$$

$$a_g = 9.8061992026 \text{ m/s}^2$$

§ 1065.640 Flow meter calibration calculations.

This section describes the calculations for calibrating various flow meters. After you calibrate a flow meter using these calculations, use the calculations described in § 1065.642 to calculate

flow during an emission test. Paragraph (a) of this section first describes how to convert reference flow meter outputs for use in the calibration equations, which are presented on a molar basis. The remaining paragraphs describe the calibration calculations that are specific to certain types of flow meters.

(a) *Reference meter conversions.* The calibration equations in this section use molar flow rate, \dot{n}_{ref} , as a reference quantity. If your reference meter outputs a flow rate in a different quantity, such as standard volume rate, \dot{V}_{stdref} , actual volume rate, \dot{V}_{actref} , or mass rate, \dot{m}_{ref} , convert your reference meter output to a molar flow rate using the following equations, noting that while values for volume rate, mass rate, pressure, temperature, and molar mass may change during an emission test, you should ensure that they are as constant as practical for each individual set point during a flow meter calibration:

$$\dot{n}_{\text{ref}} = \frac{\dot{V}_{\text{stdref}} \cdot p_{\text{std}}}{T_{\text{std}} \cdot R} = \frac{\dot{V}_{\text{actref}} \cdot p_{\text{act}}}{T_{\text{act}} \cdot R} = \frac{\dot{m}_{\text{ref}}}{M_{\text{mix}}}$$

Eq. 1065.640-1

Where:

\dot{n}_{ref} = reference molar flow rate.

\dot{V}_{stdref} = reference volume flow rate corrected to a standard pressure and a standard temperature.

\dot{V}_{actref} = reference volume flow rate at the actual pressure and temperature of the flow rate.

\dot{m}_{ref} = reference mass flow.

p_{std} = standard pressure.

p_{act} = actual pressure of the flow rate.

T_{std} = standard temperature.

T_{act} = actual temperature of the flow rate.

R = molar gas constant.

M_{mix} = molar mass of the flow rate.

Example 1:

$$\dot{V}_{\text{stdref}} = 1000.00 \text{ ft}^3/\text{min} = 0.471948 \text{ m}^3/\text{s}$$

$$p_{\text{std}} = 29.9213 \text{ in Hg @ } 32 \text{ }^\circ\text{F} = 101.325 \text{ kPa} = 101325 \text{ Pa} = 101325 \text{ kg}/(\text{m}\cdot\text{s}^2)$$

$$T_{\text{std}} = 68.0 \text{ }^\circ\text{F} = 293.15 \text{ K}$$

$$R = 8.314472 \text{ J}/(\text{mol}\cdot\text{K}) = 8.314472 \text{ (m}^2\cdot\text{kg)} / (\text{s}^2\cdot\text{mol}\cdot\text{K})$$

$$\dot{n}_{\text{ref}} = \frac{0.471948 \cdot 101325}{293.15 \cdot 8.314472}$$

$$\dot{n}_{\text{ref}} = 19.619 \text{ mol/s}$$

Example 2:

$$\dot{m}_{\text{ref}} = 17.2683 \text{ kg}/\text{min} = 287.805 \text{ g/s}$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol}$$

$$\dot{n}_{\text{ref}} = \frac{287.805}{28.7805}$$

$$\dot{n}_{\text{ref}} = 10.0000 \text{ mol/s}$$

(b) *PDP calibration calculations.* Perform the following steps to calibrate a PDP flow meter:

(1) Calculate PDP volume pumped per revolution, V_{rev} , for each restrictor position from the mean values determined in § 1065.340 as follows:

$$V_{\text{rev}} = \frac{\bar{n}_{\text{ref}} \cdot R \cdot \bar{T}_{\text{in}}}{\bar{p}_{\text{in}} \cdot \bar{f}_{\text{nPDP}}}$$

Eq. 1065.640-2

Where:

\bar{n}_{ref} = mean reference molar flow rate.

R = molar gas constant.

\bar{T}_{in} = mean temperature at the PDP inlet.

\bar{p}_{in} = mean static absolute pressure at the PDP inlet.

\bar{f}_{nPDP} = mean PDP speed.

Example:

$$\bar{n}_{\text{ref}} = 25.096 \text{ mol/s}$$

$$R = 8.314472 \text{ J}/(\text{mol}\cdot\text{K}) = 8.314472 \text{ (m}^2\cdot\text{kg)} / (\text{s}^2\cdot\text{mol}\cdot\text{K})$$

$$\bar{T}_{\text{in}} = 299.5 \text{ K}$$

$$\bar{p}_{\text{in}} = 98.290 \text{ kPa} = 98290 \text{ Pa} = 98290 \text{ kg}/(\text{m}\cdot\text{s}^2)$$

$$\bar{f}_{\text{nPDP}} = 1205.1 \text{ r/min} = 20.085 \text{ r/s}$$

$$V_{\text{rev}} = \frac{25.096 \cdot 8.314472 \cdot 299.5}{98290 \cdot 20.085}$$

$$V_{\text{rev}} = 0.03166 \text{ m}^3/\text{r}$$

(2) Calculate a PDP slip correction factor, K_s , for each restrictor position from the mean values determined in § 1065.340 as follows:

$$K_s = \frac{1}{\bar{f}_{\text{nPDP}}} \cdot \sqrt{\frac{\bar{p}_{\text{out}} - \bar{p}_{\text{in}}}{\bar{p}_{\text{out}}}}$$

Eq. 1065.640-3

Where:

\bar{f}_{nPDP} = mean PDP speed.

\bar{p}_{out} = mean static absolute pressure at the PDP outlet.

\bar{p}_{in} = mean static absolute pressure at the PDP inlet.

Example:

$$\bar{f}_{\text{nPDP}} = 1205.1 \text{ r/min} = 20.085 \text{ r/s}$$

$$\bar{p}_{\text{out}} = 100.103 \text{ kPa}$$

$$\bar{p}_{\text{in}} = 98.290 \text{ kPa}$$

$$K_s = \frac{1}{20.085} \cdot \sqrt{\frac{100.103 - 98.290}{100.103}}$$

$$K_s = 0.006700 \text{ s/r}$$

(3) Perform a least-squares regression of V_{rev} , versus K_s , by calculating slope, a_1 , and intercept, a_0 , as described for a floating intercept in § 1065.602.

(4) Repeat the procedure in paragraphs (b)(1) through (3) of this section for every speed that you run your PDP.

(5) The following table illustrates a range of typical values for different PDP speeds:

TABLE 1 OF § 1065.640—EXAMPLE OF PDP CALIBRATION DATA

\bar{f}_{nPDP} (revolution/s)	a_1 (m ³ /s)	a_0 (m ³ /revolution)
12.6	0.841	0.056
16.5	0.831	-0.013
20.9	0.809	0.028
23.4	0.788	-0.061

(6) For each speed at which you operate the PDP, use the appropriate regression equation from this paragraph (b) to calculate flow rate during emission testing as described in § 1065.642.

(c) *Venturi governing equations and permissible assumptions.* This section describes the governing equations and permissible assumptions for calibrating a venturi and calculating flow using a venturi. Because a subsonic venturi (SSV) and a critical-flow venturi (CFV) both operate similarly, their governing equations are nearly the same, except for the equation describing their pressure ratio, r (i.e., r_{SSV} versus r_{CFV}). These governing equations assume one-dimensional isentropic inviscid flow of an ideal gas. Paragraph (c)(5) of this section describes other assumptions that may apply. If good engineering judgment dictates that you account for gas compressibility, you may either use an appropriate equation of state to determine values of Z as a function of measured pressure and temperature, or you may develop your own calibration equations based on good engineering judgment. Note that the equation for the flow coefficient, C_f , is based on the ideal gas assumption that the isentropic exponent, γ , is equal to the ratio of specific heats, C_p/C_v . If good engineering judgment dictates using a real gas isentropic exponent, you may either use an appropriate equation of state to determine values of γ as a function of measured pressures and temperatures, or you may develop your own calibration equations based on good engineering judgment.

(1) Calculate molar flow rate, \dot{n} , as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{\text{in}}}{\sqrt{Z \cdot M_{\text{mix}} \cdot R \cdot T_{\text{in}}}}$$

Eq. 1065.640-4

Where:

C_d = discharge coefficient, as determined in paragraph (c)(2) of this section.

C_f = flow coefficient, as determined in paragraph (c)(3) of this section.

A_t = venturi throat cross-sectional area.

p_{in} = venturi inlet absolute static pressure.

Z = compressibility factor.

M_{mix} = molar mass of gas mixture.

R = molar gas constant.

T_{in} = venturi inlet absolute temperature.

(2) Using the data collected in § 1065.340, calculate C_d for each flow rate using the following equation:

$$C_d = \dot{n}_{\text{ref}} \cdot \frac{\sqrt{Z \cdot M_{\text{mix}} \cdot R \cdot T_{\text{in}}}}{C_f \cdot A_t \cdot p_{\text{in}}}$$

Eq. 1065.640-5

Where:

\dot{n}_{ref} = a reference molar flow rate.

(3) Determine C_f using one of the following methods:

(i) For CFV flow meters only, determine $C_{f\text{CFV}}$ from the following table based on your values for β and γ , using linear interpolation to find intermediate values:

TABLE 2 OF § 1065.640– $C_{f\text{CFV}}$ VERSUS β AND γ FOR CFV FLOW METERS

$C_{f\text{CFV}}$		
β	$\gamma^{\text{exh}} =$ 1.385	$\gamma^{\text{dexh}} =$ $\gamma^{\text{air}} =$ 1.399
0.000	0.6822	0.6846
0.400	0.6857	0.6881
0.500	0.6910	0.6934
0.550	0.6953	0.6977
0.600	0.7011	0.7036
0.625	0.7047	0.7072
0.650	0.7089	0.7114
0.675	0.7137	0.7163
0.700	0.7193	0.7219
0.720	0.7245	0.7271
0.740	0.7303	0.7329
0.760	0.7368	0.7395
0.770	0.7404	0.7431
0.780	0.7442	0.7470
0.790	0.7483	0.7511
0.800	0.7527	0.7555
0.810	0.7573	0.7602
0.820	0.7624	0.7652
0.830	0.7677	0.7707
0.840	0.7735	0.7765
0.850	0.7798	0.7828

(ii) For any CFV or SSV flow meter, you may use the following equation to calculate C_f for each flow rate:

$$C_f = \left[\frac{2 \cdot \gamma \cdot \left(r^{\frac{\gamma-1}{\gamma}} - 1 \right)}{(\gamma - 1) \cdot \left(\beta^4 - r^{\frac{-2}{\gamma}} \right)} \right]^{\frac{1}{2}}$$

Eq. 1065.640-6

Where:

γ = isentropic exponent. For an ideal gas, this is the ratio of specific heats of the gas mixture, C_p/C_v .

r = pressure ratio, as determined in paragraph (c)(4) of this section.

β = ratio of venturi throat to inlet diameters.

(4) Calculate r as follows:

(i) For SSV systems only, calculate r_{SSV} using the following equation:

$$r_{SSV} = 1 - \frac{\Delta p_{SSV}}{p_{in}}$$

Eq. 1065.640-7

Where:

Δp_{SSV} = Differential static pressure; venturi inlet minus venturi throat.

(ii) For CFV systems only, calculate r_{CFV} iteratively using the following equation:

$$r_{CFV}^{\frac{1-\gamma}{\gamma}} + \left(\frac{\gamma-1}{2} \right) \cdot \beta^4 \cdot r_{CFV}^{\frac{2}{\gamma}} = \frac{\gamma+1}{2}$$

Eq. 1065.640-8

(5) You may apply any of the following simplifying assumptions or develop other values as appropriate for your test configuration, consistent with good engineering judgment:

(i) For raw exhaust, diluted exhaust, and dilution air, you may assume that the gas mixture behaves as an ideal gas: $Z = 1$.

(ii) For raw exhaust, you may assume $\gamma = 1.385$.

(iii) For diluted exhaust and dilution air, you may assume $\gamma = 1.399$.

(iv) For diluted exhaust and dilution air, you may assume the molar mass of the mixture, M_{mix} , is a function only of the amount of water in the dilution air or calibration air, as follows:

$$M_{mix} = M_{air} \cdot (1 - x_{H_2O}) + M_{H_2O} \cdot x_{H_2O}$$

Eq. 1065.640-9

Where:

M_{air} = molar mass of dry air.

x_{H_2O} = amount of H_2O in the dilution air or calibration air, determined as described in § 1065.645.

M_{H_2O} = molar mass of water.

Example:

$$M_{\text{air}} = 28.96559 \text{ g/mol}$$

$$x_{\text{H}_2\text{O}} = 0.0169 \text{ mol/mol}$$

$$M_{\text{H}_2\text{O}} = 18.01528 \text{ g/mol}$$

$$M_{\text{mix}} = 28.96559 \cdot (1 - 0.0169) + 18.01528 \cdot 0.0169$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol}$$

(v) For diluted exhaust and dilution air, you may assume a constant molar mass of the mixture, M_{mix} , for all calibration and all testing as long as your assumed molar mass differs no more than $\pm 1\%$ from the estimated minimum and maximum molar mass during calibration and testing. You may assume this, using good engineering judgment, if you sufficiently control the amount of water in calibration air and in dilution air or if you remove sufficient water from both calibration air and dilution air. The following table gives examples of permissible ranges of dilution air dewpoint versus calibration air dewpoint:

TABLE 3 OF § 1065.640—EXAMPLES OF DILUTION AIR AND CALIBRATION AIR DEWPOINTS AT WHICH YOU MAY ASSUME A CONSTANT M_{MIX}

If calibration T_{dew} ($^{\circ}\text{C}$) is...	assume the following constant M_{mix} (g/mol)...	for the following ranges of T_{dew} ($^{\circ}\text{C}$) during emission tests ^a
dry	28.96559	dry to 18
0	28.89263	dry to 21
5	28.86148	dry to 22
10	28.81911	dry to 24
15	28.76224	dry to 26
20	28.68685	-8 to 28
25	28.58806	12 to 31
30	28.46005	23 to 34

^aRange valid for all calibration and emission testing over the atmospheric pressure range (80.000 to 103.325) kPa.

(6) The following example illustrates the use of the governing equations to calculate C_d of an SSV flow meter at one reference flow meter value. Note that calculating C_d for a CFV flow meter would be similar, except that C_f would be determined from Table 2 of this section or calculated iteratively using values of β and γ as described in paragraph (c)(2) of this section.

Example:

$$\dot{n}_{\text{ref}} = 57.625 \text{ mol/s}$$

$$Z = 1$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$$

$$R = 8.314472 \text{ J/(mol}\cdot\text{K)} = 8.314472 \text{ (m}^2\cdot\text{kg)/(s}^2\cdot\text{mol}\cdot\text{K)}$$

$$T_{\text{in}} = 298.15 \text{ K}$$

$$A_t = 0.01824 \text{ m}^2$$

$$p_{\text{in}} = 99.132 \text{ kPa} = 99132.0 \text{ Pa} = 99132 \text{ kg/(m}\cdot\text{s}^2)$$

$$\gamma = 1.399$$

$$\beta = 0.8$$

$$\Delta p = 2.312 \text{ kPa}$$

$$r_{\text{SSV}} = 1 - \frac{2.312}{99.132} = 0.977$$

$$C_f = \left[\frac{2 \cdot 1.399 \cdot \left(0.977^{\frac{1.399-1}{1.399}} - 1 \right)}{(1.399 - 1) \cdot \left(0.8^4 - 0.977^{\frac{-2}{1.399}} \right)} \right]^{\frac{1}{2}}$$

$$C_f = 0.274$$

$$C_d = 57.625 \cdot \frac{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 298.15}}{0.274 \cdot 0.01824 \cdot 99132.0}$$

$$C_d = 0.982$$

(d) *SSV calibration.* Perform the following steps to calibrate an SSV flow meter:

(1) Calculate the Reynolds number, $Re^\#$, for each reference molar flow rate, \dot{n}_{ref} , using the throat diameter of the venturi, d_t . Because the dynamic viscosity, μ , is needed to compute $Re^\#$, you may use your own fluid viscosity model to determine μ for your calibration gas (usually air), using good engineering judgment. Alternatively, you may use the Sutherland three-coefficient viscosity model to approximate μ , as shown in the following sample calculation for $Re^\#$:

$$Re^\# = \frac{4 \cdot M_{\text{mix}} \cdot \dot{n}_{\text{ref}}}{\pi \cdot d_t \cdot \mu}$$

Eq. 1065.640-10

Where, using the Sutherland three-coefficient viscosity model as captured in Table 4 of this section:

$$\mu = \mu_0 \cdot \left(\frac{T_{\text{in}}}{T_0} \right)^{\frac{3}{2}} \cdot \left(\frac{T_0 + S}{T_{\text{in}} + S} \right)$$

Eq. 1065.640-11

Where:

μ_0 = Sutherland reference viscosity.

T_0 = Sutherland reference temperature.

S = Sutherland constant.

TABLE 4 OF § 1065.640–SUTHERLAND THREE-COEFFICIENT VISCOSITY MODEL PARAMETERS

Gas ^a	μ_0	T_0	S	Temperature range within ± 2 % error ^b	Pressure limit ^b
	kg/(m·s)	K	K	K	kPa
Air	$1.716 \cdot 10^{-5}$	273	111	170 to 1900	≤ 1800
CO ₂	$1.370 \cdot 10^{-5}$	273	222	190 to 1700	≤ 3600
H ₂ O	$1.12 \cdot 10^{-5}$	350	1064	360 to 1500	≤ 10000
O ₂	$1.919 \cdot 10^{-5}$	273	139	190 to 2000	≤ 2500
N ₂	$1.663 \cdot 10^{-5}$	273	107	100 to 1500	≤ 1600

^aUse tabulated parameters only for the pure gases, as listed. Do not combine parameters in calculations to calculate viscosities of gas mixtures.

^bThe model results are valid only for ambient conditions in the specified ranges.

Example:

$$\mu_0 = 1.716 \cdot 10^{-5} \text{ kg/(m}\cdot\text{s)}$$

$$T_0 = 273 \text{ K}$$

$$S = 111 \text{ K}$$

$$\mu = 1.716 \cdot 10^{-5} \cdot \left(\frac{298.15}{273} \right)^{\frac{3}{2}} \cdot \left(\frac{273 + 111}{298.15 + 111} \right)$$

$$\mu = 1.838 \cdot 10^{-5} \text{ kg/(m}\cdot\text{s)}$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$$

$$\dot{n}_{\text{ref}} = 57.625 \text{ mol/s}$$

$$d_t = 152.4 \text{ mm} = 0.1524 \text{ m}$$

$$T_{\text{in}} = 298.15 \text{ K}$$

$$Re^{\#} = \frac{4 \cdot 0.0287805 \cdot 57.625}{3.14159 \cdot 0.1524 \cdot 1.838 \cdot 10^{-5}}$$

$$Re^{\#} = 7.538 \cdot 10^5$$

(2) Create an equation for C_d as a function of $Re^{\#}$, using paired values of the two quantities. The equation may involve any mathematical expression, including a polynomial or a power series. The following equation is an example of a commonly used mathematical expression for relating C_d and $Re^{\#}$:

$$C_d = a_0 - a_1 \cdot \sqrt{\frac{10^6}{Re^{\#}}}$$

Eq. 1065.640-12

(3) Perform a least-squares regression analysis to determine the best-fit coefficients for the equation and calculate *SEE* as described in § 1065.602. When using Eq. 1065.640-12, treat C_d as y and the radical term as y_{ref} and use Eq. 1065.602-12 to calculate *SEE*. When using another mathematical expression, use the same approach to substitute that expression into the

numerator of Eq. 1065.602-12 and replace the 2 in the denominator with the number of coefficients in the mathematical expression.

(4) If the equation meets the criterion of $SEE \leq 0.5 \% \cdot C_{dmax}$, you may use the equation for the corresponding range of $Re^\#$, as described in § 1065.642.

(5) If the equation does not meet the specified statistical criterion, you may use good engineering judgment to omit calibration data points; however you must use at least seven calibration data points to demonstrate that you meet the criterion. For example, this may involve narrowing the range of flow rates for a better curve fit.

(6) Take corrective action if the equation does not meet the specified statistical criterion even after omitting calibration data points. For example, select another mathematical expression for the C_d versus $Re^\#$ equation, check for leaks, or repeat the calibration process. If you must repeat the calibration process, we recommend applying tighter tolerances to measurements and allowing more time for flows to stabilize.

(7) Once you have an equation that meets the specified statistical criterion, you may use the equation only for the corresponding range of $Re^\#$.

(e) *CFV calibration.* Some CFV flow meters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. For CFV flow meters that consist of multiple venturis, either calibrate each venturi independently to determine a separate discharge coefficient, C_d , for each venturi, or calibrate each combination of venturis as one venturi. In the case where you calibrate a combination of venturis, use the sum of the active venturi throat areas as A_t , the square root of the sum of the squares of the active venturi throat diameters as d_t , and the ratio of the venturi throat to inlet diameters as the ratio of the square root of the sum of the active venturi throat diameters (d_t) to the diameter of the common entrance to all the venturis (D). To determine the C_d for a single venturi or a single combination of venturis, perform the following steps:

(1) Use the data collected at each calibration set point to calculate an individual C_d for each point using Eq. 1065.640-4.

(2) Calculate the mean and standard deviation of all the C_d values according to Eqs. 1065.602-1 and 1065.602-2.

(3) If the standard deviation of all the C_d values is less than or equal to 0.3 % of the mean C_d , use the mean C_d in Eq. 1065.642-4, and use the CFV only up to the highest venturi pressure ratio, r , measured during calibration using the following equation:

$$r = 1 - \frac{\Delta p_{CFV}}{p_{in}}$$

Eq. 1065.640-13

Where:

Δp_{CFV} = Differential static pressure; venturi inlet minus venturi outlet.

(4) If the standard deviation of all the C_d values exceeds 0.3 % of the mean C_d , omit the C_d value corresponding to the data point collected at the highest r measured during calibration.

(5) If the number of remaining data points is less than seven, take corrective action by checking your calibration data or repeating the calibration process. If you repeat the calibration process, we recommend checking for leaks, applying tighter tolerances to measurements and allowing more time for flows to stabilize.

- (6) If the number of remaining C_d values is seven or greater, recalculate the mean and standard deviation of the remaining C_d values.
- (7) If the standard deviation of the remaining C_d values is less than or equal to 0.3 % of the mean of the remaining C_d , use that mean C_d in Eq. 1065.642-4, and use the CFV values only up to the highest r associated with the remaining C_d .
- (8) If the standard deviation of the remaining C_d still exceeds 0.3 % of the mean of the remaining C_d values, repeat the steps in paragraph (e)(4) through (8) of this section.

§ 1065.642 PDP, SSV, and CFV molar flow rate calculations.

This section describes the equations for calculating molar flow rates from various flow meters. After you calibrate a flow meter according to § 1065.640, use the calculations described in this section to calculate flow during an emission test.

(a) *PDP molar flow rate.* (1) Based on the speed at which you operate the PDP for a test interval, select the corresponding slope, a_1 , and intercept, a_0 , as calculated in § 1065.640, to calculate PDP molar flow rate, \dot{n} , as follows:

$$\dot{n} = f_{\text{nPDP}} \cdot \frac{V_{\text{rev}} \cdot p_{\text{in}}}{R \cdot T_{\text{in}}}$$

Eq. 1065.642-1

Where:

f_{nPDP} = pump speed.

V_{rev} = PDP volume pumped per revolution, as determined in paragraph (a)(2) of this section.

p_{in} = static absolute pressure at the PDP inlet.

R = molar gas constant.

T_{in} = absolute temperature at the PDP inlet.

(2) Calculate V_{rev} using the following equation:

$$V_{\text{rev}} = \frac{a_1}{f_{\text{nPDP}}} \cdot \sqrt{\frac{p_{\text{out}} - p_{\text{in}}}{p_{\text{out}}}} + a_0$$

Eq. 1065.642-2

p_{out} = static absolute pressure at the PDP outlet.

Example:

$$a_1 = 0.8405 \text{ (m}^3\text{/s)}$$

$$f_{\text{nPDP}} = 12.58 \text{ r/s}$$

$$p_{\text{out}} = 99.950 \text{ kPa}$$

$$p_{\text{in}} = 98.575 \text{ kPa} = 98575 \text{ Pa} = 98575 \text{ kg}/(\text{m} \cdot \text{s}^2)$$

$$a_0 = 0.056 \text{ (m}^3\text{/r)}$$

$$R = 8.314472 \text{ J}/(\text{mol} \cdot \text{K}) = 8.314472 \text{ (m}^2 \cdot \text{kg})/(\text{s}^2 \cdot \text{mol} \cdot \text{K})$$

$$T_{\text{in}} = 323.5 \text{ K}$$

$$V_{\text{rev}} = \frac{0.8405}{12.58} \cdot \sqrt{\frac{99.950 - 98.575}{99.950}} + 0.056$$

$$V_{\text{rev}} = 0.06383 \text{ m}^3/\text{r}$$

$$\dot{n} = 12.58 \cdot \frac{98575 \cdot 0.06383}{8.314472 \cdot 323.5}$$

$$\dot{n} = 29.428 \text{ mol/s}$$

(b) *SSV molar flow rate*. Calculate SSV molar flow rate, \dot{n} , as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{\text{in}}}{\sqrt{Z \cdot M_{\text{mix}} \cdot R \cdot T_{\text{in}}}}$$

Eq. 1065.642-3

Where:

C_d = discharge coefficient, as determined based on the C_d versus $Re^\#$ equation in § 1065.640(d)(2).

C_f = flow coefficient, as determined in § 1065.640(c)(3)(ii).

A_t = venturi throat cross-sectional area.

p_{in} = static absolute pressure at the venturi inlet.

Z = compressibility factor.

M_{mix} = molar mass of gas mixture.

R = molar gas constant.

T_{in} = absolute temperature at the venturi inlet.

Example:

$$A_t = 0.01824 \text{ m}^2$$

$$p_{\text{in}} = 99.132 \text{ kPa} = 99132 \text{ Pa} = 99132 \text{ kg}/(\text{m} \cdot \text{s}^2)$$

$$Z = 1$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$$

$$R = 8.314472 \text{ J}/(\text{mol} \cdot \text{K}) = 8.314472 \text{ (m}^2 \cdot \text{kg)} / (\text{s}^2 \cdot \text{mol} \cdot \text{K})$$

$$T_{\text{in}} = 298.15 \text{ K}$$

$$Re^\# = 7.232 \cdot 10^5$$

$$\gamma = 1.399$$

$$\beta = 0.8$$

$$\Delta p = 2.312 \text{ kPa}$$

Using Eq. 1065.640-7:

$$r_{\text{SSV}} = 0.997$$

Using Eq. 1065.640-6:

$$C_f = 0.274$$

Using Eq. 1065.640-5:

$$C_d = 0.990$$

$$\dot{n} = 0.990 \cdot 0.274 \cdot \frac{0.01824 \cdot 99132}{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 298.15}}$$

$$\dot{n} = 58.173 \text{ mol/s}$$

(c) *CFV molar flow rate.* If you use multiple venturis and you calibrate each venturi independently to determine a separate discharge coefficient, C_d (or calibration coefficient, K_v), for each venturi, calculate the individual molar flow rates through each venturi and sum all their flow rates to determine CFV flow rate, \dot{n} . If you use multiple venturis and you calibrated venturis in combination, calculate \dot{n} using the sum of the active venturi throat areas as A_t , the square root of the sum of the squares of the active venturi throat diameters as d_t , and the ratio of the venturi throat to inlet diameters as the ratio of the square root of the sum of the active venturi throat diameters (d_t) to the diameter of the common entrance to all the venturis (D).

(1) To calculate \dot{n} through one venturi or one combination of venturis, use its respective mean C_d and other constants you determined according to § 1065.640 and calculate \dot{n} as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}}$$

Eq. 1065.642-4

Where:

C_f = flow coefficient, as determined in § 1065.640(c)(3).

Example:

$$C_d = 0.985$$

$$C_f = 0.7219$$

$$A_t = 0.00456 \text{ m}^2$$

$$p_{in} = 98.836 \text{ kPa} = 98836 \text{ Pa} = 98836 \text{ kg}/(\text{m} \cdot \text{s}^2)$$

$$Z = 1$$

$$M_{mix} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$$

$$R = 8.314472 \text{ J}/(\text{mol} \cdot \text{K}) = 8.314472 \text{ (m}^2 \cdot \text{kg)} / (\text{s}^2 \cdot \text{mol} \cdot \text{K})$$

$$T_{in} = 378.15 \text{ K}$$

$$\dot{n} = 0.985 \cdot 0.7219 \cdot \frac{0.00456 \cdot 98836}{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 378.15}}$$

$$\dot{n} = 33.690 \text{ mol/s}$$

(2) To calculate the molar flow rate through one venturi or a combination of venturis, you may use its respective mean, K_v , and other constants you determined according to § 1065.640 and calculate its molar flow rate \dot{n} during an emission test. Note that if you follow the permissible ranges of dilution air dewpoint versus calibration air dewpoint in Table 3 of § 1065.640, you may set $M_{mix-cal}$ and M_{mix} equal to 1. Calculate \dot{n} as follows:

$$\dot{n} = \frac{K_v \cdot p_{in}}{\sqrt{T_{in}}} \cdot \frac{p_{std}}{T_{std} \cdot R} \cdot \frac{\sqrt{M_{mix-cal}}}{\sqrt{M_{mix}}}$$

Eq. 1065.642-5

Where:

$$K_v = \frac{V_{stdref} \cdot \sqrt{T_{in-cal}}}{p_{in-cal}}$$

Eq. 1065.642-6

V_{stdref} = volume flow rate of the standard at reference conditions of 293.15 K and 101.325 kPa.

$T_{\text{in-cal}}$ = venturi inlet temperature during calibration.

$P_{\text{in-cal}}$ = venturi inlet pressure during calibration.

$M_{\text{mix-cal}}$ = molar mass of gas mixture used during calibration.

M_{mix} = molar mass of gas mixture during the emission test calculated using Eq. 1065.640-9.

Example:

$$V_{\text{stdref}} = 0.4895 \text{ m}^3$$

$$T_{\text{in-cal}} = 302.52 \text{ K}$$

$$P_{\text{in-cal}} = 99.654 \text{ kPa} = 99654 \text{ Pa} = 99654 \text{ kg}/(\text{m}\cdot\text{s}^2)$$

$$p_{\text{in}} = 98.836 \text{ kPa} = 98836 \text{ Pa} = 98836 \text{ kg}/(\text{m}\cdot\text{s}^2)$$

$$p_{\text{std}} = 101.325 \text{ kPa} = 101325 \text{ Pa} = 101325 \text{ kg}/(\text{m}\cdot\text{s}^2)$$

$$M_{\text{mix-cal}} = 28.9656 \text{ g/mol} = 0.0289656 \text{ kg/mol}$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$$

$$T_{\text{in}} = 353.15 \text{ K}$$

$$T_{\text{std}} = 293.15 \text{ K}$$

$$R = 8.314472 \text{ J}/(\text{mol}\cdot\text{K}) = 8.314472 \text{ (m}^2\cdot\text{kg)} / (\text{s}^2\cdot\text{mol}\cdot\text{K})$$

$$K_v = \frac{0.4895 \cdot \sqrt{302.52}}{99654} = 0.000074954 \frac{\text{m}^4 \cdot \text{s} \cdot \text{K}^{0.5}}{\text{kg}}$$

$$\dot{n} = \frac{0.000074954 \cdot 98936}{\sqrt{353.15}} \cdot \frac{101325}{293.15 \cdot 8.314472} \cdot \frac{\sqrt{0.0289656}}{\sqrt{0.0287805}}$$

$$\dot{n} = 16.457 \text{ mol/s}$$

§ 1065.643 Carbon balance error verification calculations.

This section describes how to calculate quantities used in the carbon balance error verification described in § 1065.543. Paragraphs (a) through (c) of this section describe how to calculate the mass of carbon for a test interval from carbon-carrying fluid streams, intake air into the system, and exhaust emissions, respectively. Paragraph (d) of this section describes how to use these carbon masses to calculate four different quantities for evaluating carbon balance error. Use rectangular or trapezoidal integration methods to calculate masses and amounts over a test interval from continuously measured or calculated mass and molar flow rates.

(a) *Fuel and other fluids.* Determine the mass of fuel, DEF, and other carbon-carrying fluid streams, other than intake air, flowing into the system, $m_{\text{fluid}j}$, for each test interval. Note that § 1065.543 allows you to omit all flows other than fuel. You may determine the mass of DEF based on ECM signals for DEF flow rate. You may determine fuel mass during field testing based on ECM signals for fuel flow rate. Calculate the mass of carbon from the combined carbon-carrying fluid streams flowing into the system as follows:

$$m_{\text{Cfluid}} = \sum_{j=1}^N (w_{\text{C}j} \cdot m_{\text{fluid}j})$$

Eq. 1065.643-1

Where:

j = an indexing variable that represents one carbon-carrying fluid stream.

N = total number of carbon-carrying fluid streams into the system over the test interval.

w_C = carbon mass fraction of the carbon-carrying fluid stream as determined in § 1065.655(d).

m_{fluid} = the mass of the carbon-carrying fluid stream determined over the test interval.

Example:

$$N = 2$$

$$w_{\text{Cfuel}} = 0.869$$

$$w_{\text{CDEF}} = 0.065$$

$$m_{\text{fuel}} = 1119.6 \text{ g}$$

$$m_{\text{DEF}} = 36.8 \text{ g}$$

$$m_{\text{Cfluid}} = 0.869 \cdot 1119.6 + 0.065 \cdot 36.8 = 975.3 \text{ g}$$

(b) *Intake air.* Calculate the mass of carbon in the intake air, m_{Cair} , for each test interval using one of the methods in this paragraph (b). The methods are listed in order of preference. Use the first method where all the inputs are available for your test configuration. For methods that calculate m_{Cair} based on the amount of CO₂ per mole of intake air, we recommend measuring intake air concentration, but you may calculate $x_{\text{CO}_2\text{int}}$ using Eq. 1065.655-10 and letting $x_{\text{CO}_2\text{intdry}} = 375 \text{ } \mu\text{mol/mol}$.

(1) Calculate m_{Cair} , using the following equation if you measure intake air flow:

$$m_{\text{Cair}} = M_C \cdot n_{\text{int}} \cdot x_{\text{CO}_2\text{int}}$$

Eq. 1065.643-2

Where:

M_C = molar mass of carbon.

n_{int} = measured amount of intake air over the test interval.

$x_{\text{CO}_2\text{int}}$ = amount of intake air CO₂ per mole of intake air.

Example:

$$M_C = 12.0107 \text{ g/mol}$$

$$n_{\text{int}} = 62862 \text{ mol}$$

$$x_{\text{CO}_2\text{int}} = 369 \text{ } \mu\text{mol/mol} = 0.000369 \text{ mol/mol}$$

$$m_{\text{Cair}} = 12.0107 \cdot 62862 \cdot 0.000369 = 278.6 \text{ g}$$

(2) Calculate m_{Cair} , using the following equation if you measure or calculate raw exhaust flow and you calculate chemical balance terms:

$$m_{\text{Cair}} = M_C \cdot n_{\text{exh}} \cdot (1 - x_{\text{H}_2\text{Oexh}}) \cdot x_{\text{CO}_2\text{int}} \cdot (x_{\text{dil/exhdry}} + x_{\text{int/exhdry}})$$

Eq. 1065.643-3

Where:

M_C = molar mass of carbon.

n_{exh} = calculated or measured amount of raw exhaust over the test interval.

$x_{\text{H}_2\text{Oexh}}$ = amount of H₂O in exhaust per mole of exhaust.

$x_{\text{CO}_2\text{int}}$ = amount of intake air CO₂ per mole of intake air.

$x_{\text{dil/exhdry}}$ = amount of excess air per mole of dry exhaust. Note that excess air and intake air have the same composition, so $x_{\text{CO}_2\text{dil}} = x_{\text{CO}_2\text{int}}$ and $x_{\text{H}_2\text{Odil}} = x_{\text{H}_2\text{Oint}}$ for the chemical balance calculation for raw exhaust.

$x_{\text{int/exhdry}}$ = amount of intake air required to produce actual combustion products per mole of dry exhaust.

Example:

$$M_C = 12.0107 \text{ g/mol}$$

$$n_{\text{exh}} = 62862 \text{ mol}$$

$$x_{\text{H}_2\text{Oexh}} = 0.034 \text{ mol/mol}$$

$$x_{\text{CO}_2\text{int}} = 369 \text{ } \mu\text{mol/mol} = 0.000369 \text{ mol/mol}$$

$$x_{\text{dil/exhdry}} = 0.570 \text{ mol/mol}$$

$$x_{\text{int/exhdry}} = 0.465 \text{ mol/mol}$$

$$m_{\text{Cair}} = 12.0107 \cdot 62862 \cdot (1 - 0.034) \cdot 0.000369 \cdot (0.570 + 0.465) = 278.6 \text{ g}$$

(3) Calculate m_{Cair} , using the following equation if you measure raw exhaust flow:

$$m_{\text{Cair}} = M_C \cdot n_{\text{exh}} \cdot x_{\text{CO}_2\text{int}}$$

Eq. 1065.643-4

Where:

M_C = molar mass of carbon.

n_{exh} = measured amount of raw exhaust over the test interval.

$x_{\text{CO}_2\text{int}}$ = amount of intake air CO_2 per mole of intake air.

Example:

$$M_C = 12.0107 \text{ g/mol}$$

$$n_{\text{exh}} = 62862 \text{ mol}$$

$$x_{\text{CO}_2\text{int}} = 369 \text{ } \mu\text{mol/mol} = 0.000369 \text{ mol/mol}$$

$$m_{\text{Cair}} = 12.0107 \cdot 62862 \cdot 0.000369 = 278.6 \text{ g}$$

(4) Calculate m_{Cair} , using the following equation if you measure diluted exhaust flow and dilution air flow:

$$m_{\text{Cair}} = M_C \cdot (n_{\text{dexh}} - n_{\text{dil}}) \cdot x_{\text{CO}_2\text{int}}$$

Eq. 1065.643-5

Where:

M_C = molar mass of carbon.

n_{dexh} = measured amount of diluted exhaust over the test interval as determined in § 1065.642.

n_{dil} = measured amount of dilution air over the test interval as determined in § 1065.667(b).

$x_{\text{CO}_2\text{int}}$ = amount of intake air CO_2 per mole of intake air.

Example:

$$M_C = 12.0107 \text{ g/mol}$$

$$n_{\text{dexh}} = 942930 \text{ mol}$$

$$n_{\text{dil}} = 880068 \text{ mol}$$

$$x_{\text{CO}_2\text{int}} = 369 \mu\text{mol/mol} = 0.000369 \text{ mol/mol}$$

$$m_{\text{Cair}} = 12.0107 \cdot (942930 - 880068) \cdot 0.000369 = 278.6 \text{ g}$$

(5) Determined m_{Cair} based on ECM signals for intake air flow as described in paragraph (b)(1) of this section.

(6) If you measure diluted exhaust, determine m_{Cair} as described in paragraph (b)(4) of this section using a calculated amount of dilution air over the test interval as determined in § 1065.667(d) instead of the measured amount of dilution air.

(c) *Exhaust emissions.* Calculate the mass of carbon in exhaust emissions, m_{Cexh} , for each test interval as follows:

$$m_{\text{Cexh}} = M_{\text{C}} \cdot \left(\frac{m_{\text{CO}_2}}{M_{\text{CO}_2}} + \frac{m_{\text{CO}}}{M_{\text{CO}}} + \frac{m_{\text{THC}}}{M_{\text{THC}}} \right)$$

Eq. 1065.643-6

Where:

M_{C} = molar mass of carbon.

m_{CO_2} = mass of CO_2 over the test interval as determined in § 1065.650(c).

M_{CO_2} = molar mass of carbon dioxide.

m_{CO} = mass of CO over the test interval as determined in § 1065.650(c).

M_{CO} = molar mass of carbon monoxide.

m_{THC} = mass of THC over the test interval as determined in § 1065.650(c).

M_{THC} = effective C_1 molar mass of total hydrocarbon as defined in § 1065.1005(f)(2).

Example:

$$M_{\text{C}} = 12.0107 \text{ g/mol}$$

$$m_{\text{CO}_2} = 4567 \text{ g}$$

$$M_{\text{CO}_2} = 44.0095 \text{ g/mol}$$

$$m_{\text{CO}} = 0.803 \text{ g}$$

$$M_{\text{CO}} = 28.0101 \text{ g/mol}$$

$$m_{\text{THC}} = 0.537 \text{ g}$$

$$M_{\text{THC}} = 13.875389 \text{ g/mol}$$

$$m_{\text{Cexh}} = 12.0107 \cdot \left(\frac{4567}{44.0095} + \frac{0.803}{28.0101} + \frac{0.537}{13.875389} \right) = 1247.2 \text{ g}$$

(d) *Carbon balance error quantities.* Calculate carbon balance error quantities as follows:

(1) Calculate carbon mass absolute error, ϵ_{aC} , for a test interval as follows:

$$\epsilon_{\text{aC}} = m_{\text{Cexh}} - m_{\text{Cfluid}} - m_{\text{Cair}}$$

Eq. 1065.643-7

Where:

m_{Cexh} = mass of carbon in exhaust emissions over the test interval as determined in paragraph (d) of this section.

m_{Cfluid} = mass of carbon in all the carbon-carrying fluid streams flowing into the system over the test interval as determined in paragraph (a) of this section.

m_{Cair} = mass of carbon in the intake air flowing into the system over the test interval as determined in paragraph (b) of this section.

Example:

$$m_{\text{Cexh}} = 1247.2 \text{ g}$$

$$m_{\text{Cfluid}} = 975.3 \text{ g}$$

$$m_{\text{Cair}} = 278.6 \text{ g}$$

$$\epsilon_{\text{aC}} = 1247.2 - 975.3 - 278.6$$

$$\epsilon_{\text{aC}} = -6.7 \text{ g}$$

(2) Calculate carbon mass rate absolute error, ϵ_{aCrate} , for a test interval as follows:

$$\epsilon_{\text{aCrate}} = \frac{\epsilon_{\text{aC}}}{t}$$

Eq. 1065.643-8

Where:

t = duration of the test interval.

Example:

$$\epsilon_{\text{aC}} = -6.7 \text{ g}$$

$$t = 1202.2 \text{ s} = 0.3339 \text{ hr}$$

$$\epsilon_{\text{aCrate}} = \frac{-6.7}{0.3339}$$

$$\epsilon_{\text{aCrate}} = -20.065 \text{ g/hr}$$

(3) Calculate carbon mass relative error, ϵ_{rC} , for a test interval as follows:

$$\epsilon_{\text{rC}} = \frac{\epsilon_{\text{aC}}}{m_{\text{Cfluid}} + m_{\text{Cair}}}$$

Eq. 1065.643-9

Example:

$$\epsilon_{\text{aC}} = -6.7 \text{ g}$$

$$m_{\text{Cfluid}} = 975.3 \text{ g}$$

$$m_{\text{Cair}} = 278.6 \text{ g}$$

$$\epsilon_{\text{rC}} = \frac{-6.7}{975.3 + 278.6}$$

$$\epsilon_{\text{rC}} = -0.0053$$

(4) Calculate composite carbon mass relative error, ϵ_{rCcomp} , for a duty cycle with multiple test intervals as follows:

(i) Calculate ϵ_{rCcomp} using the following equation:

$$\epsilon_{\text{rCcomp}} = \frac{\sum_{i=1}^N WF_i \cdot \frac{(m_{\text{Cexhi}} - m_{\text{Cfluidi}} - m_{\text{Cairi}})}{t_i}}{\sum_{i=1}^N WF_i \cdot \frac{(m_{\text{Cfluidi}} + m_{\text{Cairi}})}{t_i}}$$

Eq. 1065.643-10

Where:

i = an indexing variable that represents one test interval.

N = number of test intervals.

WF = weighting factor for the test interval as defined in the standard-setting part.

m_{Cexh} = mass of carbon in exhaust emissions over the test interval as determined in paragraph (c) of this section.

m_{Cfluid} = mass of carbon in all the carbon-carrying fluid streams that flowed into the system over the test interval as determined in paragraph (a) of this section.

m_{Cair} = mass of carbon in the intake air that flowed into the system over the test interval as determined in paragraph (b) of this section.

t = duration of the test interval. For duty cycles with multiple test intervals of a prescribed duration, such as cold-start and hot-start transient cycles, set $t = 1$ for all test intervals.

For discrete-mode steady-state duty cycles with multiple test intervals of varying duration, set t equal to the actual duration of each test interval.

(ii) The following example illustrates calculation of ϵ_{rCcomp} , for cold-start and hot-start transient cycles:

$$N = 2$$

$$WF_1 = 1/7$$

$$WF_2 = 6/7$$

$$m_{Cexh1} = 1255.3 \text{ g}$$

$$m_{Cexh2} = 1247.2 \text{ g}$$

$$m_{Cfluid1} = 977.8 \text{ g}$$

$$m_{Cfluid2} = 975.3 \text{ g}$$

$$m_{Cair1} = 280.2 \text{ g}$$

$$m_{Cair2} = 278.6 \text{ g}$$

$$\epsilon_{rCcomp} = \frac{\frac{1}{7} \cdot \frac{(1255.3 - 977.8 - 280.2)}{1} + \frac{6}{7} \cdot \frac{(1247.2 - 975.3 - 278.6)}{1}}{\frac{1}{7} \cdot \frac{(977.8 + 280.2)}{1} + \frac{6}{7} \cdot \frac{(975.3 + 278.6)}{1}}$$

$$\epsilon_{rCcomp} = -0.0049$$

(iii) The following example illustrates calculation of ϵ_{rCcomp} for multiple test intervals with varying duration, such as discrete-mode steady-state duty cycles:

$$N = 2$$

$$WF_1 = 0.85$$

$$WF_2 = 0.15$$

$$m_{Cexh1} = 2.873 \text{ g}$$

$$m_{Cexh2} = 0.125 \text{ g}$$

$$m_{Cfluid1} = 2.864 \text{ g}$$

$$m_{Cfluid2} = 0.095 \text{ g}$$

$$m_{Cair1} = 0.023 \text{ g}$$

$$m_{Cair2} = 0.024 \text{ g}$$

$$t_1 = 123 \text{ s}$$

$$t_2 = 306 \text{ s}$$

$$\epsilon_{rCcomp} = \frac{0.85 \cdot \left(\frac{2.873 - 2.864 - 0.023}{123} \right) + 0.15 \cdot \left(\frac{0.125 - 0.095 - 0.024}{306} \right)}{0.85 \cdot \left(\frac{2.864 + 0.023}{123} \right) + 0.15 \cdot \left(\frac{0.095 + 0.024}{306} \right)}$$

$$\epsilon_{rC\text{comp}} = -0.0047$$

§ 1065.644 Vacuum-decay leak rate.

This section describes how to calculate the leak rate of a vacuum-decay leak verification, which is described in § 1065.345(e). Use the following equation to calculate the leak rate, \dot{n}_{leak} , and compare it to the criterion specified in § 1065.345(e):

$$\dot{n}_{\text{leak}} = \frac{V_{\text{vac}}}{R} \cdot \frac{\left(\frac{p_2}{T_2} - \frac{p_1}{T_1}\right)}{(t_2 - t_1)}$$

Eq. 1065.644-1

Where:

V_{vac} = geometric volume of the vacuum-side of the sampling system.

R = molar gas constant.

p_2 = vacuum-side absolute pressure at time t_2 .

T_2 = vacuum-side absolute temperature at time t_2 .

p_1 = vacuum-side absolute pressure at time t_1 .

T_1 = vacuum-side absolute temperature at time t_1 .

t_2 = time at completion of vacuum-decay leak verification test.

t_1 = time at start of vacuum-decay leak verification test.

Example:

$$V_{\text{vac}} = 2.0000 \text{ L} = 0.00200 \text{ m}^3$$

$$R = 8.314472 \text{ J}/(\text{mol} \cdot \text{K}) = 8.314472 \text{ (m}^2 \cdot \text{kg)} / (\text{s}^2 \cdot \text{mol} \cdot \text{K})$$

$$p_2 = 50.600 \text{ kPa} = 50600 \text{ Pa} = 50600 \text{ kg}/(\text{m} \cdot \text{s}^2)$$

$$T_2 = 293.15 \text{ K}$$

$$p_1 = 25.300 \text{ kPa} = 25300 \text{ Pa} = 25300 \text{ kg}/(\text{m} \cdot \text{s}^2)$$

$$T_1 = 293.15 \text{ K}$$

$$t_2 = 10:57:35 \text{ AM}$$

$$t_1 = 10:56:25 \text{ AM}$$

$$\dot{n}_{\text{leak}} = \frac{0.0002}{8.314472} \cdot \frac{\left(\frac{50600}{293.15} - \frac{25300}{293.15}\right)}{(10:57:35 - 10:56:25)}$$

$$\dot{n}_{\text{leak}} = \frac{0.00200}{8.314472} \cdot \frac{86.304}{70}$$

$$\dot{n}_{\text{leak}} = 0.00030 \text{ mol/s}$$

§ 1065.645 Amount of water in an ideal gas.

This section describes how to determine the amount of water in an ideal gas, which you need for various performance verifications and emission calculations. Use the equation for the vapor pressure of water in paragraph (a) of this section or another appropriate equation and, depending on whether you measure dewpoint or relative humidity, perform one of the calculations in paragraph (b) or (c) of this section. Paragraph (d) of this section provides an equation for

determining dewpoint from relative humidity and dry bulb temperature measurements. The equations for the vapor pressure of water as presented in this section are derived from equations in “Saturation Pressure of Water on the New Kelvin Temperature Scale” (Goff, J.A., Transactions American Society of Heating and Air-Conditioning Engineers, Vol. 63, No. 1607, pages 347 – 354). Note that the equations were originally published to derive vapor pressure in units of atmospheres and have been modified to derive results in units of kPa by converting the last term in each equation.

(a) *Vapor pressure of water.* Calculate the vapor pressure of water for a given saturation temperature condition, T_{sat} , as follows, or use good engineering judgment to use a different relationship of the vapor pressure of water to a given saturation temperature condition:

(1) For humidity measurements made at ambient temperatures from (0 to 100) °C, or for humidity measurements made over super-cooled water at ambient temperatures from (–50 to 0) °C, use the following equation:

$$\log_{10}(p_{\text{H}_2\text{O}}) = 10.79574 \cdot \left(1 - \frac{273.16}{T_{\text{sat}}}\right) - 5.02800 \cdot \log_{10}\left(\frac{T_{\text{sat}}}{273.16}\right) + 1.50475 \cdot 10^{-4} \cdot$$

$$\left(1 - 10^{-8.2969 \cdot \left(\frac{T_{\text{sat}}}{273.16} - 1\right)}\right) + 0.42873 \cdot 10^{-3} \cdot \left(10^{4.76955 \cdot \left(1 - \frac{273.16}{T_{\text{sat}}}\right)} - 1\right) - 0.2138602$$

Eq. 1065.645-1

Where:

$p_{\text{H}_2\text{O}}$ = vapor pressure of water at saturation temperature condition, kPa.

T_{sat} = saturation temperature of water at measured conditions, K.

Example:

$$T_{\text{sat}} = 9.5 \text{ °C} = 282.65 \text{ K}$$

$$\begin{aligned} \log_{10}(p_{\text{H}_2\text{O}}) &= 10.79574 \cdot \left(1 - \frac{273.16}{282.65}\right) - 5.02800 \cdot \log_{10}\left(\frac{282.65}{273.16}\right) + 1.50475 \cdot 10^{-4} \\ &\quad \cdot \left(1 - 10^{-8.2969 \cdot \left(\frac{282.65}{273.16} - 1\right)}\right) + 0.42873 \cdot 10^{-3} \cdot \left(10^{4.76955 \cdot \left(1 - \frac{273.16}{282.65}\right)} - 1\right) \\ &\quad - 0.2138602 \end{aligned}$$

$$\log_{10}(p_{\text{H}_2\text{O}}) = 0.074297$$

$$p_{\text{H}_2\text{O}} = 10^{0.074297} = 1.186581 \text{ kPa}$$

(2) For humidity measurements over ice at ambient temperatures from (–100 to 0) °C, use the following equation:

$$\begin{aligned} \log_{10}(p_{\text{H}_2\text{O}}) &= -9.096853 \cdot \left(\frac{273.16}{T_{\text{sat}}} - 1\right) - 3.566506 \cdot \log_{10}\left(\frac{273.16}{T_{\text{sat}}}\right) + 0.876812 \\ &\quad \cdot \left(1 - \frac{T_{\text{sat}}}{273.16}\right) - 0.2138602 \end{aligned}$$

Eq. 1065.645-2

Example:

$$T_{\text{ice}} = -15.4 \text{ °C} = 257.75 \text{ K}$$

$$\log_{10}(p_{\text{H}_2\text{O}}) = -9.096853 \cdot \left(\frac{273.16}{257.75} - 1\right) - 3.566506 \cdot \log_{10}\left(\frac{273.16}{257.75}\right) + 0.876812$$

$$\cdot \left(1 - \frac{257.75}{273.16}\right) - 0.2138602$$

$$\log_{10}(p_{\text{H}_2\text{O}}) = -0.798207$$

$$p_{\text{H}_2\text{O}} = 10^{-0.79821} = 0.159145 \text{ kPa}$$

(b) *Dewpoint*. If you measure humidity as a dewpoint, determine the amount of water in an ideal gas, $x_{\text{H}_2\text{O}}$, as follows:

$$x_{\text{H}_2\text{O}} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{abs}}}$$

Eq. 1065.645-3

Where:

$x_{\text{H}_2\text{O}}$ = amount of water in an ideal gas.

$p_{\text{H}_2\text{O}}$ = water vapor pressure at the measured dewpoint, $T_{\text{sat}} = T_{\text{dew}}$.

p_{abs} = wet static absolute pressure at the location of your dewpoint measurement.

Example:

$$p_{\text{abs}} = 99.980 \text{ kPa}$$

$$T_{\text{sat}} = T_{\text{dew}} = 9.5 \text{ }^\circ\text{C}$$

Using Eq. 1065.645-1,

$$p_{\text{H}_2\text{O}} = 1.186581 \text{ kPa}$$

$$x_{\text{H}_2\text{O}} = 1.186581 / 99.980$$

$$x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$$

(c) *Relative humidity*. If you measure humidity as a relative humidity, RH, determine the amount of water in an ideal gas, $x_{\text{H}_2\text{O}}$, as follows:

$$x_{\text{H}_2\text{O}} = \frac{RH \cdot p_{\text{H}_2\text{O}}}{p_{\text{abs}}}$$

Eq. 1065.645-4

Where:

$x_{\text{H}_2\text{O}}$ = amount of water in an ideal gas.

RH = relative humidity.

$p_{\text{H}_2\text{O}}$ = water vapor pressure at 100 % relative humidity at the location of your relative humidity measurement, $T_{\text{sat}} = T_{\text{amb}}$.

p_{abs} = wet static absolute pressure at the location of your relative humidity measurement.

Example:

$$RH = 50.77 \% = 0.5077$$

$$p_{\text{abs}} = 99.980 \text{ kPa}$$

$$T_{\text{sat}} = T_{\text{amb}} = 20 \text{ }^\circ\text{C}$$

Using Eq. 1065.645-1,

$$p_{\text{H}_2\text{O}} = 2.3371 \text{ kPa}$$

$$x_{\text{H}_2\text{O}} = (0.5077 \cdot 2.3371) / 99.980$$

$$x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$$

(d) *Dewpoint determination from relative humidity and dry bulb temperature.* This paragraph (d) describes how to calculate dewpoint temperature from relative humidity, *RH*. This is based on “ITS-90 Formulations for Vapor Pressure, Frostpoint Temperature, Dewpoint Temperature, and Enhancement Factors in the Range –100 to +100 °C” (Hardy, B., The Proceedings of the Third International Symposium on Humidity & Moisture, Teddington, London, England, April 1998). Calculate $p_{\text{H}_2\text{Osat}}$ as described in paragraph (a) of this section based on setting T_{sat} equal to T_{amb} . Calculate $p_{\text{H}_2\text{Oscaled}}$ by multiplying $p_{\text{H}_2\text{Osat}}$ by *RH*. Calculate the dewpoint, T_{dew} , from $p_{\text{H}_2\text{O}}$ using the following equation:

$$T_{\text{dew}} = \frac{2.0798233 \cdot 10^2 - 2.0156028 \cdot 10^1 \cdot \ln(p_{\text{H}_2\text{O}}) + 4.6778925 \cdot 10^{-1} \cdot \ln(p_{\text{H}_2\text{O}})^2 - 9.2288067 \cdot 10^{-6} \cdot \ln(p_{\text{H}_2\text{O}})^3}{1 - 1.3319669 \cdot 10^{-1} \cdot \ln(p_{\text{H}_2\text{O}}) + 5.6577518 \cdot 10^{-3} \cdot \ln(p_{\text{H}_2\text{O}})^2 - 7.5172865 \cdot 10^{-5} \cdot \ln(p_{\text{H}_2\text{O}})^3}$$

Eq. 1065.645-5

Where:

$\ln(p_{\text{H}_2\text{O}})$ = the natural log of $p_{\text{H}_2\text{Oscaled}}$, which is the water vapor pressure scaled to the relative humidity at the location of the relative humidity measurement, $T_{\text{sat}} = T_{\text{amb}}$.

Example:

$$RH = 39.61 \% = 0.3961$$

$$T_{\text{sat}} = T_{\text{amb}} = 20.00 \text{ °C} = 293.15\text{K}$$

Using Eq. 1065.645-1,

$$p_{\text{H}_2\text{Osat}} = 2.3371 \text{ kPa}$$

$$p_{\text{H}_2\text{Oscaled}} = (0.3961 \cdot 2.3371) = 0.925717 \text{ kPa} = 925.717 \text{ Pa}$$

$$T_{\text{dew}} = \frac{2.0798233 \cdot 10^2 - 2.0156028 \cdot 10^1 \cdot \ln(925.717) + 4.6778925 \cdot 10^{-1} \cdot \ln(925.717)^2 - 9.2288067 \cdot 10^{-6} \cdot \ln(925.717)^3}{1 - 1.3319669 \cdot 10^{-1} \cdot \ln(925.717) + 5.6577518 \cdot 10^{-3} \cdot \ln(925.717)^2 - 7.5172865 \cdot 10^{-5} \cdot \ln(925.717)^3}$$

$$T_{\text{dew}} = 279.00 \text{ K} = 5.85 \text{ °C}$$

§ 1065.650 Emission calculations.

(a) *General.* Calculate brake-specific emissions over each applicable duty cycle or test interval. For test intervals with zero work (or power), calculate the emission mass (or mass rate), but do not calculate brake-specific emissions. Unless specified otherwise, for the purposes of calculating and reporting emission mass (or mass rate), do not alter any negative values of measured or calculated quantities. You may truncate negative values in chemical balance quantities listed in § 1065.655(c) to facilitate convergence. For duty cycles with multiple test intervals, refer to the standard-setting part for calculations you need to determine a composite result, such as a calculation that weights and sums the results of individual test intervals in a duty cycle. If the standard-setting part does not include those calculations, use the equations in paragraph (g) of this section. This section is written based on rectangular integration, where each indexed value (i.e., “i”) represents (or approximates) the mean value of the parameter for its

respective time interval, delta-t. You may also integrate continuous signals using trapezoidal integration consistent with good engineering judgment.

(b) *Brake-specific emissions over a test interval.* We specify three alternative ways to calculate brake-specific emissions over a test interval, as follows:

(1) For any testing, you may calculate the total mass of emissions, as described in paragraph (c) of this section, and divide it by the total work generated over the test interval, as described in paragraph (d) of this section, using the following equation:

$$e = \frac{m}{W}$$

Eq. 1065.650-1

Example:

$$m_{\text{NO}_x} = 64.975 \text{ g}$$

$$W = 25.783 \text{ kW}\cdot\text{hr}$$

$$e_{\text{NO}_x} = 64.975/25.783$$

$$e_{\text{NO}_x} = 2.520 \text{ g}/(\text{kW}\cdot\text{hr})$$

(2) For discrete-mode steady-state testing, you may calculate the brake-specific emissions over a test interval using the ratio of emission mass rate to power, as described in paragraph (e) of this section, using the following equation:

$$e = \frac{\dot{m}}{P}$$

Eq. 1065.650-2

(3) For field testing, you may calculate the ratio of total mass to total work, where these individual values are determined as described in paragraph (f) of this section. You may also use this approach for laboratory testing, consistent with good engineering judgment. Good engineering judgment dictates that this method not be used if there are any work flow paths described in § 1065.210 that cross the system boundary, other than the primary output shaft (crankshaft). This is a special case in which you use a signal linearly proportional to raw exhaust molar flow rate to determine a value proportional to total emissions. You then use the same linearly proportional signal to determine total work using a chemical balance of fuel, DEF, intake air, and exhaust as described in § 1065.655, plus information about your engine's brake-specific fuel consumption. Under this method, flow meters need not meet accuracy specifications, but they must meet the applicable linearity and repeatability specifications in subpart D or J of this part. The result is a brake-specific emission value calculated as follows:

$$e = \frac{\tilde{m}}{\tilde{W}}$$

Eq. 1065.650-3

Example:

$$\tilde{m} = 805.5 \text{ g}$$

$$\tilde{W} = 52.102 \text{ kW}\cdot\text{hr}$$

$$e_{\text{CO}} = 805.5/52.102$$

$$e_{\text{CO}} = 2.520 \text{ g}/(\text{kW}\cdot\text{hr})$$

(c) *Total mass of emissions over a test interval.* To calculate the total mass of an emission, multiply a concentration by its respective flow. For all systems, make preliminary calculations as described in paragraph (c)(1) of this section to correct concentrations. Next, use the method in paragraphs (c)(2) through (4) of this section that is appropriate for your system. Finally, if necessary, calculate the mass of NMHC as described in paragraph (c)(5) of this section for all systems. Calculate the total mass of emissions as follows:

(1) *Concentration corrections.* Perform the following sequence of preliminary calculations on recorded concentrations:

- (i) Use good engineering judgment to time-align flow and concentration data to match transformation time, t_{50} , to within ± 1 s.
- (ii) Correct all gaseous emission analyzer concentration readings, including continuous readings, sample bag readings, and dilution air background readings, for drift as described in § 1065.672. Note that you must omit this step where brake-specific emissions are calculated without the drift correction for performing the drift validation according to § 1065.550(b). When applying the initial THC and CH₄ contamination readings according to § 1065.520(fg), use the same values for both sets of calculations. You may also use as-measured values in the initial set of calculations and corrected values in the drift-corrected set of calculations as described in § 1065.520(fg)(7).
- (iii) Correct all THC and CH₄ concentrations for initial contamination as described in § 1065.660(a), including continuous readings, sample bags readings, and dilution air background readings.
- (iv) Correct all concentrations measured on a “dry” basis to a “wet” basis, including dilution air background concentrations, as described in § 1065.659.
- (v) Calculate all NMHC and CH₄ concentrations, including dilution air background concentrations, as described in § 1065.660.
- (vi) For emission testing with an oxygenated fuel, calculate any HC concentrations, including dilution air background concentrations, as described in § 1065.665. See subpart I of this part for testing with oxygenated fuels.
- (vii) Correct all the NO_x concentrations, including dilution air background concentrations, for intake-air humidity as described in § 1065.670.

(2) *Continuous sampling.* For continuous sampling, you must frequently record a continuously updated concentration signal. You may measure this concentration from a changing flow rate or a constant flow rate (including discrete-mode steady-state testing), as follows:

- (i) *Varying flow rate.* If you continuously sample from a varying exhaust flow rate, time align and then multiply concentration measurements by the flow rate from which you extracted it. We consider the following to be examples of varying flows that require a continuous multiplication of concentration times molar flow rate: raw exhaust, exhaust diluted with a constant flow rate of dilution air, and CVS dilution with a CVS flow meter that does not have an upstream heat exchanger or electronic flow control. This multiplication results in the flow rate of the emission itself. Integrate the emission flow rate over a test interval to determine the total emission. If the total emission is a molar quantity, convert this quantity to a mass by multiplying it by its molar mass, M . The result is the mass of the emission, m . Calculate m for continuous sampling with variable flow using the following equations:

$$m = M \cdot \sum_{i=1}^N x_i \cdot \dot{n}_i \cdot \Delta t$$

Eq. 1065.650-4

Where:

$$\Delta t = 1/f_{\text{record}}$$

Eq. 1065.650-5

Example:

$$M_{\text{NMHC}} = 13.875389 \text{ g/mol}$$

$$N = 1200$$

$$x_{\text{NMHC1}} = 84.5 \text{ } \mu\text{mol/mol} = 84.5 \cdot 10^{-6} \text{ mol/mol}$$

$$x_{\text{NMHC2}} = 86.0 \text{ } \mu\text{mol/mol} = 86.0 \cdot 10^{-6} \text{ mol/mol}$$

$$\dot{n}_{\text{exh1}} = 2.876 \text{ mol/s}$$

$$\dot{n}_{\text{exh2}} = 2.224 \text{ mol/s}$$

$$f_{\text{record}} = 1 \text{ Hz}$$

Using Eq. 1065.650-5,

$$\Delta t = 1/1 = 1 \text{ s}$$

$$m_{\text{NMHC}} = 13.875389 \cdot (84.5 \cdot 10^{-6} \cdot 2.876 + 86.0 \cdot 10^{-6} \cdot 2.224 + \dots + x_{\text{NMHC1200}} \cdot \dot{n}_{\text{exh}}) \cdot 1$$

$$m_{\text{NMHC}} = 25.23 \text{ g}$$

(ii) *Constant flow rate.* If you continuously sample from a constant exhaust flow rate, use the same emission calculations described in paragraph (c)(2)(i) of this section or calculate the mean or flow-weighted concentration recorded over the test interval and treat the mean as a batch sample, as described in paragraph (c)(3)(ii) of this section. We consider the following to be examples of constant exhaust flows: CVS diluted exhaust with a CVS flow meter that has either an upstream heat exchanger, electronic flow control, or both.

(3) *Batch sampling.* For batch sampling, the concentration is a single value from a proportionally extracted batch sample (such as a bag, filter, impinger, or cartridge). In this case, multiply the mean concentration of the batch sample by the total flow from which the sample was extracted. You may calculate total flow by integrating a varying flow rate or by determining the mean of a constant flow rate, as follows:

(i) *Varying flow rate.* If you collect a batch sample from a varying exhaust flow rate, extract a sample proportional to the varying exhaust flow rate. We consider the following to be examples of varying flows that require proportional sampling: raw exhaust, exhaust diluted with a constant flow rate of dilution air, and CVS dilution with a CVS flow meter that does not have an upstream heat exchanger or electronic flow control. Integrate the flow rate over a test interval to determine the total flow from which you extracted the proportional sample. Multiply the mean concentration of the batch sample by the total flow from which the sample was extracted to determine the total emission. If the total emission is a molar quantity, convert this quantity to a mass by multiplying it by its molar mass, M . The result is the total emission mass, m . In the case of PM emissions, where the mean PM concentration is already in units of mass per mole of exhaust, simply multiply

it by the total flow. The result is the total mass of PM, m_{PM} . Calculate m for each constituent as follows:

(A) Calculate m for measuring gaseous emission constituents with sampling that results in a molar concentration, \bar{x} , using the following equation:

$$m = M \cdot \bar{x} \cdot \sum_{i=1}^N \dot{n}_i \cdot \Delta t$$

Eq. 1065.650-6

Example:

$$M_{\text{NO}_x} = 46.0055 \text{ g/mol}$$

$$N = 9000$$

$$\bar{x}_{\text{NO}_x} = 85.6 \text{ } \mu\text{mol/mol} = 85.6 \cdot 10^{-6} \text{ mol/mol}$$

$$\dot{n}_{\text{dexh1}} = 25.534 \text{ mol/s}$$

$$\dot{n}_{\text{dexh2}} = 26.950 \text{ mol/s}$$

$$f_{\text{record}} = 5 \text{ Hz}$$

Using Eq. 1065.650-5:

$$\Delta t = 1/5 = 0.2 \text{ s}$$

$$m_{\text{NO}_x} = 46.0055 \cdot 85.6 \cdot 10^{-6} \cdot (25.534 + 26.950 + \dots + \dot{n}_{\text{exh9000}}) \cdot 0.2$$

$$m_{\text{NO}_x} = 4.201 \text{ g}$$

(B) Calculate m for sampling PM or any other analysis of a batch sample that yields a mass per mole of exhaust, \bar{M} , using the following equation:

$$m = \bar{M} \cdot \sum_{i=1}^N \dot{n}_i \cdot \Delta t$$

Eq. 1065.650-7

(ii) *Proportional or constant flow rate.* If you batch sample from a constant exhaust flow rate, extract a sample at a proportional or constant flow rate. We consider the following to be examples of constant exhaust flows: CVS diluted exhaust with a CVS flow meter that has either an upstream heat exchanger, electronic flow control, or both. Determine the mean molar flow rate from which you extracted the sample. Multiply the mean concentration of the batch sample by the mean molar flow rate of the exhaust from which the sample was extracted to determine the total emission and multiply the result by the time of the test interval. If the total emission is a molar quantity, convert this quantity to a mass by multiplying it by its molar mass, M . The result is the total emission mass, m . In the case of PM emissions, where the mean PM concentration is already in units of mass per mole of exhaust, simply multiply it by the total flow, and the result is the total mass of PM, m_{PM} . Calculate m for each constituent as follows:

(A) Calculate m for measuring gaseous emission constituents with sampling that results in a molar concentration, \bar{x} , using the following equation:

$$m = M \cdot \bar{x} \cdot \bar{n} \cdot \Delta t$$

Eq. 1065.650-8

(B) Calculate m for sampling PM or any other analysis of a batch sample that yields a mass per mole of exhaust, \bar{M} , using the following equation:

$$m = \bar{M} \cdot \dot{n} \cdot \Delta t$$

Eq. 1065.650-9

(C) The following example illustrates a calculation of m_{PM} :

$$\bar{M}_{\text{PM}} = 144.0 \text{ } \mu\text{g/mol} = 144.0 \cdot 10^{-6} \text{ g/mol}$$

$$\dot{n}_{\text{dexh}} = 57.692 \text{ mol/s}$$

$$\Delta t = 1200 \text{ s}$$

$$m_{\text{PM}} = 144.0 \cdot 10^{-6} \cdot 57.692 \cdot 1200$$

$$m_{\text{PM}} = 9.9692 \text{ g}$$

(4) *Additional provisions for diluted exhaust sampling; continuous or batch.* The following additional provisions apply for sampling emissions from diluted exhaust:

(i) For sampling with a constant dilution ratio, DR , of diluted exhaust versus exhaust flow (e.g., secondary dilution for PM sampling), calculate m using the following equation:

$$m_{\text{PM}} = m_{\text{PMdil}} \cdot DR$$

Eq. 1065.650-10

Example:

$$m_{\text{PMdil}} = 6.853 \text{ g}$$

$$DR = 6:1$$

$$m_{\text{PM}} = 6.853 \cdot 6$$

$$m_{\text{PM}} = 41.118 \text{ g}$$

(ii) For continuous or batch sampling, you may measure background emissions in the dilution air. You may then subtract the measured background emissions, as described in § 1065.667.

(5) *Mass of NMHC.* Compare the corrected mass of NMHC to corrected mass of THC. If the corrected mass of NMHC is greater than 0.98 times the corrected mass of THC, take the corrected mass of NMHC to be 0.98 times the corrected mass of THC. If you omit the NMHC calculations as described in § 1065.660(b)(1), take the corrected mass of NMHC to be 0.98 times the corrected mass of THC.

(6) *Mass of NMNEHC.* Determine the mass of NMNEHC using one of the following methods:

(i) If the test fuel has less than 0.010 mol/mol of ethane and you omit the NMNEHC calculations as described in § 1065.660(c)(1), take the corrected mass of NMNEHC to be 0.95 times the corrected mass of NMHC.

(ii) If the test fuel has at least 0.010 mol/mol of ethane and you omit the NMNEHC calculations as described in § 1065.660(c)(1), take the corrected mass of NMNEHC to be 1.0 times the corrected mass of NMHC.

(d) *Total work over a test interval.* To calculate the total work from the engine over a test interval, add the total work from all the work paths described in § 1065.210 that cross the system boundary including electrical energy/work, mechanical shaft work, and fluid pumping work. For all work paths, except the engine's primary output shaft (crankshaft), the total work for the path over the test interval is the integration of the net work flow rate (power) out of the system

boundary. When energy/work flows into the system boundary, this work flow rate signal becomes negative; in this case, include these negative work rate values in the integration to calculate total work from that work path. Some work paths may result in a negative total work. Include negative total work values from any work path in the calculated total work from the engine rather than setting the values to zero. The rest of this paragraph (d) describes how to calculate total work from the engine’s primary output shaft over a test interval. Before integrating power on the engine’s primary output shaft, adjust the speed and torque data for the time alignment used in § 1065.514(c). Any advance or delay used on the feedback signals for cycle validation must also be used for calculating work. Account for work of accessories according to § 1065.110. Exclude any work during cranking and starting. Exclude work during actual motoring operation (negative feedback torques), unless the engine was connected to one or more energy storage devices. Examples of such energy storage devices include hybrid powertrain batteries and hydraulic accumulators, like the ones illustrated in Figure 1 of § 1065.210. Exclude any work during reference zero-load idle periods (0 % speed or idle speed with 0 N·m reference torque). Note, that there must be two consecutive reference zero load idle points to establish a period where the zero-load exclusion applies. Include work during idle points with simulated minimum torque such as Curb Idle Transmissions Torque (CITT) for automatic transmissions in “drive”. The work calculation method described in paragraphs (d)(1) through (7) of this section meets these requirements of this paragraph (d) using rectangular integration. You may use other logic that gives equivalent results. For example, you may use a trapezoidal integration method as described in paragraph (d)(8) of this section.

- (1) Time align the recorded feedback speed and torque values by the amount used in § 1065.514(c).
- (2) Calculate shaft power at each point during the test interval by multiplying all the recorded feedback engine speeds by their respective feedback torques.
- (3) Adjust (reduce) the shaft power values for accessories according to § 1065.110.
- (4) Set all power values during any cranking or starting period to zero. See § 1065.525 for more information about engine cranking.
- (5) Set all negative power values to zero, unless the engine was connected to one or more energy storage devices. If the engine was tested with an energy storage device, leave negative power values unaltered.
- (6) Set all power values to zero during idle periods with a corresponding reference torque of 0 N·m.
- (7) Integrate the resulting values for power over the test interval. Calculate total work as follows:

$$W = \sum_{i=1}^N P_i \cdot \Delta t$$

Eq. 1065.650-11

Where:

W = total work from the primary output shaft.

P_i = instantaneous power from the primary output shaft over an interval i .

$P_i = f_{ni} \cdot T_i$

Eq. 1065.650-12

Example:

$$\begin{aligned}
N &= 9000 \\
f_{n1} &= 1800.2 \text{ r/min} \\
f_{n2} &= 1805.8 \text{ r/min} \\
T_1 &= 177.23 \text{ N}\cdot\text{m} \\
T_2 &= 175.00 \text{ N}\cdot\text{m} \\
C_{\text{rev}} &= 2\cdot\pi \text{ rad/r} \\
C_{t1} &= 60 \text{ s/min} \\
C_p &= 1000 \text{ (N}\cdot\text{m}\cdot\text{rad/s)/kW} \\
f_{\text{record}} &= 5 \text{ Hz} \\
C_{t2} &= 3600 \text{ s/hr} \\
P_1 &= \frac{1800.2 \cdot 177.23 \cdot 2 \cdot 3.14159}{60 \cdot 1000} \\
P_1 &= 33.41 \text{ kW} \\
P_2 &= 33.09 \text{ kW}
\end{aligned}$$

Using Eq. 1065.650-5:

$$\begin{aligned}
\Delta t &= 1/5 = 0.2 \text{ s} \\
W &= \frac{(33.41 + 33.09 + \dots + P_{9000}) \cdot 0.2}{3600} \\
W &= 16.875 \text{ kW}\cdot\text{hr}
\end{aligned}$$

(8) You may use a trapezoidal integration method instead of the rectangular integration described in this paragraph (d). To do this, you must integrate the fraction of work between points where the torque is positive. You may assume that speed and torque are linear between data points. You may not set negative values to zero before running the integration.

(e) *Steady-state mass rate divided by power.* To determine steady-state brake-specific emissions for a test interval as described in paragraph (b)(2) of this section, calculate the mean steady-state mass rate of the emission, \bar{m} , and the mean steady-state power, \bar{P} , as follows:

(1) To calculate, \bar{m} , multiply its mean concentration, \bar{x} , by its corresponding mean molar flow rate, \bar{n} . If the result is a molar flow rate, convert this quantity to a mass rate by multiplying it by its molar mass, M . The result is the mean mass rate of the emission, \bar{m} . In the case of PM emissions, where the mean PM concentration is already in units of mass per mole of exhaust, simply multiply it by the mean molar flow rate, \bar{n} . The result is the mass rate of PM, \dot{m}_{PM} . Calculate \bar{m} using the following equation:

$$\bar{m} = M \cdot \bar{x} \cdot \bar{n}$$

Eq. 1065.650-13

(2) To calculate an engine's mean steady-state total power, \bar{P} , add the mean steady-state power from all the work paths described in § 1065.210 that cross the system boundary including electrical power, mechanical shaft power, and fluid pumping power. For all work paths, except the engine's primary output shaft (crankshaft), the mean steady-state power over the test interval is the integration of the net work flow rate (power) out of the system boundary divided by the period of the test interval. When power flows into the system boundary, the power/work flow rate signal becomes negative; in this case, include these negative power/work rate values in the integration to calculate the mean power from that work path. Some work paths may result in a negative mean power. Include negative mean

power values from any work path in the mean total power from the engine rather than setting these values to zero. The rest of this paragraph (e)(2) describes how to calculate the mean power from the engine's primary output shaft. Calculate \bar{P} using Eq. 1065.650-13, noting that \bar{P} , \bar{f}_n , and \bar{T} refer to mean power, mean rotational shaft frequency, and mean torque from the primary output shaft. Account for the power of simulated accessories according to § 1065.110 (reducing the mean primary output shaft power or torque by the accessory power or torque). Set the power to zero during actual motoring operation (negative feedback torques), unless the engine was connected to one or more energy storage devices. Examples of such energy storage devices include hybrid powertrain batteries and hydraulic accumulators, like the ones denoted "Acc." and "Batt." as illustrated in Figure 1 of § 1065.210. Set the power to zero for modes with a zero reference load (0 N·m reference torque or 0 kW reference power). Include power during idle modes with simulated minimum torque or power.

$$\bar{P} = \bar{f}_n \cdot \bar{T}$$

Eq. 1065.650-14

(3) Divide emission mass rate by power to calculate a brake-specific emission result as described in paragraph (b)(2) of this section.

(4) The following example shows how to calculate mass of emissions using mean mass rate and mean power:

$$M_{CO} = 28.0101 \text{ g/mol}$$

$$\bar{x}_{CO} = 12.00 \text{ mmol/mol} = 0.01200 \text{ mol/mol}$$

$$\bar{\dot{n}} = 1.530 \text{ mol/s}$$

$$\bar{f}_n = 3584.5 \text{ r/min} = 375.37 \text{ rad/s}$$

$$\bar{T} = 121.50 \text{ N}\cdot\text{m}$$

$$\bar{\dot{m}} = 28.0101 \cdot 0.01200 \cdot 1.530$$

$$\bar{\dot{m}} = 0.514 \text{ g/s} = 1850.4 \text{ g/hr}$$

$$\bar{P} = 121.5 \cdot 375.37$$

$$\bar{P} = 45607 \text{ W}$$

$$\bar{P} = 45.607 \text{ kW}$$

$$eco = 1850.4/45.61$$

$$eco = 40.57 \text{ g/(kW}\cdot\text{hr)}$$

(f) *Ratio of total mass of emissions to total work.* To determine brake-specific emissions for a test interval as described in paragraph (b)(3) of this section, calculate a value proportional to the total mass of each emission. Divide each proportional value by a value that is similarly proportional to total work.

(1) *Total mass.* To determine a value proportional to the total mass of an emission, determine total mass as described in paragraph (c) of this section, except substitute for the molar flow rate, \dot{n} , or the total flow, n , with a signal that is linearly proportional to molar flow rate, $\tilde{\dot{n}}$, or linearly proportional to total flow, \tilde{n} , as follows:

$$\tilde{m}_{fueli} = \frac{1}{w_{fuel}} \cdot \frac{M_C \cdot \tilde{\dot{n}}_i \cdot x_{Ccombdryi}}{1 + x_{H2Oexhdryi}}$$

Eq. 1065.650-15

(2) *Total work.* To calculate a value proportional to total work over a test interval, integrate a value that is proportional to power. Use information about the brake-specific fuel consumption of your engine, e_{fuel} , to convert a signal proportional to fuel flow rate to a signal proportional to power. To determine a signal proportional to fuel flow rate, divide a signal that is proportional to the mass rate of carbon products by the fraction of carbon in your fuel, w_C . You may use a measured w_C or you may use default values for a given fuel as described in § 1065.655(e). Calculate the mass rate of carbon from the amount of carbon and water in the exhaust, which you determine with a chemical balance of fuel, DEF, intake air, and exhaust as described in § 1065.655. In the chemical balance, you must use concentrations from the flow that generated the signal proportional to molar flow rate, \tilde{n} , in paragraph (e)(1) of this section. Calculate a value proportional to total work as follows:

$$W = \sum_{i=1}^N \tilde{P}_i \cdot \Delta t$$

Eq. 1065.650-16

Where:

$$\tilde{P}_i = \frac{\tilde{m}_{\text{fuel}i}}{e_{\text{fuel}}}$$

Eq. 1065.650-17

(3) *Brake-specific emissions.* Divide the value proportional to total mass by the value proportional to total work to determine brake-specific emissions, as described in paragraph (b)(3) of this section.

(4) *Example.* The following example shows how to calculate mass of emissions using proportional values:

$N = 3000$

$f_{\text{record}} = 5 \text{ Hz}$

$e_{\text{fuel}} = 285 \text{ g/(kW}\cdot\text{hr)}$

$w_{\text{fuel}} = 0.869 \text{ g/g}$

$M_C = 12.0107 \text{ g/mol}$

$\tilde{n}_1 = 3.922 \text{ mol/s} = 14119.2 \text{ mol/hr}$

$x_{\text{Ccombdry1}} = 91.634 \text{ mmol/mol} = 0.091634 \text{ mol/mol}$

$x_{\text{H}_2\text{Oexh1}} = 27.21 \text{ mmol/mol} = 0.02721 \text{ mol/mol}$

Using Eq. 1065.650-5,

$\Delta t = 0.2 \text{ s}$

$$\tilde{W} = \frac{12.0107 \left(\frac{3.922 \cdot 0.091634}{1 + 0.02721} + \frac{\tilde{n}_2 \cdot x_{\text{Ccombdry2}}}{1 + x_{\text{H}_2\text{Oexh2}}} + \dots + \frac{\tilde{n}_{3000} \cdot x_{\text{Ccombdry3000}}}{1 + x_{\text{H}_2\text{Oexh3000}}} \right) \cdot 0.2}{285 \cdot 0.869}$$

$\tilde{W} = 5.09 \text{ (kW}\cdot\text{hr)}$

(g) *Brake-specific emissions over a duty cycle with multiple test intervals.* The standard-setting part may specify a duty cycle with multiple test intervals, such as with discrete-mode steady-state testing. Unless we specify otherwise, calculate composite brake-specific emissions over the duty cycle as described in this paragraph (g). If a measured mass (or mass rate) is negative, set it to zero for calculating composite brake-specific emissions, but leave it unchanged for drift

validation. In the case of calculating composite brake-specific emissions relative to a combined emission standard (such as a NO_x + NMHC standard), change any negative mass (or mass rate) values to zero for a particular pollutant before combining the values for the different pollutants.

(1) Use the following equation to calculate composite brake-specific emissions for duty cycles with multiple test intervals all with prescribed durations, such as cold-start and hot-start transient cycles:

$$e_{\text{comp}} = \frac{\sum_{i=1}^N WF_i \cdot m_i}{\sum_{i=1}^N WF_i \cdot W_i}$$

Eq. 1065.650-18

Where:

i = test interval number.

N = number of test intervals.

WF = weighting factor for the test interval as defined in the standard-setting part.

m = mass of emissions over the test interval as determined in paragraph (c) of this section.

W = total work from the engine over the test interval as determined in paragraph (d) of this section.

Example:

$N = 2$

$WF_1 = 0.1428$

$WF_2 = 0.8572$

$m_1 = 70.125 \text{ g}$

$m_2 = 64.975 \text{ g}$

$W_1 = 25.783 \text{ kW}\cdot\text{hr}$

$W_2 = 25.783 \text{ kW}\cdot\text{hr}$

$$e_{\text{NO}_x\text{comp}} = \frac{(0.1428 \cdot 70.125) + (0.8572 \cdot 64.975)}{(0.1428 \cdot 25.783) + (0.8572 \cdot 25.783)}$$

$e_{\text{NO}_x\text{comp}} = 2.548 \text{ g/kW}\cdot\text{hr}$

(2) Calculate composite brake-specific emissions for duty cycles with multiple test intervals that allow use of varying duration, such as discrete-mode steady-state duty cycles, as follows:

(i) Use the following equation if you calculate brake-specific emissions over test intervals based on total mass and total work as described in paragraph (b)(1) of this section:

$$e_{\text{comp}} = \frac{\sum_{i=1}^N WF_i \cdot \frac{m_i}{t_i}}{\sum_{i=1}^N WF_i \cdot \frac{W_i}{t_i}}$$

Eq. 1065.650-19

Where:

i = test interval number.

N = number of test intervals.

WF = weighting factor for the test interval as defined in the standard-setting part.

m = mass of emissions over the test interval as determined in paragraph (c) of this section.

W = total work from the engine over the test interval as determined in paragraph (d) of this section.

t = duration of the test interval.

Example:

$$N = 2$$

$$WF_1 = 0.85$$

$$WF_2 = 0.15$$

$$m_1 = 1.3753 \text{ g}$$

$$m_2 = 0.4135 \text{ g}$$

$$t_1 = 120 \text{ s}$$

$$t_2 = 200 \text{ s}$$

$$W_1 = 2.8375 \text{ kW}\cdot\text{hr}$$

$$W_2 = 0.0 \text{ kW}\cdot\text{hr}$$

$$e_{\text{NO}_x\text{comp}} = \frac{\left(0.85 \cdot \frac{1.3753}{120}\right) + \left(0.15 \cdot \frac{0.4135}{200}\right)}{\left(0.85 \cdot \frac{2.8375}{120}\right) + \left(0.15 \cdot \frac{0.0}{200}\right)}$$

$$e_{\text{NO}_x\text{comp}} = 0.5001 \text{ g/kW}\cdot\text{hr}$$

(ii) Use the following equation if you calculate brake-specific emissions over test intervals based on the ratio of mass rate to power as described in paragraph (b)(2) of this section:

$$e_{\text{comp}} = \frac{\sum_{i=1}^N WF_i \cdot \bar{m}_i}{\sum_{i=1}^N WF_i \cdot \bar{P}_i}$$

Eq. 1065.650-20

Where:

i = test interval number.

N = number of test intervals.

WF = weighting factor for the test interval as defined in the standard-setting part.

\bar{m} = mean steady-state mass rate of emissions over the test interval as determined in paragraph (e) of this section.

\bar{P} = mean steady-state power over the test interval as described in paragraph (e) of this section.

Example:

$$N = 2$$

$$WF_1 = 0.85$$

$$WF_2 = 0.15$$

$$\bar{m}_1 = 2.25842 \text{ g/hr}$$

$$\bar{m}_2 = 0.063443 \text{ g/hr}$$

$$\bar{P}_1 = 4.5383 \text{ kW}$$

$$\bar{P}_2 = 0.0 \text{ kW}$$

$$e_{\text{NO}_x\text{comp}} = \frac{(0.85 \cdot 2.25842) + (0.15 \cdot 0.063443)}{(0.85 \cdot 4.5383) + (0.15 \cdot 0.0)}$$

$$e_{\text{NOxcomp}} = 0.5001 \text{ g/kW}\cdot\text{hr}$$

(h) *Rounding*. Round the final brake-specific emission values to be compared to the applicable standard only after all calculations are complete (including any drift correction, applicable deterioration factors, adjustment factors, and allowances) and the result is in g/(kW·hr) or units equivalent to the units of the standard, such as g/(hp·hr). See the definition of “Round” in § 1065.1001.

§ 1065.655 Carbon-based cChemical balances of carbon-containing fuel, DEF, intake air, and exhaust.

(a) *General*. Chemical balances of fuel, intake air, and exhaust may be used to calculate flows, the amount of water in their flows, and the wet concentration of constituents in their flows. [See § 1065.520\(f\) for information about when to use this carbon-based chemical balance procedure. Use the chemical balance calculations in this section for carbon containing fuels. For fuels other than carbon-containing fuels use the chemical balance calculations of section § 1065.656.](#) With one flow rate of either fuel, intake air, or exhaust, you may use chemical balances to determine the flows of the other two. For example, you may use chemical balances along with either intake air or fuel flow to determine raw exhaust flow. Note that chemical balance calculations allow measured values for the flow rate of diesel exhaust fluid for engines with urea-based selective catalytic reduction.

(b) *Procedures that require chemical balances*. We require chemical balances when you determine the following:

- (1) A value proportional to total work, \tilde{W} when you choose to determine brake-specific emissions as described in § 1065.650(f).
- (2) Raw exhaust molar flow rate either from measured intake air molar flow rate or from fuel mass flow rate as described in paragraph (f) of this section.
- (3) Raw exhaust molar flow rate from measured intake air molar flow rate and dilute exhaust molar flow rate as described in paragraph (g) of this section.
- (4) The amount of water in a raw or diluted exhaust flow, $x_{\text{H}_2\text{Oexh}}$, when you do not measure the amount of water to correct for the amount of water removed by a sampling system. [Note that you may not use the FTIR-based water measurement methods in § 1065.257 to determine \$x_{\text{H}_2\text{Oexh}}\$.](#) Correct for removed water according to § 1065.659.
- (5) The calculated total dilution air flow when you do not measure dilution air flow to correct for background emissions as described in § 1065.667(c) and (d).

(c) *Chemical balance procedure*. The calculations for a chemical balance involve a system of equations that require iteration. We recommend using a computer to solve this system of equations. You must guess the initial values of up to three quantities: the amount of water in the measured flow, $x_{\text{H}_2\text{Oexh}}$, fraction of dilution air in diluted exhaust, $x_{\text{dil/exh}}$, and the amount of products on a C₁ basis per dry mole of dry measured flow, x_{Ccombdry} . You may use time-weighted mean values of intake air humidity and dilution air humidity in the chemical balance; as long as your intake air and dilution air humidities remain within tolerances of ± 0.0025 mol/mol of their respective mean values over the test interval. For each emission concentration, x , and amount of water, $x_{\text{H}_2\text{Oexh}}$, you must determine their completely dry concentrations, x_{dry} and $x_{\text{H}_2\text{Oexhdry}}$. You must also use your fuel mixture’s atomic hydrogen-to-carbon ratio, α , oxygen-to-carbon ratio, β , sulfur-to-carbon ratio, γ , and nitrogen-to-carbon ratio, δ ; you may optionally account for diesel

exhaust fluid (or other fluids injected into the exhaust), if applicable. You may calculate α , β , γ , and δ based on measured fuel composition or based on measured fuel and diesel exhaust fluid (or other fluids injected into the exhaust) composition together, as described in paragraph (e) of this section. You may alternatively use any combination of default values and measured values as described in paragraph (e) of this section. Use the following steps to complete a chemical balance:

(1) Convert your measured concentrations such as, $x_{\text{CO}_2\text{meas}}$, x_{NOmeas} , and $x_{\text{H}_2\text{Oint}}$, to dry concentrations by dividing them by one minus the amount of water present during their respective measurements; for example: $x_{\text{H}_2\text{OxCO}_2\text{meas}}$, $x_{\text{H}_2\text{OxNOmeas}}$, and $x_{\text{H}_2\text{Oint}}$. If the amount of water present during a “wet” measurement is the same as the unknown amount of water in the exhaust flow, $x_{\text{H}_2\text{Oexh}}$, iteratively solve for that value in the system of equations. If you measure only total NO_x and not NO and NO_2 separately, use good engineering judgment to estimate a split in your total NO_x concentration between NO and NO_2 for the chemical balances. For example, if you measure emissions from a stoichiometric spark-ignition engine, you may assume all NO_x is NO . For a compression-ignition engine, you may assume that your molar concentration of NO_x , x_{NO_x} , is 75 % NO and 25 % NO_2 . For NO_2 storage aftertreatment systems, you may assume x_{NO_x} is 25 % NO and 75 % NO_2 . Note that for calculating the mass of NO_x emissions, you must use the molar mass of NO_2 for the effective molar mass of all NO_x species, regardless of the actual NO_2 fraction of NO_x .

(2) Enter the equations in paragraph (c)(4) of this section into a computer program to iteratively solve for $x_{\text{H}_2\text{Oexh}}$, x_{Ccombdry} , and $x_{\text{dil/exh}}$. Use good engineering judgment to guess initial values for $x_{\text{H}_2\text{Oexh}}$, x_{Ccombdry} , and $x_{\text{dil/exh}}$. We recommend guessing an initial amount of water that is about twice the amount of water in your intake or dilution air. We recommend guessing an initial value of x_{Ccombdry} as the sum of your measured CO_2 , CO , and THC values. We also recommend guessing an initial $x_{\text{dil/exh}}$ between 0.75 and 0.95, such as 0.8. Iterate values in the system of equations until the most recently updated guesses are all within ± 1 % of their respective most recently calculated values.

(3) Use the following symbols and subscripts in the equations for performing the chemical balance calculations in this paragraph (c):

TABLE 1 OF § 1065.655—SYMBOLS AND SUBSCRIPTS FOR CHEMICAL BALANCE EQUATIONS

$x_{\text{dil/exh}}$	amount of dilution gas or excess air per mole of exhaust
$x_{\text{H}_2\text{Oexh}}$	amount of H ₂ O in exhaust per mole of exhaust
x_{Ccombdry}	amount of carbon from fuel and any injected fluids in the exhaust per mole of dry exhaust
$x_{\text{H}_2\text{dry}}$	amount of H ₂ in exhaust per amount of dry exhaust
$K_{\text{H}_2\text{Ogas}}$	water-gas reaction equilibrium coefficient; you may use 3.5 or calculate your own value using good engineering judgment
$x_{\text{H}_2\text{Oexhdry}}$	amount of H ₂ O in exhaust per dry mole of dry exhaust
$x_{\text{prod/intdry}}$	amount of dry stoichiometric products per dry mole of intake air
$x_{\text{dil/exhdry}}$	amount of dilution gas and/or excess air per mole of dry exhaust
$x_{\text{int/exhdry}}$	amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust
$x_{\text{raw/exhdry}}$	amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust
$x_{\text{O}_2\text{int}}$	amount of intake air O ₂ per mole of intake air
$x_{\text{CO}_2\text{intdry}}$	amount of intake air CO ₂ per mole of dry intake air; you may use $x_{\text{CO}_2\text{intdry}} = 375 \mu\text{mol/mol}$, but we recommend measuring the actual concentration in the intake air
$x_{\text{H}_2\text{Ointdry}}$	amount of intake air H ₂ O per mole of dry intake air
$x_{\text{CO}_2\text{int}}$	amount of intake air CO ₂ per mole of intake air
$x_{\text{CO}_2\text{dil}}$	amount of dilution gas CO ₂ per mole of dilution gas
$x_{\text{CO}_2\text{dildry}}$	amount of dilution gas CO ₂ per mole of dry dilution gas; if you use air as diluent, you may use $x_{\text{CO}_2\text{dildry}} = 375 \mu\text{mol/mol}$, but we recommend measuring the actual concentration in the intake air
$x_{\text{H}_2\text{Odildry}}$	amount of dilution gas H ₂ O per mole of dry dilution gas
$x_{\text{H}_2\text{Odil}}$	amount of dilution gas H ₂ O per mole of dilution gas
$x_{\text{[emission]meas}}$	amount of measured emission in the sample at the respective gas analyzer
$x_{\text{[emission]dry}}$	amount of emission per dry mole of dry sample
$x_{\text{H}_2\text{O[emission]meas}}$	amount of H ₂ O in sample at emission-detection location; measure or estimate these values according to § 1065.145(e)(2)
$x_{\text{H}_2\text{Oint}}$	amount of H ₂ O in the intake air, based on a humidity measurement of intake air
α	atomic hydrogen-to-carbon ratio of the fuel (or mixture of test fuels) and any injected fluids
β	atomic oxygen-to-carbon ratio of the fuel (or mixture of test fuels) and any injected fluids
γ	atomic sulfur-to-carbon ratio of the fuel (or mixture of test fuels) and any injected fluids
δ	atomic nitrogen-to-carbon ratio of the fuel (or mixture of test fuels) and any injected fluids

(4) Use the following equations to iteratively solve for $x_{\text{dil/exh}}$, $x_{\text{H}_2\text{Oexh}}$, and x_{Ccombdry} :

$$x_{\text{dil/exh}} = 1 - \frac{x_{\text{raw/exhdry}}}{1 + x_{\text{H}_2\text{Oexhdry}}}$$

Eq. 1065.655-1

$$x_{\text{H}_2\text{Oexh}} = \frac{x_{\text{H}_2\text{Oexhdry}}}{1 + x_{\text{H}_2\text{Oexhdry}}}$$

Eq. 1065.655-2

$$x_{\text{Ccombdry}} = x_{\text{CO}_2\text{dry}} + x_{\text{COdry}} + x_{\text{THCdry}} - x_{\text{CO}_2\text{dil}} \cdot x_{\text{dil/exhdry}} - x_{\text{CO}_2\text{int}} \cdot x_{\text{int/exhdry}}$$

Eq. 1065.655-3

$$x_{\text{H2dry}} = \frac{x_{\text{COdry}} \cdot (x_{\text{H2Oexhdry}} - x_{\text{H2Odil}} \cdot x_{\text{dil/exhdry}})}{K_{\text{H2O-gas}} \cdot (x_{\text{CO2dry}} - x_{\text{CO2dil}} \cdot x_{\text{dil/exhdry}})}$$

Eq. 1065.655-4

$$x_{\text{H2Oexhdry}} = \frac{\alpha}{2} (x_{\text{Ccombdry}} - x_{\text{THCdry}}) + x_{\text{H2Odil}} \cdot x_{\text{dil/exhdry}} + x_{\text{H2Oint}} \cdot x_{\text{int/exhdry}} - x_{\text{H2dry}}$$

Eq. 1065.655-5

$$x_{\text{dil/exhdry}} = \frac{x_{\text{dil/exh}}}{1 - x_{\text{H2Oexh}}}$$

Eq. 1065.655-6

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot x_{\text{O2int}}} \left(\left(\frac{\alpha}{2} - \beta + 2 + 2 \cdot \gamma \right) (x_{\text{Ccombdry}} - x_{\text{THCdry}}) - (x_{\text{COdry}} - x_{\text{NOdry}} - 2 \cdot x_{\text{NO2dry}} + x_{\text{H2dry}}) \right)$$

Eq. 1065.655-7

$$x_{\text{raw/exhdry}} = \frac{1}{2} \left(\left(\frac{\alpha}{2} + \beta + \delta \right) (x_{\text{Ccombdry}} - x_{\text{THCdry}}) + (2 \cdot x_{\text{THCdry}} + x_{\text{COdry}} - x_{\text{NO2dry}} + x_{\text{H2dry}}) \right) + x_{\text{int/exhdry}}$$

Eq. 1065.655-8

$$x_{\text{O2int}} = \frac{0.209820 - x_{\text{CO2intdry}}}{1 + x_{\text{H2Ointdry}}}$$

Eq. 1065.655-9

$$x_{\text{CO2int}} = \frac{x_{\text{CO2intdry}}}{1 + x_{\text{H2Ointdry}}}$$

Eq. 1065.655-10

$$x_{\text{H2Ointdry}} = \frac{x_{\text{H2Oint}}}{1 - x_{\text{H2Oint}}}$$

Eq. 1065.655-11

$$x_{\text{CO2dil}} = \frac{x_{\text{CO2dildry}}}{1 + x_{\text{H2Odildry}}}$$

Eq. 1065.655-12

$$x_{\text{H2Odildry}} = \frac{x_{\text{H2Odil}}}{1 - x_{\text{H2Odil}}}$$

Eq. 1065.655-13

$$x_{\text{COdry}} = \frac{x_{\text{COmeas}}}{1 - x_{\text{H2OCO}_{\text{meas}}}}$$

Eq. 1065.655-14

$$x_{\text{CO}_2\text{dry}} = \frac{x_{\text{CO}_2\text{meas}}}{1 - x_{\text{H}_2\text{OCO}_2\text{meas}}}$$

Eq. 1065.655-15

$$x_{\text{NOdry}} = \frac{x_{\text{NOmeas}}}{1 - x_{\text{H}_2\text{ONOmeas}}}$$

Eq. 1065.655-16

$$x_{\text{NO}_2\text{dry}} = \frac{x_{\text{NO}_2\text{meas}}}{1 - x_{\text{H}_2\text{ONO}_2\text{meas}}}$$

Eq. 1065.655-17

$$x_{\text{THCdry}} = \frac{x_{\text{THCmeas}}}{1 - x_{\text{H}_2\text{OTHCmeas}}}$$

Eq. 1065.655-18

(5) The following example is a solution for $x_{\text{dil/exh}}$, $x_{\text{H}_2\text{Oexh}}$, and x_{Ccombdry} using the equations in paragraph (c)(4) of this section:

$$x_{\text{dil/exh}} = 1 - \frac{0.184}{1 + \frac{35.37}{1000}} = 0.822 \text{ mol/mol}$$

$$x_{\text{H}_2\text{Oexh}} = \frac{35.37}{1 + \frac{35.37}{1000}} = 34.16 \text{ mmol/mol}$$

$$x_{\text{Ccombdry}} = 0.0252 + \frac{29.3}{1000000} + \frac{47.6}{1000000} - \frac{0.371}{1000} \cdot 0.851 - \frac{0.369}{1000} \cdot 0.172$$

$$= 0.0249 \frac{\text{mol}}{\text{mol}}$$

$$x_{\text{H}_2\text{dry}} = \frac{29.3 \cdot (0.034 - 0.012 \cdot 0.851)}{3.5 \cdot \left(\frac{25.2}{1000} - \frac{0.371}{1000} \cdot 0.851 \right)} = 8.5 \text{ } \mu\text{mol/mol}$$

$$x_{\text{H}_2\text{Oexhdry}} = \frac{1.8}{2} \left(0.0249 - \frac{47.6}{1000000} \right) + 0.012 \cdot 0.851 + 0.017 \cdot 0.172 - \frac{8.5}{1000000}$$

$$= 0.0353 \text{ mol/mol}$$

$$x_{\text{dil/exhdry}} = \frac{0.822}{1 - 0.034} = 0.851 \text{ mol/mol}$$

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot 0.206} \left(\left(\frac{1.8}{2} - 0.050 + 2 + 2 \cdot 0.0003 \right) \left(0.0249 - \frac{47.6}{1000000} \right) - \left(\frac{29.3}{1000000} - \frac{50.4}{1000000} - 2 \cdot \frac{12.1}{1000000} + \frac{8.5}{1000000} \right) \right) = 0.172 \text{ mol/mol}$$

$$x_{\text{raw/exhdry}} = \frac{1}{2} \left(\left(\frac{1.8}{2} + 0.050 + 0.0001 \right) \left(0.0249 - \frac{47.6}{1000000} \right) + \left(2 \cdot \frac{47.6}{1000000} + \frac{29.3}{1000000} - \frac{12.1}{1000000} + \frac{8.5}{1000000} \right) \right) + 0.172 = 0.184 \text{ mol/mol}$$

$$x_{\text{O}_2\text{int}} = \frac{0.209820 - 0.000375}{1 + \frac{17.22}{1000}} = 0.206 \text{ mol/mol}$$

$$x_{\text{CO}_2\text{int}} = \frac{0.000375 \cdot 1000}{1 + \frac{17.22}{1000}} = 0.369 \text{ mmol/mol}$$

$$x_{\text{H}_2\text{Ointdry}} = \frac{16.93}{1 - \frac{16.93}{1000}} = 17.22 \text{ mmol/mol}$$

$$x_{\text{CO}_2\text{dil}} = \frac{0.375}{1 + \frac{12.01}{1000}} = 0.371 \text{ mmol/mol}$$

$$x_{\text{H}_2\text{Odildry}} = \frac{11.87}{1 - \frac{11.87}{1000}} = 12.01 \text{ mmol/mol}$$

$$x_{\text{COdry}} = \frac{29.0}{1 - \frac{8.601}{1000}} = 29.3 \text{ } \mu\text{mol/mol}$$

$$x_{\text{CO}_2\text{dry}} = \frac{24.98}{1 - \frac{8.601}{1000}} = 25.2 \text{ mmol/mol}$$

$$x_{\text{NOdry}} = \frac{50.0}{1 - \frac{8.601}{1000}} = 50.4 \text{ } \mu\text{mol/mol}$$

$$x_{\text{NO}_2\text{dry}} = \frac{12.0}{1 - \frac{8.601}{1000}} = 12.1 \text{ } \mu\text{mol/mol}$$

$$x_{\text{THCdry}} = \frac{46}{1 - \frac{34.16}{1000}} = 47.6 \text{ } \mu\text{mol/mol}$$

$$\alpha = 1.8$$

$$\beta = 0.05$$

$$\gamma = 0.0003$$

$$\delta = 0.0001$$

(d) *Carbon mass fraction of fuel.* Determine carbon mass fraction of fuel, w_C , based on the fuel properties as determined in paragraph (e) of this section, optionally accounting for diesel exhaust fluid's contribution to α , β , γ , and δ , or other fluids injected into the exhaust, if applicable (for example, the engine is equipped with an emission control system that utilizes DEF). Calculate w_C using the following equation:

$$w_C = \frac{1 \cdot M_C}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N}$$

Eq. 1065.655-19

Where:

w_C = carbon mass fraction of the fuel (or mixture of test fuels) and any injected fluids.

M_C = molar mass of carbon.

α = atomic hydrogen-to-carbon ratio of the fuel (or mixture of test fuels) and any injected fluids.

M_H = molar mass of hydrogen.

β = atomic oxygen-to-carbon ratio of the fuel (or mixture of test fuels) and any injected fluids.

M_O = molar mass of oxygen.

γ = atomic sulfur-to-carbon ratio of the fuel (or mixture of test fuels) and any injected fluids.

M_S = molar mass of sulfur.

δ = atomic nitrogen-to-carbon ratio of the fuel (or mixture of test fuels) and any injected fluids.

M_N = molar mass of nitrogen.

Example:

$$\alpha = 1.8$$

$$\beta = 0.05$$

$$\gamma = 0.0003$$

$$\delta = 0.0001$$

$$M_C = 12.0107$$

$$M_H = 1.00794$$

$$M_O = 15.9994$$

$$M_S = 32.065$$

$$M_N = 14.0067$$

$$w_C = \frac{1 \cdot 12.0107}{1 \cdot 12.0107 + 1.8 \cdot 1.00794 + 0.05 \cdot 15.9994 + 0.0003 \cdot 32.065 + 0.0001 \cdot 14.0067}$$

$w_C = 0.8206$

(e) *Fuel and diesel exhaust fluid composition.* Determine fuel and diesel exhaust fluid composition represented by α , β , γ , and δ as described in this paragraph (e). When using measured fuel or diesel exhaust fluid properties, you must determine values for α and β in all cases. If you determine compositions based on measured values and the default value listed in Table 2 of this section is zero, you may set γ and δ to zero; otherwise determine γ and δ (along with α and β) based on measured values. Determine elemental mass fractions and values for α , β , γ , and δ as follows:

(1) For liquid fuels, use the default values for α , β , γ , and δ in Table 2 of this section or determine mass fractions of liquid fuels for calculation of α , β , γ , and δ as follows:

(i) Determine the carbon and hydrogen mass fractions according to ASTM D5291 (incorporated by reference, [see-in](#) § 1065.1010). When using ASTM D5291 to determine carbon and hydrogen mass fractions of gasoline (with or without blended ethanol), use good engineering judgment to adapt the method as appropriate. This may include consulting with the instrument manufacturer on how to test high-volatility fuels. Allow the weight of volatile fuel samples to stabilize for 20 minutes before starting the analysis; if the weight still drifts after 20 minutes, prepare a new sample). Retest the sample if the carbon, hydrogen, oxygen, sulfur, and nitrogen mass fractions do not add up to a total mass of 100 ± 0.5 %; you may assume oxygen has a zero mass contribution for this specification for diesel fuel and neat (E0) gasoline. You may also assume that sulfur and nitrogen have a zero mass contribution for this specification for all fuels except residual fuel blends.

(ii) Determine oxygen mass fraction of gasoline (with or without blended ethanol) according to ASTM D5599 (incorporated by reference, [see-in](#) § 1065.1010). For all other liquid fuels, determine the oxygen mass fraction using good engineering judgment.

(iii) Determine the nitrogen mass fraction according to ASTM D4629 or ASTM D5762 (incorporated by reference, [see-in](#) § 1065.1010) for all liquid fuels. Select the correct method based on the expected nitrogen content.

(iv) Determine the sulfur mass fraction according to subpart H of this part.

(2) For gaseous fuels and diesel exhaust fluid, use the default values for α , β , γ , and δ in Table 2 of this section, or use good engineering judgment to determine those values based on measurement.

(3) For nonconstant fuel mixtures, you must account for the varying proportions of the different fuels. This paragraph (e)(3) generally applies for dual-fuel and flexible-fuel engines, but it also applies if diesel exhaust fluid is injected in a way that is not strictly proportional to fuel flow. Account for these varying concentrations either with a batch measurement that provides averaged values to represent the test interval, or by analyzing data from continuous mass rate measurements. Application of average values from a batch measurement generally applies to situations where one fluid is a minor component of the total fuel mixture, for example dual-fuel and flexible-fuel engines with diesel pilot injection, where the diesel pilot fuel mass is less than 5 % of the total fuel mass and diesel exhaust fluid injection; consistent with good engineering judgment.

(4) Calculate α , β , γ , and δ as described in this paragraph (e)(4) using the following equations: If your fuel mixture contains fuels other than carbon-containing fuels, then calculate those fuels' mass fractions w_{HC} , w_{CH} , w_O , w_S , and w_N as described in § 1065.656(d) and set the fuels' mass fraction w_S to zero. Calculate α , β , γ , and δ using the following equations:

$$\alpha = \frac{M_C}{M_H} \cdot \frac{\sum_{j=1}^N \dot{m}_j \cdot w_{Hmeasj}}{\sum_{j=1}^N \dot{m}_j \cdot w_{Cmeasj}}$$

Eq. 1065.655-20

$$\beta = \frac{M_C}{M_O} \cdot \frac{\sum_{j=1}^N \dot{m}_j \cdot w_{Omeasj}}{\sum_{j=1}^N \dot{m}_j \cdot w_{Cmeasj}}$$

Eq. 1065.655-21

$$\gamma = \frac{M_C}{M_S} \cdot \frac{\sum_{j=1}^N \dot{m}_j \cdot w_{Smeasj}}{\sum_{j=1}^N \dot{m}_j \cdot w_{Cmeasj}}$$

Eq. 1065.655-22

$$\delta = \frac{M_C}{M_N} \cdot \frac{\sum_{j=1}^N \dot{m}_j \cdot w_{Nmeasj}}{\sum_{j=1}^N \dot{m}_j \cdot w_{Cmeasj}}$$

Eq. 1065.655-23

Where:

N = total number of fuels and injected fluids over the duty cycle.

j = an indexing variable that represents one fuel or injected fluid, starting with $j = 1$.

\dot{m}_j = the mass flow rate of the fuel or any injected fluid j . For applications using a single fuel and no DEF fluid, set this value to 1. For batch measurements, divide the total mass of fuel over the test interval duration to determine a mass rate.

w_{Hmeasj} = hydrogen mass fraction of fuel or any injected fluid j .

w_{Cmeasj} = carbon mass fraction of fuel or any injected fluid j .

w_{Omeasj} = oxygen mass fraction of fuel or any injected fluid j .

w_{Smeasj} = sulfur mass fraction of fuel or any injected fluid j .

$w_{N_{meas}j}$ = nitrogen mass fraction of fuel or any injected fluid j .

Example:

$$N = 1$$

$$j = 1$$

$$\dot{m}_1 = 1$$

$$w_{H_{meas}1} = 0.1239$$

$$w_{C_{meas}1} = 0.8206$$

$$w_{O_{meas}1} = 0.0547$$

$$w_{S_{meas}1} = 0.00066$$

$$w_{N_{meas}1} = 0.000095$$

$$M_C = 12.0107 \text{ g/mol}$$

$$M_H = 1.00794 \text{ g/mol}$$

$$M_O = 15.9994 \text{ g/mol}$$

$$M_S = 32.065 \text{ g/mol}$$

$$M_N = 14.0067$$

$$\alpha = \frac{12.0107 \cdot 1 \cdot 0.1239}{1.00794 \cdot 1 \cdot 0.8206 + 12.0107 \cdot 1 \cdot 0.0547}$$

$$\beta = \frac{15.9994 \cdot 1 \cdot 0.8206}{12.0107 \cdot 1 \cdot 0.00066}$$

$$\gamma = \frac{32.065 \cdot 1 \cdot 0.8206}{12.0107 \cdot 1 \cdot 0.000095}$$

$$\delta = \frac{14.0067 \cdot 1 \cdot 0.8206}{14.0067 \cdot 1 \cdot 0.8206}$$

$$\alpha = 1.799$$

$$\beta = 0.05004$$

$$\gamma = 0.0003012$$

$$\delta = 0.0001003$$

(5) Table 2 follows:

TABLE 2 OF § 1065.655—DEFAULT VALUES OF α , β , γ , δ , and w_c

Fuel or injected fluid	Atomic hydrogen, oxygen, sulfur, and nitrogen-to-carbon ratios $CH_\alpha O_\beta S_\gamma N_\delta$	Carbon mass fraction, w_c g/g
Gasoline	$CH_{1.85}O_0S_0N_0$	0.866
E10 Gasoline	$CH_{1.92}O_{0.03}S_0N_0$	0.833
E15 Gasoline	$CH_{1.95}O_{0.05}S_0N_0$	0.817
E85 Gasoline	$CH_{2.73}O_{0.38}S_0N_0$	0.576
E100 Ethanol	$CH_3O_{0.5}S_0N_0$	0.521
M100 Methanol	$CH_4O_1S_0N_0$	0.375
#1 Diesel	$CH_{1.93}O_0S_0N_0$	0.861
#2 Diesel	$CH_{1.80}O_0S_0N_0$	0.869
Liquefied petroleum gas	$CH_{2.64}O_0S_0N_0$	0.819
Natural gas	$CH_{3.78}O_{0.016}S_0N_0$	0.747
Residual fuel blends	Must be determined by measured fuel properties as described in paragraph (e)(1) of this section.	
Diesel exhaust fluid	$CH_{17.85}O_{7.92}S_0N_2$	0.065

(f) *Calculated raw exhaust molar flow rate from measured intake air molar flow rate or fuel mass flow rate.* You may calculate the raw exhaust molar flow rate from which you sampled emissions, \dot{n}_{exh} , based on the measured intake air molar flow rate, \dot{n}_{int} , or the measured fuel mass flow rate, \dot{m}_{fuel} , and the values calculated using the chemical balance in paragraph (c) of this section. The chemical balance must be based on raw exhaust gas concentrations. Solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record \dot{n}_{int} or \dot{m}_{fuel} . For laboratory tests, calculating raw exhaust molar flow rate using measured fuel mass flow rate is valid only for steady-state testing. See § 1065.915(d)(5)(iv) for application to field testing.

(1) *Crankcase flow rate.* If engines are not subject to crankcase controls under the standard-setting part, you may calculate raw exhaust flow based on \dot{n}_{int} or \dot{m}_{fuel} using one of the following:

- (i) You may measure flow rate through the crankcase vent and subtract it from the calculated exhaust flow.
- (ii) You may estimate flow rate through the crankcase vent by engineering analysis as long as the uncertainty in your calculation does not adversely affect your ability to show that your engines comply with applicable emission standards.
- (iii) You may assume your crankcase vent flow rate is zero.

(2) *Intake air molar flow rate calculation.* Calculate \dot{n}_{exh} based on \dot{n}_{int} using the following equation:

$$\dot{n}_{\text{exh}} = \frac{\dot{n}_{\text{int}}}{\left(1 + \frac{(x_{\text{int/exhdry}} - x_{\text{raw/exhdry}})}{(1 + x_{\text{H}_2\text{O/exhdry}})}\right)}$$

Eq. 1065.655-24

Where:

\dot{n}_{exh} = raw exhaust molar flow rate from which you measured emissions.

\dot{n}_{int} = intake air molar flow rate including humidity in intake air.

Example:

$$\dot{n}_{\text{int}} = 3.780 \text{ mol/s}$$

$$x_{\text{int/exhdry}} = 0.69021 \text{ mol/mol}$$

$$x_{\text{raw/exhdry}} = 1.10764 \text{ mol/mol}$$

$$x_{\text{H2Oexhdry}} = 107.64 \text{ mmol/mol} = 0.10764 \text{ mol/mol}$$

$$\dot{n}_{\text{exh}} = \frac{3.780}{\left(1 + \frac{(0.69021 - 1.10764)}{(1 + 0.10764)}\right)}$$

$$\dot{n}_{\text{exh}} = 6.066 \text{ mol/s}$$

(3) *Fluid mass flow rate calculation.* This calculation may be used only for steady-state laboratory testing. You may not use this calculation if the standard-setting part requires carbon balance error verification as described in § 1065.543. See § 1065.915(d)(5)(iv) for application to field testing. Calculate \dot{n}_{exh} based on \dot{m}_j using the following equation:

$$\dot{n}_{\text{exh}} = \frac{1 + x_{\text{H2Oexhdry}}}{M_{\text{C}} \cdot x_{\text{Ccombdry}}} \cdot \sum_{j=1}^N \dot{m}_j \cdot w_{\text{C}j}$$

Eq. 1065.655-25

Where:

\dot{n}_{exh} = raw exhaust molar flow rate from which you measured emissions.

j = an indexing variable that represents one fuel or injected fluid, starting with $j = 1$.

N = total number of fuels and injected fluids over the duty cycle.

\dot{m}_j = the mass flow rate of the fuel or any injected fluid j .

$w_{\text{C}j}$ = carbon mass fraction of the fuel and any injected fluid j , [as determined in paragraph \(d\) of this section](#).

Example:

$$N = 1$$

$$j = 1$$

$$\dot{m}_1 = 7.559 \text{ g/s}$$

$$w_{\text{C}1} = 0.869 \text{ g/g}$$

$$M_{\text{C}} = 12.0107 \text{ g/mol}$$

$$x_{\text{Ccombdry}1} = 99.87 \text{ mmol/mol} = 0.09987 \text{ mol/mol}$$

$$x_{\text{H2Oexhdry}1} = 107.64 \text{ mmol/mol} = 0.10764 \text{ mol/mol}$$

$$\dot{n}_{\text{exh}} = \frac{1 + 0.10764}{12.0107 \cdot 0.09987} \cdot 7.559 \cdot 0.869$$

$$\dot{n}_{\text{exh}} = 6.066 \text{ mol/s}$$

(g) *Calculated raw exhaust molar flow rate from measured intake air molar flow rate, dilute exhaust molar flow rate, and dilute chemical balance.* You may calculate the raw exhaust molar

flow rate, \dot{n}_{exh} , based on the measured intake air molar flow rate, \dot{n}_{int} , the measured dilute exhaust molar flow rate, \dot{n}_{dexh} , and the values calculated using the chemical balance in paragraph (c) of this section. Note that the chemical balance must be based on dilute exhaust gas concentrations. For continuous-flow calculations, solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record \dot{n}_{int} and \dot{n}_{dexh} . This calculated \dot{n}_{dexh} may be used for the PM dilution ratio verification in § 1065.546; the calculation of dilution air molar flow rate in the background correction in § 1065.667; and the calculation of mass of emissions in § 1065.650(c) for species that are measured in the raw exhaust.

(1) *Crankcase flow rate.* If engines are not subject to crankcase controls under the standard-setting part, calculate raw exhaust flow as described in paragraph (f)(1) of this section.

(2) *Dilute exhaust and intake air molar flow rate calculation.* Calculate \dot{n}_{exh} as follows:

$$\dot{n}_{\text{exh}} = (x_{\text{raw/exhdry}} - x_{\text{int/exhdry}}) \cdot (1 - x_{\text{H}_2\text{Oexh}}) \cdot \dot{n}_{\text{dexh}} + \dot{n}_{\text{int}}$$

Eq. 1065.655-26

Example:

$$\dot{n}_{\text{int}} = 7.930 \text{ mol/s}$$

$$x_{\text{raw/exhdry}} = 0.1544 \text{ mol/mol}$$

$$x_{\text{int/exhdry}} = 0.1451 \text{ mol/mol}$$

$$x_{\text{H}_2\text{Oexh}} = 32.46 \text{ mmol/mol} = 0.03246 \text{ mol/mol}$$

$$\dot{n}_{\text{dexh}} = 49.02 \text{ mol/s}$$

$$\dot{n}_{\text{exh}} = (0.1544 - 0.1451) \cdot (1 - 0.03246) \cdot 49.02 + 7.930 = 0.4411 + 7.930 = 8.371 \text{ mol/s}$$

§ 1065.656 Hydrogen-based cChemical balances of fuels other than carbon-containing fuel,

DEF, intake air, and exhaust.

(a) General. Chemical balances of fuel, DEF, intake air, and exhaust may be used to calculate flows, the amount of water in their flows, and the wet concentration of constituents in their flows. See § 1065.520(f) for information about when to use this hydrogen-based chemical balance procedure. Use the chemical balance calculations in this section for fuels other than carbon-containing fuels. For carbon-containing fuels, use the chemical balance calculations in section § 1065.655, including any dual fuels or flexible fuels where one of the fuels contains carbon. With one flow rate of either fuel, intake air, or exhaust, you may use chemical balances to determine the flows of the other two. For example, you may use chemical balances along with either intake air or fuel flow to determine raw exhaust flow. Note that chemical balance calculations allow measured values for the flow rate of diesel exhaust fluid for engines with urea-based selective catalytic reduction.

(b) Procedures that require chemical balances. We require chemical balances when you determine the following:

(1) A value proportional to total work, \tilde{W} when you choose to determine brake-specific emissions as described in § 1065.650(f).

(2) Raw exhaust molar flow rate either from measured intake air molar flow rate or from fuel mass flow rate as described in paragraph (f) of this section.

(3) Raw exhaust molar flow rate from measured intake air molar flow rate and dilute exhaust molar flow rate as described in paragraph (g) of this section.

(4) The amount of water in a raw or diluted exhaust flow, $x_{H_2O_{exh}}$, when you do not measure the amount of water to correct for the amount of water removed by a sampling system. Correct for removed water according to § 1065.659.

(5) The calculated total dilution air flow when you do not measure dilution air flow to correct for background emissions as described in § 1065.667(c) and (d).

(c) *Chemical balance procedure.* The calculations for a chemical balance involve a system of equations that require iteration. We recommend using a computer to solve this system of equations. You must guess the initial values of two of the following quantities: ~~the amount of water in the measured flow, $x_{H_2O_{exhdry}}$,~~ the amount of hydrogen in the measured flow, $x_{H_2_{exhdry}}$, the fraction of dilution air in diluted exhaust, $x_{dil/exhdry}$, and the amount of intake air required to produce actual combustion products per mole of dry exhaust, $x_{int/exhdry}$. You may use time-weighted mean values of intake air humidity and dilution air humidity in the chemical balance; as long as your intake air and dilution air humidities remain within tolerances of ± 0.0025 mol/mol of their respective mean values over the test interval. For each emission concentration, x , and amount of water, $x_{H_2O_{exh}}$, you must determine their completely dry concentrations, x_{dry} and $x_{H_2O_{exhdry}}$. You must also use your fuel mixture's carbon mass fraction, w_C , hydrogen mass fraction, w_H , oxygen mass fraction, w_O , sulfur mass fraction, w_S , and nitrogen mass fraction, w_N ; atomic carbon to hydrogen ratio, τ , oxygen to hydrogen ratio, ϕ , and nitrogen to hydrogen ratio, ω ; you may optionally account for diesel exhaust fluid (or other fluids injected into the exhaust), if applicable. ~~You may calculate w_C , w_H , w_O , w_S , and w_N , τ , ϕ , and ω based on measured fuel composition or based on measured fuel and diesel exhaust fluid (or other fluids injected into the exhaust) composition together,~~ as described in paragraphs (d) and (e) of this section. You may alternatively use any combination of default values and measured values as described in paragraphs (d) and (e) of this section. Use the following steps to complete a chemical balance:

(1) Convert your measured concentrations such as $x_{H_2_{meas}}$, $x_{NH_3_{meas}}$, $x_{CO_2_{meas}}$, $x_{CO_{meas}}$, $x_{THC_{meas}}$, ~~$x_{H_2O_{meas}}$, $x_{O_2_{meas}}$, $x_{H_2_{meas}}$, $x_{NO_{meas}}$, $x_{NO_2_{meas}}$, $x_{NH_3_{meas}}$,~~ and $x_{H_2O_{int}}$, to dry concentrations by dividing them by one minus the amount of water present during their respective measurements; for example: $x_{H_2O_{meas}}$, $x_{H_2O_{xO_2_{meas}}}$, $x_{H_2O_{xNO_{meas}}}$, and $x_{H_2O_{int}}$. If the amount of water present during a "wet" measurement is the same as an unknown amount of water in the exhaust flow, $x_{H_2O_{exh}}$, iteratively solve for that value in the system of equations. If you measure only total NO_x and not NO and NO_2 separately, use good engineering judgment to estimate a split in your total NO_x concentration between NO and NO_2 for the chemical balances. For example, if you measure emissions from a stoichiometric combustion engine, you may assume all NO_x is NO. For a lean-burn combustion engine, you may assume that your molar concentration of NO_x , x_{NO_x} , is 75 % NO and 25 % NO_2 . For NO_2 storage aftertreatment systems, you may assume x_{NO_x} is 25 % NO and 75 % NO_2 . Note that for calculating the mass of NO_x emissions, you must use the molar mass of NO_2 for the effective molar mass of all NO_x species, regardless of the actual NO_2 fraction of NO_x .

(2) Enter the equations in paragraph (c)(45) of this section into a computer program to iteratively solve for ~~$x_{H_2O_{exhdry}}$, $x_{H_2_{exhdry}}$, $x_{dil/exhdry}$, and $x_{int/exhdry}$.~~ Use good engineering judgment to guess initial values for ~~$x_{H_2O_{exhdry}}$, $x_{H_2_{exhdry}}$, $x_{dil/exhdry}$, and $x_{int/exhdry}$.~~ We recommend guessing an initial amount of water that is about twice the amount of water in your intake or dilution air. We recommend guessing an initial amount of hydrogen of 0 mol/mol. We recommend guessing an initial $x_{int/exhdry}$ of 1 mol/mol. We also recommend guessing an initial $x_{dil/exhdry}$ of 0.8 mol/mol. Iterate values in the system of equations until the most recently

updated guesses are all within $\pm 1\%$ or $\pm 1 \mu\text{mol/mol}$, whichever is larger, of their respective most recently calculated values.

(3) Use the following symbols and subscripts in the equations for performing the chemical balance calculations in this paragraph (c):

TABLE 1 OF § 1065.656—SYMBOLS AND SUBSCRIPTS FOR CHEMICAL BALANCE EQUATIONS

$x_{\text{[emission]meas}}$	Amount of measured emission in the sample at the respective gas analyzer.
$x_{\text{[emission]exh}}$	Amount of emission per dry mole of exhaust.
$x_{\text{[emission]exhdry}}$	Amount of emission per dry mole of dry exhaust.
$x_{\text{H}_2\text{O[emission]meas}}$	Amount of H_2O in sample at emission-detection location; measure or estimate these values according to § 1065.145(e)(2).
x_{Ccombdry}	Amount of carbon from fuel and any injected fluids in the exhaust per mole of dry exhaust.
x_{Hcombdry}	Amount of hydrogen from fuel and any injected fluids in the exhaust per mole of dry exhaust.
$x_{\text{dil/exh}}$	Amount of dilution gas or excess air per mole of exhaust.
$x_{\text{dil/exhdry}}$	amount of dilution gas and/or excess air per mole of dry exhaust.
x_{Hcombdry}	Amount of hydrogen from fuel and any injected fluids in the exhaust per mole of dry exhaust.
$x_{\text{int/exhdry}}$	Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust.
$x_{\text{raw/exhdry}}$	Amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust.
$x_{\text{CO}_2\text{int}}$	Amount of intake air CO_2 per mole of intake air.
$x_{\text{CO}_2\text{intdry}}$	amount of intake air CO_2 per mole of dry intake air; you may use $x_{\text{CO}_2\text{intdry}} = 375 \mu\text{mol/mol}$, but we recommend measuring the actual concentration in the intake air.
$x_{\text{H}_2\text{Oint}}$	Amount of H_2O in the intake air, based on a humidity measurement of intake air.
$x_{\text{H}_2\text{Ointdry}}$	Amount of intake air H_2O per mole of dry intake air.
$x_{\text{O}_2\text{int}}$	Amount of intake air O_2 per mole of intake air.
$x_{\text{CO}_2\text{dil}}$	Amount of dilution gas CO_2 per mole of dilution gas.
$x_{\text{CO}_2\text{dildry}}$	Amount of dilution gas CO_2 per mole of dry dilution gas; if you use air as diluent, you may use $x_{\text{CO}_2\text{dildry}} = 375 \mu\text{mol/mol}$, but we recommend measuring the actual concentration in the dilution gas.
$x_{\text{H}_2\text{Odil}}$	Amount of dilution gas H_2O per mole of dilution gas.
$x_{\text{H}_2\text{Odildry}}$	Amount of dilution gas H_2O per mole of dry dilution gas.
τ	Atomic-Effective carbon-to-hydrogen-ratio content of the fuel (or mixture of test fuels) and any injected fluids.
χ	Effective hydrogen content of the fuel and any injected fluids.
φ	Effective Atomic-oxygen-to-hydrogen-ratio content of the fuel (or mixture of test fuels) and any injected fluids.
ξ	Effective sulfur content of the fuel and any injected fluids.
ω	Atomic-nEffective nitrogen-to-hydrogen-ratio content of the fuel (or mixture of test fuels) and any injected fluids.
w_{C}	Carbon mass fraction of the fuel (or mixture of test fuels) and any injected fluids.
w_{H}	Hydrogen mass fraction of the fuel (or mixture of test fuels) and any injected fluids.
w_{O}	Oxygen mass fraction of the fuel (or mixture of test fuels) and any injected fluids.
w_{S}	Sulfur mass fraction of the fuel (or mixture of test fuels) and any injected fluids.
w_{N}	Nitrogen mass fraction of the fuel (or mixture of test fuels) and any injected fluids.

(4) Use the equations specified in this section to iteratively solve for $x_{\text{int/exhdry}}$, $x_{\text{dil/exhdry}}$, $x_{\text{H}_2\text{Oexhdry}}$, and $x_{\text{H}_2\text{Oexhdry}}$. The following exceptions apply:

(i) For $x_{H_2O,exhdry}$ ~~some quantities~~ multiple equations are provided, see table 2 of this section to determine for which cases the equations apply.

(ii) The calculation of $x_{CO_2,exhdry}$ is only required when $x_{CO_2,meas}$ is measured.

(iii) The calculation of $x_{NH_3,exhdry}$ is only required for engines that use ammonia as fuel and engines that are subject to NH_3 measurement under the standard setting part, for all other fuel engines $x_{NH_3,exhdry}$ may be set to zero.

(iv) The calculation of $x_{CO_2,exhdry}$ is only required for engines that use carbon-containing fuels or fluids, either as single fuel or as part of the fuel mixture, and for engines that are subject to CO_2 measurement under the standard setting part, for all other engines $x_{CO_2,exhdry}$ may be set to a value that yields for $x_{C,combdry}$ a value of zero.

(v) The calculation of $x_{CO,exhdry}$ and $x_{THC,exhdry}$ is only required for engines that use carbon-containing fuels and for engines that are subject to CO and THC measurement under the standard setting part, for all other engines $x_{CO,exhdry}$ and $x_{THC,exhdry}$ may be set to zero.

(vi) The calculation of $x_{N_2O,exhdry}$ is only required for engines that are subject to N_2O measurement under the standard setting part, for all other engines $x_{N_2O,exhdry}$ may be set to zero.

(5) Chemical Balance Equations:

$$x_{C,combdry} = x_{CO_2,exhdry} + x_{CO,exhdry} + x_{THC,exhdry} - x_{CO_2,dil} \cdot x_{dil/exhdry} - x_{CO_2,int} \cdot x_{int/exhdry}$$

Eq. 1065.656-1

$$x_{CO,exhdry} = \frac{x_{CO,meas}}{1 - x_{H_2O,CO,meas}}$$

Eq. 1065.656-2

$$x_{CO_2,exhdry} = \frac{x_{CO_2,meas}}{1 - x_{H_2O,CO_2,meas}}$$

Eq. 1065.656-3

$$x_{dil/exh} = 1 - \frac{x_{raw/exhdry}}{1 + x_{H_2O,exhdry}}$$

Eq. 1065.656-14

$$x_{dil/exhdry} = \frac{x_{dil/exh}}{1 - x_{H_2O,exh}}$$

Eq. 1065.656-25

$$x_{H_2,exhdry} = \frac{x_{H_2,meas}}{1 - x_{H_2O,H_2,meas}}$$

Eq. 1065.656-36 (see table 2 of § 1065.656 this section)

$$\begin{aligned}
 x_{\text{H}_2\text{exhdry}} &= 2 \cdot (x_{\text{raw/exhdry}} - x_{\text{int/exhdry}}) - \left(\frac{1}{2} + \phi + \omega\right) \cdot x_{\text{Hcombdry}} + \frac{1}{2} \cdot x_{\text{NH}_3\text{exhdry}} \\
 &\quad + x_{\text{NO}_2\text{exhdry}} \cdot x_{\text{H}_2\text{exhdry}} \\
 &= 2 \\
 &\quad \cdot \left(1 + x_{\text{H}_2\text{Oexhdry}} - \frac{1 + x_{\text{H}_2\text{O}dildry}}{0.209820 - x_{\text{CO}_2dildry}} \cdot x_{\text{O}_2\text{exhdry}} - x_{\text{int/exhdry}} \right. \\
 &\quad \left. - x_{\text{THCexhdry}}\right) + x_{\text{NO}_2\text{exhdry}} + x_{\text{N}_2\text{Oexhdry}} - x_{\text{COexhdry}} - \frac{1}{2} \\
 &\quad \cdot (x_{\text{Hcombdry}} + x_{\text{NH}_3\text{exhdry}}) - \left(\frac{W_{\text{O}}}{M_{\text{O}}} + \frac{W_{\text{N}}}{M_{\text{N}}}\right) \cdot \frac{x_{\text{Ccombdry}} \cdot M_{\text{C}} + x_{\text{Hcombdry}} \cdot M_{\text{H}}}{W_{\text{C}} + W_{\text{H}}}
 \end{aligned}$$

Eq. 1065.656-47 (see Table 2 of § 1065.656 this section)

$$x_{\text{H}_2\text{Oexh}} = \frac{x_{\text{H}_2\text{Oexhdry}}}{1 + x_{\text{H}_2\text{Oexhdry}}}$$

Eq. 1065.656-58

$$x_{\text{H}_2\text{Oexhdry}} = \frac{x_{\text{H}_2\text{Omeas}}}{1 - x_{\text{H}_2\text{Omeas}}}$$

Eq. 1065.656-6 (see Table 2 of § 1065.656)9

$$\begin{aligned}
 x_{\text{H}_2\text{Oexhdry}} &= \frac{1}{2} \cdot x_{\text{Hcombdry}} - x_{\text{H}_2\text{exhdry}} - \frac{3}{2} \cdot x_{\text{NH}_3\text{exhdry}} + x_{\text{H}_2\text{O}dil} \cdot x_{\text{dil/exhdry}} + x_{\text{H}_2\text{O}int} \\
 &\quad \cdot x_{\text{int/exhdry}}
 \end{aligned}$$

Eq. 1065.656-7 (see Table 2 of § 1065.656)

$$\begin{aligned}
 x_{\text{Hcombdry}} &= 2 \cdot x_{\text{H}_2\text{Oexhdry}} + 2 \cdot x_{\text{H}_2\text{exhdry}} + 3 \cdot x_{\text{NH}_3\text{exhdry}} - 2 \cdot x_{\text{H}_2\text{O}dil} \cdot x_{\text{dil/exhdry}} - 2 \\
 &\quad \cdot x_{\text{H}_2\text{O}int} \cdot x_{\text{int/exhdry}}
 \end{aligned}$$

Eq. 1065.656-108 (see Table 2 of § 1065.656)

$$\begin{aligned}
 x_{\text{int/exhdry}} &= \frac{1}{2 \cdot x_{\text{O}_2\text{int}}} \cdot \left(\frac{1}{2} \cdot (x_{\text{Hcombdry}} - 2 \cdot x_{\text{H}_2\text{exhdry}} - 3 \cdot x_{\text{NH}_3\text{exhdry}}) \right. \\
 &\quad \left. + 2 \cdot \left(x_{\text{Ccombdry}} - \frac{1}{2} \cdot x_{\text{COexhdry}} - x_{\text{THCexhdry}} \right) \cdot x_{\text{Hcombdry}} \right. \\
 &\quad \left. + \left(2 \cdot \frac{W_{\text{S}}}{M_{\text{S}}} - \frac{W_{\text{O}}}{M_{\text{O}}} \right) \cdot \frac{x_{\text{Ccombdry}} \cdot M_{\text{C}} + x_{\text{Hcombdry}} \cdot M_{\text{H}}}{W_{\text{C}} + W_{\text{H}}} \right. \\
 &\quad \left. + 2 \cdot x_{\text{NO}_2\text{exhdry}} + x_{\text{NOexhdry}} + x_{\text{N}_2\text{Oexhdry}} \right) \\
 &= \frac{2 \cdot (x_{\text{raw/exhdry}} - x_{\text{int/exhdry}}) - x_{\text{H}_2\text{exhdry}} + \frac{1}{2} \cdot x_{\text{NH}_3\text{exhdry}} + x_{\text{NO}_2\text{exhdry}}}{\frac{1}{2} + \phi + \omega}
 \end{aligned}$$

Eq. 1065.656-119 (see Table 2 of § 1065.656)

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot x_{\text{O}_2\text{int}}} \cdot \left(\left(2 \cdot \tau + \frac{1}{2} \cdot \phi \right) \cdot x_{\text{Hcombdry}} - x_{\text{H}_2\text{exhdry}} - \frac{3}{2} \cdot x_{\text{NH}_3\text{exhdry}} + x_{\text{NOexhdry}} + 2 \cdot x_{\text{NO}_2\text{exhdry}} \right)$$

Eq. 1065.656-10

$$x_{\text{NH}_3\text{exhdry}} = \frac{x_{\text{NH}_3\text{meas}}}{1 - x_{\text{H}_2\text{ONH}_3\text{meas}}}$$

Eq. 1065.656-11

$$x_{\text{NOexhdry}} = \frac{x_{\text{NOmeas}}}{1 - x_{\text{H}_2\text{ONomeas}}}$$

Eq. 1065.656-12

$$x_{\text{NO}_2\text{exhdry}} = \frac{x_{\text{NO}_2\text{meas}}}{1 - x_{\text{H}_2\text{ONO}_2\text{meas}}}$$

Eq. 1065.656-13

$$x_{\text{N}_2\text{Oexhdry}} = \frac{x_{\text{N}_2\text{Omeas}}}{1 - x_{\text{H}_2\text{ON}_2\text{Omeas}}}$$

Eq. 1065.656-15

$$x_{\text{O}_2\text{exhdry}} = \frac{x_{\text{O}_2\text{meas}}}{1 - x_{\text{H}_2\text{OO}_2\text{meas}}}$$

Eq. 1065.656-16 (see Table 2 of § 1065.656 this section)

$$x_{\text{raw/exhdry}} = 1 + x_{\text{H}_2\text{Oexhdry}} - \frac{1 + x_{\text{H}_2\text{Oairdry}}}{0.209820 - x_{\text{CO}_2\text{airdry}}} \cdot x_{\text{O}_2\text{exhdry}}$$

$$x_{\text{raw/exhdry}} = \frac{1}{2} \cdot x_{\text{COexhdry}} + x_{\text{THCexhdry}} + \frac{1}{4} \cdot x_{\text{Hcombdry}} + \frac{1}{2} \cdot x_{\text{H}_2\text{exhdry}} + \frac{1}{4} \cdot x_{\text{NH}_3\text{exhdry}} + \frac{1}{2} \cdot \left(\frac{w_{\text{O}}}{M_{\text{O}}} + \frac{w_{\text{N}}}{M_{\text{N}}} \right) \cdot \frac{x_{\text{Ccombdry}} \cdot M_{\text{C}} + x_{\text{Hcombdry}} \cdot M_{\text{H}}}{w_{\text{C}} + w_{\text{H}}} - \frac{1}{2} \cdot x_{\text{NO}_2\text{exhdry}} - \frac{1}{2} \cdot x_{\text{N}_2\text{Oexhdry}} + x_{\text{int/exhdry}}$$

Eq. 1065.656-17 (see Table 2 of § 1065.656)

$$x_{\text{raw/exhdry}} = \left(\frac{1}{4} + \frac{\phi}{2} + \frac{\omega}{2} \right) \cdot x_{\text{Hcombdry}} + \frac{1}{2} \cdot x_{\text{H}_2\text{exhdry}} - \frac{1}{4} \cdot x_{\text{NH}_3\text{exhdry}} - \frac{1}{2} \cdot x_{\text{NO}_2\text{exhdry}} + x_{\text{int/exhdry}}$$

Eq. 1065.656-16 (see Table 2 of § 1065.656)

$$x_{\text{THCdry}} = \frac{x_{\text{THCmeas}}}{1 - x_{\text{H}_2\text{OTHCmeas}}}$$

Eq. 1065.656-18

$$x_{\text{CO}_2\text{intdry}} = \frac{x_{\text{CO}_2\text{int}}}{1 - x_{\text{H}_2\text{Oint}}}$$

Eq. 1065.656-179

$$x_{\text{H}_2\text{Ointdry}} = \frac{x_{\text{H}_2\text{Oint}}}{1 - x_{\text{H}_2\text{Oint}}}$$

Eq. 1065.656-1208

$$x_{\text{O}_2\text{int}} = \frac{0.209820 - x_{\text{CO}_2\text{intdry}}}{1 + x_{\text{H}_2\text{Ointdry}}}$$

Eq. 1065.656-2119

$$x_{\text{CO}_2\text{dildry}} = \frac{x_{\text{CO}_2\text{dil}}}{1 - x_{\text{H}_2\text{Odil}}}$$

Eq. 1065.656-2022

$$x_{\text{H}_2\text{Odildry}} = \frac{x_{\text{H}_2\text{Odil}}}{1 - x_{\text{H}_2\text{Odil}}}$$

Eq. 1065.656-213

(56) Depending on your measurements, use the equations and guess the quantities specified in Table 2 of this section the following table:

TABLE 2 OF § 1065.656—CHEMICAL BALANCE EQUATIONS FOR DIFFERENT MEASUREMENTS

When measuring...	Guess...	Calculate...
(i) $x_{\text{O}_2\text{meas}}$ and $x_{\text{H}_2\text{Omeas}}$	$x_{\text{int/exhdry}}$ and $x_{\text{H}_2\text{exhdry}}$	(A) $x_{\text{H}_2\text{exhdry}}$ using Eq. 1065.656-4
		(B) $x_{\text{H}_2\text{Oexhdry}}$ using Eq. 1065.656-6
		(C) x_{Heombdry} using Eq. 1065.656-8
		(D) $x_{\text{O}_2\text{exhdry}}$ using Eq. 1065.656-14
		(E) $x_{\text{raw/exhdry}}$ using Eq. 1065.656-15
(ii) $x_{\text{O}_2\text{meas}}$ and $x_{\text{H}_2\text{meas}}$	$x_{\text{int/exhdry}}$ and $x_{\text{H}_2\text{Oexhdry}}$	(A) $x_{\text{H}_2\text{exhdry}}$ using Eq. 1065.656-3
		(B) $x_{\text{H}_2\text{Oexhdry}}$ using Eq. 1065.656-7
		(C) x_{Heombdry} using Eq. 1065.656-9
		(D) $x_{\text{O}_2\text{exhdry}}$ using Eq. 1065.656-14
		(E) $x_{\text{raw/exhdry}}$ using Eq. 1065.656-15
		(A) $x_{\text{H}_2\text{exhdry}}$ using Eq. 1065.656-3
		(B) $x_{\text{H}_2\text{Oexhdry}}$ using Eq. 1065.656-6
		(C) x_{Heombdry} using Eq. 1065.656-8
		(D) $x_{\text{raw/exhdry}}$ using Eq. 1065.656-16
When measuring...	Guess...	Calculate...
(i) $x_{\text{O}_2\text{meas}}$	$x_{\text{int/exhdry}}$ and $x_{\text{H}_2\text{exhdry}}$	(A) $x_{\text{H}_2\text{exhdry}}$ using Eq. 1065.656-7
		(B) $x_{\text{O}_2\text{exhdry}}$ using Eq. 1065.656-16

(ii) x_{H2meas}	$x_{int/exhdry}$ and $x_{dil/exhdry}$	(A) $x_{H2exhdry}$ using Eq. 1065.656-6
		(B) [Reserved]

(7) The following example is a solution for $x_{int/exhdry}$, $x_{dil/exhdry}$, and $x_{HOexhdry}$ using the equations in paragraph (c)(5) of this section:

$$x_{Ccombdry} = 0.00634752 + 0.000303075 + 0.000187618 - 0.000368652 \cdot 0.280097 - 0.000368652 \cdot 0.758282 = 0.00645541 \text{ mol/mol}$$

$$x_{COexhdry} = \frac{0.000231}{1 - \frac{0.237813}{0.004838}} = 0.000303075 \text{ mol/mol}$$

$$x_{CO2exhdry} = \frac{0.00634752}{1 - 0.237813} = 0.00634752 \text{ mol/mol}$$

$$x_{dil/exh} = 1 - \frac{1.03192}{1 + \frac{0.312013}{0.213487}} = 0.213487 \text{ mol/mol}$$

$$x_{dil/exhdry} = \frac{0.280097}{1 - \frac{0.237813}{0.003757}} = 0.280097 \text{ mol/mol}$$

$$x_{H2exhdry} = \frac{0.00492923}{1 - 0.237813} = 0.00492923 \text{ mol/mol}$$

$$x_{H2exhdry} = 2 \cdot \left(1 + 0.312013 - \frac{1 + 0.0172199}{0.209820 - 0.000375} \cdot 0.0576719 - 0.758282 - 0.000187618 \right) + 0.000000472325 + 0.0000314883 - 0.000303075 - \frac{1}{2} \cdot (0.641384 + 0.014218289) - \left(\frac{0.00121459}{15.9994} + \frac{0.804173}{14.0067} \right) \cdot \frac{0.00645541 \cdot 12.0107 + 0.641384 \cdot 1.00794}{0.0182358 + 0.176362} = 0.00492923 \text{ mol/mol}$$

$$x_{H2Oexh} = \frac{0.312013}{1 + \frac{0.312013}{0.237813}} = 0.237813 \text{ mol/mol}$$

$$x_{H2Oexhdry} = \frac{0.312013}{1 - 0.237813} = 0.312013 \text{ mol/mol}$$

$$x_{Hcombdry} = 2 \cdot 0.312013 + 2 \cdot 0.00492923 + 3 \cdot 0.014218289 - 2 \cdot 0.0169284 \cdot 0.280097 - 2 \cdot 0.0169284 \cdot 0.758282 = 0.641384 \text{ mol/mol}$$

$$\begin{aligned}
x_{\text{int/exhdry}} &= \frac{1}{2 \cdot 0.205899} \\
&\quad \frac{1}{2} \cdot (0.641384 - 2 \cdot 0.00492923 - 3 \cdot 0.014218289) \\
&\quad + 2 \cdot \left(0.00645541 - \frac{1}{2} \cdot 0.000303075 - 0.000187618 \right) \\
&\quad \left(+ \left(2 \cdot \frac{0.0000146052}{32.065} - \frac{0.00121459}{15.9994} \right) \cdot \frac{0.00645541 \cdot 12.0107 + 0.641384 \cdot 1.00794}{0.0182358 + 0.176362} \right. \\
&\quad \left. + 2 \cdot 0.000000472325 + 0.00583846 + 0.0000314883 \right) \\
&= 0.758282 \text{ mol/mol} \\
x_{\text{NH}_3\text{exhdry}} &= \frac{0.010837}{1 - 0.237813} = 0.014218289 \text{ mol/mol} \\
x_{\text{NOexhdry}} &= \frac{0.004450}{1 - 0.237813} = 0.00583846 \text{ mol/mol} \\
x_{\text{NO}_2\text{exhdry}} &= \frac{0.00000036}{1 - 0.237813} = 0.000000472325 \text{ mol/mol} \\
x_{\text{N}_2\text{Oexhdry}} &= \frac{0.0439568}{1 - 0.237813} = 0.0000314883 \text{ mol/mol} \\
x_{\text{O}_2\text{exhdry}} &= \frac{0.0576719}{1 - 0.237813} = 0.0576719 \text{ mol/mol} \\
x_{\text{raw/exhdry}} &= \frac{1}{2} \cdot 0.000303075 + 0.000187618 + \frac{0.641384}{4} + \frac{0.00492923}{2} \\
&\quad + \frac{0.014218289}{4} \\
&\quad + \frac{1}{2} \cdot \left(\frac{0.00121459}{15.9994} + \frac{0.804173}{14.0067} \right) \cdot \frac{0.00645541 \cdot 12.0107 + 0.641384 \cdot 1.00794}{0.0182358 + 0.176362} \\
&\quad - \frac{1}{2} \cdot 0.000000472325 - \frac{1}{2} \cdot 0.0000314883 + 0.758282 = 1.03192 \text{ mol/mol} \\
x_{\text{THCdry}} &= \frac{0.000143}{1 - 0.237813} = 0.000187618 \text{ mol/mol} \\
x_{\text{CO}_2\text{intdry}} &= \frac{0.000368652}{1 - 0.0169284} = 0.000375 \text{ mol/mol} \\
x_{\text{H}_2\text{Ointdry}} &= \frac{0.0169284}{1 - 0.0169284} = 0.0172199 \text{ mol/mol} \\
x_{\text{O}_2\text{int}} &= \frac{0.209820 - 0.000375}{1 + 0.0172199} = 0.205899 \text{ mol/mol} \\
x_{\text{CO}_2\text{dildry}} &= \frac{0.000368652}{1 - 0.0169284} = 0.000375 \text{ mol/mol} \\
x_{\text{H}_2\text{Odildry}} &= \frac{0.0169284}{1 - 0.0169284} = 0.0172199 \text{ mol/mol}
\end{aligned}$$

(d) Mass fractions of fuel. (1) For fuels other than carbon-containing fuels ~~D~~Determine the mass fractions of fuel, w_{HC} , w_{CH} , w_{O} , w_{S} , and w_{N} , based on the fuel properties as determined in paragraph (e) of this section, optionally accounting for diesel exhaust fluid's contribution to τ , ϕ , and ω , or other fluids injected into the exhaust, if applicable (for example, the engine is equipped

with an emission control system that utilizes DEF). Calculate w_{HC} , w_{CH} , w_O , w_S , and w_N using the following equations:

$$w_H = \frac{1 \cdot M_H}{1 \cdot M_H + \tau \cdot M_C + \varphi \cdot M_O + \omega \cdot M_N} \quad w_C = \frac{\tau \cdot M_C}{\tau \cdot M_C + \chi \cdot M_H + \varphi \cdot M_O + \xi \cdot M_S + \omega \cdot M_N}$$

Eq. 1065.656-224

$$w_C = \frac{\tau \cdot M_C}{1 \cdot M_H + \tau \cdot M_C + \varphi \cdot M_O + \omega \cdot M_N} \quad w_H = \frac{\chi \cdot M_H}{\tau \cdot M_C + \chi \cdot M_H + \varphi \cdot M_O + \xi \cdot M_S + \omega \cdot M_N}$$

Eq. 1065.656-235

$$w_O = \frac{\varphi \cdot M_O}{1 \cdot M_H + \tau \cdot M_C + \varphi \cdot M_O + \omega \cdot M_N} \quad w_O = \frac{\varphi \cdot M_O}{\tau \cdot M_C + \chi \cdot M_H + \varphi \cdot M_O + \xi \cdot M_S + \omega \cdot M_N}$$

Eq. 1065.656-246

$$w_N = \frac{\omega \cdot M_N}{1 \cdot M_H + \tau \cdot M_C + \varphi \cdot M_O + \omega \cdot M_N} \quad w_S = \frac{\xi \cdot M_S}{\tau \cdot M_C + \chi \cdot M_H + \varphi \cdot M_O + \xi \cdot M_S + \omega \cdot M_N}$$

Eq. 1065.656-27

$$w_N = \frac{\omega \cdot M_N}{\tau \cdot M_C + \chi \cdot M_H + \varphi \cdot M_O + \xi \cdot M_S + \omega \cdot M_N}$$

Eq. 1065.656-285

Where:

w_H = hydrogen mass fraction of the fuel (or mixture of test fuels) and any injected fluids.

w_C = carbon mass fraction of the fuel (or mixture of test fuels) and any injected fluids.

w_H = hydrogen mass fraction of the fuel and any injected fluids.

w_O = oxygen mass fraction of the fuel (or mixture of test fuels) and any injected fluids.

w_S = sulfur mass fraction of the fuel and any injected fluids.

w_N = nitrogen mass fraction of the fuel (or mixture of test fuels) and any injected fluids.

M_H = molar mass of hydrogen.

τ = effective atomic carbon content to hydrogen ratio of the fuel (or mixture of test fuels) and any injected fluids.

M_C = molar mass of carbon.

χ = effective hydrogen content of the fuel and any injected fluids.

M_H = molar mass of hydrogen.

φ = atomic effective oxygen to hydrogen ratio content of the fuel (or mixture of test fuels) and any injected fluids.

M_O = molar mass of oxygen.

ξ = effective sulfur content of the fuel and any injected fluids.

M_S = molar mass of nitrogen.

ω = atomic sulfur to hydrogen ratio effective nitrogen content of the fuel (or mixture of test fuels) and any injected fluids.

M_N = molar mass of nitrogen.

Example for NH_3 fuel:

$$\tau = 0$$

$$\chi = 3$$

$$\varphi = 0$$

$$\xi = 0$$

$$\omega = 1$$

$$M_C = 12.0107 \text{ g/mol}$$

$$M_H = 1.00794 \text{ g/mol}$$

$$M_O = 15.9994 \text{ g/mol}$$

$$M_S = 32.065 \text{ g/mol}$$

$$M_N = 14.0067 \text{ g/mol}$$

$$w_C = \frac{0 \cdot 12.0107}{0 \cdot 12.0107 + 3 \cdot 1.00794 + 0 \cdot 15.9994 + 0 \cdot 32.065 + 1 \cdot 14.0067}$$

$$w_H = \frac{3 \cdot 1.00794}{0 \cdot 12.0107 + 3 \cdot 1.00794 + 0 \cdot 15.9994 + 0 \cdot 32.065 + 1 \cdot 14.0067}$$

$$w_O = \frac{0 \cdot 15.9994}{0 \cdot 12.0107 + 3 \cdot 1.00794 + 0 \cdot 15.9994 + 0 \cdot 32.065 + 1 \cdot 14.0067}$$

$$w_S = \frac{0 \cdot 32.065}{0 \cdot 12.0107 + 3 \cdot 1.00794 + 0 \cdot 15.9994 + 0 \cdot 32.065 + 1 \cdot 14.0067}$$

$$w_N = \frac{1 \cdot 14.0067}{0 \cdot 12.0107 + 3 \cdot 1.00794 + 0 \cdot 15.9994 + 0 \cdot 32.065 + 1 \cdot 14.0067}$$

$$w_C = 0 \text{ g/g}$$

$$w_H = 0.1775530 \text{ g/g}$$

$$w_O = 0 \text{ g/g}$$

$$w_S = 0 \text{ g/g}$$

$$w_N = 0.8224470 \text{ g/g}$$

(2) For carbon-containing fuels and diesel exhaust fluid determine the mass fractions of fuel, w_C , w_H , w_O , w_S , and w_N , based on properties determined according to § 1065.655(d). Calculate w_C , w_H , w_O , w_S , and w_N using the following equations:

$$w_C = \frac{1 \cdot M_C}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N}$$

Eq. 1065.656-29

$$w_H = \frac{\alpha \cdot M_H}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N}$$

Eq. 1065.656-30

$$w_O = \frac{\beta \cdot M_O}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N}$$

Eq. 1065.656-31

$$w_S = \frac{\gamma \cdot M_S}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N}$$

Eq. 1065.656-32

$$w_N = \frac{\delta \cdot M_N}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N}$$

Eq. 1065.656-33

Where:

w_C = carbon mass fraction of the fuel and any injected fluids.

w_H = hydrogen mass fraction of the fuel and any injected fluids.

w_O = oxygen mass fraction of the fuel and any injected fluids.

w_S = sulfur mass fraction of the fuel and any injected fluids.

w_N = nitrogen mass fraction of the fuel and any injected fluids.

M_C = molar mass of carbon.

α = atomic hydrogen-to-carbon ratio of the fuel and any injected fluids.

M_H = molar mass of hydrogen.

β = atomic oxygen-to-carbon ratio of the fuel and any injected fluids.

M_O = molar mass of oxygen.

γ = atomic sulfur-to-carbon ratio of the fuel and any injected fluids.

M_S = molar mass of sulfur.

δ = atomic nitrogen-to-carbon ratio of the fuel and any injected fluids.

M_N = molar mass of nitrogen.

Example:

$$\alpha = 1.8$$

$$\beta = 0.05$$

$$\gamma = 0.0003$$

$$\delta = 0.0001$$

$$M_C = 12.0107$$

$$M_H = 1.00794$$

$$M_O = 15.9994$$

$$M_S = 32.065$$

$$M_N = 14.0067$$

$$w_C = \frac{1 \cdot 12.0107}{1 \cdot 12.0107 + 1.8 \cdot 1.00794 + 0.05 \cdot 15.9994 + 0.0003 \cdot 32.065 + 0.0001 \cdot 14.0067}$$

$w_C = 0.820628$

$$w_H = \frac{1.8 \cdot 1.00794}{1 \cdot 12.0107 + 1.8 \cdot 1.00794 + 0.05 \cdot 15.9994 + 0.0003 \cdot 32.065 + 0.0001 \cdot 14.0067}$$

$w_H = 0.123961$

$$w_O = \frac{0.05 \cdot 15.9994}{1 \cdot 12.0107 + 1.8 \cdot 1.00794 + 0.05 \cdot 15.9994 + 0.0003 \cdot 32.065 + 0.0001 \cdot 14.0067}$$

$w_O = 0.0546578$

$$w_S = \frac{0.0003 \cdot 32.065}{1 \cdot 12.0107 + 1.8 \cdot 1.00794 + 0.05 \cdot 15.9994 + 0.0003 \cdot 32.065 + 0.0001 \cdot 14.0067}$$

$$w_S = 0.000657250$$

$$w_N = \frac{0.0001 \cdot 14.0067}{1 \cdot 12.0107 + 1.8 \cdot 1.00794 + 0.05 \cdot 15.9994 + 0.0003 \cdot 32.065 + 0.0001 \cdot 14.0067}$$

$$w_N = 0.0000957004$$

(3) For nonconstant fuel mixtures, you must account for the varying proportions of the different fuels. This paragraph (d)(3) generally applies for dual-fuel and flexible-fuel engines, but optionally it may also be applied if diesel exhaust fluid or other fluids injected into the exhaust are injected in a way that is not strictly proportional to fuel flow. Account for these varying concentrations either with a batch measurement that provides averaged values to represent the test interval, or by analyzing data from continuous mass rate measurements. Application of average values from a batch measurement generally applies to situations where one fluid is a minor component of the total fuel mixture; consistent with good engineering judgment. Calculate w_C , w_H , w_O , w_S , and w_N of the fuel mixture using the following equations:

$$w_C = \frac{\sum_{j=1}^N \dot{m}_j \cdot w_{Cmeasj}}{\sum_{j=1}^N \dot{m}_j}$$

Eq. 1065.656-34

$$w_H = \frac{\sum_{j=1}^N \dot{m}_j \cdot w_{Hmeasj}}{\sum_{j=1}^N \dot{m}_j}$$

Eq. 1065.656-35

$$w_O = \frac{\sum_{j=1}^N \dot{m}_j \cdot w_{Omeasj}}{\sum_{j=1}^N \dot{m}_j}$$

Eq. 1065.656-36

$$w_S = \frac{\sum_{j=1}^N \dot{m}_j \cdot w_{Smeasj}}{\sum_{j=1}^N \dot{m}_j}$$

Eq. 1065.656-37

$$w_N = \frac{\sum_{j=1}^N \dot{m}_j \cdot w_{Nmeasj}}{\sum_{j=1}^N \dot{m}_j}$$

Eq. 1065.656-38

Where:

w_C = carbon mass fraction of the mixture of test fuels and any injected fluids.

w_H = hydrogen mass fraction of the mixture of test fuels and any injected fluids.

w_O = oxygen mass fraction of the mixture of test fuels and any injected fluids.

w_S = sulfur mass fraction of the mixture of test fuels and any injected fluids.

w_N = nitrogen mass fraction of the mixture of test fuels and any injected fluids.

N = total number of fuels and injected fluids over the duty cycle.

j = an indexing variable that represents one fuel or injected fluid, starting with $j = 1$.
 \dot{m}_j = the mass flow rate of the fuel or any injected fluid j . For batch measurements, divide the total mass of fuel over the test interval duration to determine a mass rate.

w_{Cmeasj} = carbon mass fraction of fuel or any injected fluid j .

w_{Hmeasj} = hydrogen mass fraction of fuel or any injected fluid j .

w_{Omeasj} = oxygen mass fraction of fuel or any injected fluid j .

w_{Smeasj} = sulfur mass fraction of fuel or any injected fluid j .

w_{Nmeasj} = nitrogen mass fraction of fuel or any injected fluid j .

Example for a mixture of diesel and NH₃ fuel where diesel represents 15% of energy:

$N = 2$

$\dot{m}_1 = 0.5352$ g/s

$\dot{m}_2 = 7.024$ g/s

$w_{Cmeas1} = 0.820628$ g/g

$w_{Hmeas1} = 0.123961$ g/g

$w_{Omeas1} = 0.0546578$ g/g

$w_{Smeas1} = 0.00065725$ g/g

$w_{Nmeas1} = 0.0000957004$ g/g

$w_{Cmeas2} = 0$ g/g

$w_{Hmeas2} = 0.177553$ g/g

$w_{Omeas2} = 0$ g/g

$w_{Smeas2} = 0$ g/g

$w_{Nmeas2} = 0.822447$ g/g

$$w_C = \frac{0.5352 \cdot 0.820628 + 7.024 \cdot 0}{0.5352 + 7.024}$$

$$w_H = \frac{0.5352 \cdot 0.123961 + 7.024 \cdot 0.177553}{0.5352 + 7.024}$$

$$w_O = \frac{0.5352 \cdot 0.0546578 + 7.024 \cdot 0}{0.5352 + 7.024}$$

$$w_S = \frac{0.5352 \cdot 0.00065725 + 7.024 \cdot 0}{0.5352 + 7.024}$$

$$w_N = \frac{0.5352 \cdot 0.0000957004 + 7.024 \cdot 0.822447}{0.5352 + 7.024}$$

$w_C = 0.0581014$ g/g

$w_H = 0.1737586$ g/g

$w_O = 0.00386983$ g/g

$w_S = 0.0000465341$ g/g

$w_N = 0.76422359$ g/g

(e) Fuel and diesel exhaust fluid composition. (1) For carbon-containing fuels and diesel exhaust fluid determine the composition represented by α , β , γ , and δ , as described in § 1065.655(e).

(2) For fuels other than carbon-containing fuels use the default values for τ , χ , ϕ , ξ , and ω in table 3 to this section, or use good engineering judgment to determine those values based on measurement. If you determine compositions based on measured values and the default value listed in table 3 to this section is zero, you may set τ , ϕ , ξ , and ω to zero; otherwise determine τ , ϕ , ξ , and ω (along with χ) based on measured values.

(3) If your fuel mixture contains carbon-containing fuels and your testing requires fuel composition values referencing carbon, calculate α , β , γ , and δ for the fuel mixture as described in § 1065.655(e)(4). Determine fuel and diesel exhaust fluid composition represented by τ , ϕ , and ω , as described in this paragraph (e). When using measured fuel or diesel exhaust fluid properties, you must determine values for τ , ϕ , and ω in all cases. If you determine compositions based on measured values and the default value listed in Table 3 of this section is zero, you may set τ , ϕ , and ω to zero; otherwise determine τ , ϕ , and ω based on measured values. Determine elemental mass fractions and values for τ , ϕ , and ω as follows:

(1) For fuel and diesel exhaust fluid, use the default values for τ , ϕ , and ω in Table 3 of this section, or use good engineering judgment to determine those values based on measurement.

(2) For nonconstant fuel mixtures, you must account for the varying proportions of the different fuels. This paragraph (e)(2) generally applies for dual-fuel and flexible-fuel engines, but it also applies if diesel exhaust fluid is injected in a way that is not strictly proportional to fuel flow. Account for these varying concentrations either with a batch measurement that provides averaged values to represent the test interval, or by analyzing data from continuous mass rate measurements. Application of average values from a batch measurement generally applies to situations where one fluid is a minor component of the total fuel mixture; consistent with good engineering judgment.

(4) Calculate τ , ϕ , and ω using the following equations:

$$\tau = \frac{M_H \cdot \sum_{j=1}^N \dot{m}_j \cdot w_{Cj}}{M_C \cdot \sum_{j=1}^N \dot{m}_j \cdot w_{Hj}}$$

Eq. 1065.656-26

$$\phi = \frac{M_H \cdot \sum_{j=1}^N \dot{m}_j \cdot w_{Oj}}{M_O \cdot \sum_{j=1}^N \dot{m}_j \cdot w_{Hj}}$$

Eq. 1065.656-27

$$\omega = \frac{M_H \cdot \sum_{j=1}^N \dot{m}_j \cdot w_{Nj}}{M_N \cdot \sum_{j=1}^N \dot{m}_j \cdot w_{Hj}}$$

Eq. 1065.656-28

Where:

N = total number of fuels and injected fluids over the duty cycle.

j = an indexing variable that represents one fuel or injected fluid, starting with $j = 1$.

\dot{m}_j = the mass flow rate of the fuel or any injected fluid j . For applications using a single fuel and no DEF fluid, set this value to 1. For batch measurements, divide the total mass of fuel over the test interval duration to determine a mass rate.

w_{Hj} = hydrogen mass fraction of fuel or any injected fluid j .

w_{Cj} = carbon mass fraction of fuel or any injected fluid j .

w_{Oj} = oxygen mass fraction of fuel or any injected fluid j .

w_{Nj} = nitrogen mass fraction of fuel or any injected fluid j .

(4) Table 3 follows:

TABLE 3 OF § 1065.656—DEFAULT VALUES OF τ , χ , ϕ , ζ , AND ω_T , Φ , AND Ω

<u>Fuel or injected fluid</u>	<u>Atomic carbon, oxygen, and nitrogen-to-hydrogen ratios</u> <u>$C_{\tau}H_{\chi}O_{\phi}S_{\zeta}N_{\omega}HC_{\tau}O_{\phi}N_{\omega}$</u>
Hydrogen	$HC_0H_2O_0S_0N_0$
Ammonia	$HC_0H_3O_0S_0N_{10.333}$
Diesel exhaust fluid	$HC_{0.056}O_{0.444}N_{0.112}$

(f) Calculated raw exhaust molar flow rate from measured intake air molar flow rate or fuel mass flow rate. You may calculate the raw exhaust molar flow rate from which you sampled emissions, \dot{n}_{exh} , based on the measured intake air molar flow rate, \dot{n}_{int} , or the measured fuel mass flow rate, \dot{m}_{fuel} , and the values calculated using the chemical balance in paragraph (c) of this section. The chemical balance must be based on raw exhaust gas concentrations. Solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record \dot{n}_{int} or \dot{m}_{fuel} . For laboratory tests, calculating raw exhaust molar flow rate using measured fuel mass flow rate is valid only for steady-state testing. See § 1065.915(d)(5)(iv) for application to field testing.

(1) Crankcase flow rate. If engines are not subject to crankcase controls under the standard-setting part, you may calculate raw exhaust flow based on \dot{n}_{int} or \dot{m}_{fuel} using one of the following:

- (i) You may measure flow rate through the crankcase vent and subtract it from the calculated exhaust flow.
- (ii) You may estimate flow rate through the crankcase vent by engineering analysis as long as the uncertainty in your calculation does not adversely affect your ability to show that your engines comply with applicable emission standards.
- (iii) You may assume your crankcase vent flow rate is zero.

(2) Intake air molar flow rate calculation. Calculate \dot{n}_{exh} based on \dot{n}_{int} using the following equation:

$$\dot{n}_{\text{exh}} = \frac{\dot{n}_{\text{int}}}{\left(1 + \frac{(x_{\text{int/exhdry}} - x_{\text{raw/exhdry}})}{(1 + x_{\text{H}_2\text{Oexhdry}})}\right)}$$

Eq. 1065.656-2939

Where:

\dot{n}_{exh} = raw exhaust molar flow rate from which you measured emissions.

\dot{n}_{int} = intake air molar flow rate including humidity in intake air.

Example:

$\dot{n}_{\text{int}} = 3.780 \text{ mol/s}$

$x_{\text{int/exhdry}} = 0.69021 \text{ mol/mol}$

$x_{\text{raw/exhdry}} = 1.10764 \text{ mol/mol}$

$x_{\text{H}_2\text{Oexhdry}} = 107.64 \text{ mmol/mol} = 0.10764 \text{ mol/mol}$

$$\dot{n}_{\text{exh}} = \frac{3.780}{\left(1 + \frac{(0.69021 - 1.10764)}{(1 + 0.10764)}\right)}$$

$$\dot{n}_{\text{exh}} = 6.066 \text{ mol/s}$$

(3) Fluid mass flow rate calculation. This calculation may be used only for steady-state laboratory testing. See § 1065.915(d)(5)(iv) for application to field testing. Calculate \dot{n}_{exh} based on \dot{m}_j using the following equation:

$$\begin{aligned} \dot{n}_{\text{exh}} \dot{n}_{\text{exh}} &= \frac{1 + x_{\text{H}_2\text{Oexhdry}}}{M_{\text{H}} \cdot x_{\text{Hcombdry}}} \cdot \sum_{j=1}^N \dot{m}_j \cdot w_{\text{H}j} \\ &= \frac{1 + x_{\text{H}_2\text{Oexhdry}}}{M_{\text{C}} \cdot x_{\text{Ccombdry}} + M_{\text{H}} \cdot x_{\text{Hcombdry}}} \cdot \sum_{j=1}^N \dot{m}_j \cdot (w_{\text{C}j} + w_{\text{H}j}) \end{aligned}$$

Eq. 1065.656-4030

Where:

\dot{n}_{exh} = raw exhaust molar flow rate from which you measured emissions.

j = an indexing variable that represents one fuel or injected fluid, starting with $j = 1$.

N = total number of fuels and injected fluids over the duty cycle.

\dot{m}_j = the mass flow rate of the fuel or any injected fluid j .

$w_{\text{C}j}$ = carbon mass fraction of the fuel (or mixture of test fuels) and any injected fluid j .

$w_{\text{H}j}$ = hydrogen mass fraction of the fuel (or mixture of test fuels) and any injected fluid j .

Example:

$$x_{\text{H}_2\text{Oexhdry}1} = 107.64312.013 \text{ mmol/mol} = 0.10764 \text{ mol/mol}$$

$$M_{\text{C}} = 12.0107 \text{ g/mol}$$

$$M_{\text{H}} = 1.00794 \text{ g/mol}$$

$$x_{\text{Ccombdry}1} = 99.876.45541 \text{ mmol/mol} = 0.099870645541 \text{ mol/mol}$$

$$x_{\text{Hcombdry}1} = 641.384 \text{ mmol/mol} = 0.641384 \text{ mol/mol}$$

$$\dot{m}_1 = 7.5590.167974 \text{ g/s}$$

$$\dot{m}_2 = 7.39103 \text{ g/s}$$

$$w_{\text{C}1} = 0.820628 \text{ g/g}$$

$$w_{\text{C}2} = 0 \text{ g/g}$$

$$w_{\text{H}1} = 0.07293123961 \text{ g/g}$$

$$w_{\text{H}2} = 0.177553 \text{ g/g}$$

$$N = 2$$

$$j = 1$$

$$\dot{n}_{\text{exh}} = \frac{1 + 0.10764312013}{12.0107 \cdot 0.00645541 + 1.00794 \cdot 0.09987641384} \cdot (0.167974 \cdot (0.820628 + 0.123961) + 7.39103 \cdot (0 + 0.177553)) - 0.07293$$

$$\dot{n}_{\text{exh}} = 6.0662.66561 \text{ mol/s}$$

(g) Calculated raw exhaust molar flow rate from measured intake air molar flow rate, dilute exhaust molar flow rate, and dilute chemical balance. You may calculate the raw exhaust molar

flow rate, \dot{n}_{exh} , based on the measured intake air molar flow rate, \dot{n}_{int} , the measured dilute exhaust molar flow rate, \dot{n}_{dexh} , and the values calculated using the chemical balance in paragraph (c) of this section. Note that the chemical balance must be based on dilute exhaust gas concentrations. For continuous-flow calculations, solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record \dot{n}_{int} and \dot{n}_{dexh} . This calculated \dot{n}_{dexh} may be used for the PM dilution ratio verification in § 1065.546; the calculation of dilution air molar flow rate in the background correction in § 1065.667; and the calculation of mass of emissions in § 1065.650(c) for species that are measured in the raw exhaust.

(1) Crankcase flow rate. If engines are not subject to crankcase controls under the standard-setting part, calculate raw exhaust flow as described in paragraph (f)(1) of this section.

(2) Dilute exhaust and intake air molar flow rate calculation. Calculate \dot{n}_{exh} as follows:

$$\dot{n}_{\text{exh}} = (x_{\text{raw/exhdry}} - x_{\text{int/exhdry}}) \cdot (1 - x_{\text{H}_2\text{Oexh}}) \cdot \dot{n}_{\text{dexh}} + \dot{n}_{\text{int}}$$

Eq. 1065.656-4131

Example:

$$\dot{n}_{\text{int}} = 7.930 \text{ mol/s}$$

$$x_{\text{raw/exhdry}} = 0.1544 \text{ mol/mol}$$

$$x_{\text{int/exhdry}} = 0.1451 \text{ mol/mol}$$

$$x_{\text{H}_2\text{Oexh}} = 32.46 \text{ mmol/mol} = 0.03246 \text{ mol/mol}$$

$$\dot{n}_{\text{dexh}} = 49.02 \text{ mol/s}$$

$$\dot{n}_{\text{exh}} = (0.1544 - 0.1451) \cdot (1 - 0.03246) \cdot 49.02 + 7.930 = 0.4411 + 7.930 = 8.371 \text{ mol/s}$$

§ 1065.659 Removed water correction.

(a) If you remove water upstream of a concentration measurement, x , correct for the removed water. Perform this correction based on the amount of water at the concentration measurement, $x_{\text{H}_2\text{O[emission]meas}}$, and at the flow meter, $x_{\text{H}_2\text{Oexh}}$, whose flow is used to determine the mass emission rate or total mass over a test interval. For continuous analyzers downstream of a sample dryer for transient and ramped-modal cycles, you must apply this correction on a continuous basis over the test interval, even if you use one of the options in § 1065.145(e)(2) that results in a constant value for $x_{\text{H}_2\text{O[emission]meas}}$ because $x_{\text{H}_2\text{Oexh}}$ varies over the test interval. For batch analyzers, determine the flow-weighted average based on the continuous $x_{\text{H}_2\text{Oexh}}$ values determined as described in paragraph (c) of this section. For batch analyzers, you may determine the flow-weighted average $x_{\text{H}_2\text{Oexh}}$ based on a single value of $x_{\text{H}_2\text{Oexh}}$ determined as described in paragraphs (c)(2) and (3) of this section, using flow-weighted average or batch concentration inputs.

(b) Determine the amount of water remaining downstream of a sample dryer and at the concentration measurement using one of the methods described in § 1065.145(e)(2). If you use a sample dryer upstream of an analyzer and if the calculated amount of water remaining downstream of the sample dryer and at the concentration measurement, $x_{\text{H}_2\text{O[emission]meas}}$, is higher than the amount of water at the flow meter, $x_{\text{H}_2\text{Oexh}}$, set $x_{\text{H}_2\text{O[emission]meas}}$ equal to $x_{\text{H}_2\text{Oexh}}$. If you use a sample dryer upstream of storage media, you must be able to demonstrate that the sample dryer is removing water continuously (i.e., $x_{\text{H}_2\text{Oexh}}$ is higher than $x_{\text{H}_2\text{O[emission]meas}}$ throughout the test interval).

(c) For a concentration measurement where you did not remove water, you may set $x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}$ equal to $x_{\text{H}_2\text{O}[\text{exh}]}$. You may determine the amount of water at the flow meter, $x_{\text{H}_2\text{O}[\text{exh}]}$, using any of the following methods:

(1) Measure the dewpoint and absolute pressure and calculate the amount of water as described in § 1065.645.

(2) If the measurement comes from raw exhaust, you may determine the amount of water based on intake-air humidity, plus a chemical balance of fuel, DEF, intake air, and exhaust as described in § 1065.655.

(3) If the measurement comes from diluted exhaust, you may determine the amount of water based on intake-air humidity, dilution air humidity, and a chemical balance of fuel, DEF, intake air, and exhaust as described in § 1065.655.

(d) Perform a removed water correction to the concentration measurement using the following equation:

$$x = x_{[\text{emission}]_{\text{meas}}} \cdot \left(\frac{1 - x_{\text{H}_2\text{O}[\text{exh}]}}{1 - x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}} \right)$$

Eq. 1065.659-1

Example:

$$x_{\text{CO}_{\text{meas}}} = 29.0 \text{ } \mu\text{mol/mol}$$

$$x_{\text{H}_2\text{O}_{\text{CO}_{\text{meas}}}} = 8.601 \text{ mmol/mol} = 0.008601 \text{ mol/mol}$$

$$x_{\text{H}_2\text{O}[\text{exh}]} = 34.04 \text{ mmol/mol} = 0.03404 \text{ mol/mol}$$

$$x_{\text{CO}} = 29.0 \cdot \left(\frac{1 - 0.03404}{1 - 0.008601} \right)$$

$$x_{\text{CO}} = 28.3 \text{ } \mu\text{mol/mol}$$

§ 1065.660 THC, NMHC, NMNEHC, CH₄, and C₂H₆ determination.

(a) *THC determination and initial THC/CH₄ contamination corrections.* (1) If we require you to determine THC emissions, calculate $x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$ using the initial THC contamination concentration $x_{\text{THC}[\text{THC-FID}]_{\text{init}}}$ from § 1065.520 as follows:

$$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = x_{\text{THC}[\text{THC-FID}]_{\text{uncor}}} - x_{\text{THC}[\text{THC-FID}]_{\text{init}}}$$

Eq. 1065.660-1

Example:

$$x_{\text{THC}_{\text{uncor}}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$x_{\text{THC}_{\text{init}}} = 1.1 \text{ } \mu\text{mol/mol}$$

$$x_{\text{THC}_{\text{cor}}} = 150.3 - 1.1$$

$$x_{\text{THC}_{\text{cor}}} = 149.2 \text{ } \mu\text{mol/mol}$$

(2) For the NMHC determination described in paragraph (b) of this section, correct $x_{\text{THC}[\text{THC-FID}]}$ for initial THC contamination using Eq. 1065.660-1. You may correct $x_{\text{THC}[\text{NMC-FID}]}$ for initial contamination of the CH₄ sample train using Eq. 1065.660-1, substituting in CH₄ concentrations for THC.

(3) For the NMNEHC determination described in paragraph (c) of this section, correct $x_{\text{THC}[\text{THC-FID}]}$ for initial THC contamination using Eq. 1065.660-1. You may correct $x_{\text{THC}[\text{NMC-}$

FID] for initial contamination of the CH₄ sample train using Eq. 1065.660-1, substituting in CH₄ concentrations for THC.

(4) For the CH₄ determination described in paragraph (d) of this section, you may correct $x_{\text{THC}[\text{NMC-FID}]}$ for initial THC contamination of the CH₄ sample train using Eq. 1065.660-1, substituting in CH₄ concentrations for THC.

(5) You may calculate THC as the sum of NMHC and CH₄ if you determine CH₄ with an FTIR as described in paragraph (d)(2) of this section and NMHC with an FTIR using the additive method from paragraph (b)(4) of this section.

(6) You may calculate THC as the sum of NMNEHC, C₂H₆, and CH₄ if you determine CH₄ with an FTIR as described in paragraph (d)(2) of this section, C₂H₆ with an FTIR as described in paragraph (e) of this section, and NMNEHC with an FTIR using the additive method from paragraph (c)(3) of this section.

(b) *NMHC determination.* Use one of the following to determine NMHC concentration, x_{NMHC} :

(1) If you do not measure CH₄, you may omit the calculation of NMHC concentrations and calculate the mass of NMHC as described in § 1065.650(c)(5).

(2) For ~~an nonmethane cutter (NMC)s~~, calculate x_{NMHC} using the ~~nonmethane cutter NMC's penetration fractions, response factors, and/or combined penetration fractions and response factors as described in methane penetration fraction, $PF_{\text{CH}_4[\text{NMC-FID}]}$, and the ethane response factor penetration fraction, $RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$, from § 1065.365, the THC FID's methane CH₄ response factor, $RF_{\text{CH}_4[\text{THC-FID}]}$, from § 1065.360, the initial THC contamination and dry-to-wet corrected THC concentration, $x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$, as determined in paragraph (a) of this section, and the dry-to-wet corrected CH₄ methane concentration, $x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$, optionally corrected for initial THC contamination as determined in paragraph (a) of this section.~~

(i) ~~If you need to account for penetration fractions determined as a function of molar water concentration, use Eq. 1065.660-4. Otherwise, u~~Use the following equation for ~~penetration fractions determined using an NMC configuration as outlined described in § 1065.365(d):~~

$$x_{\text{NMHC}} = \frac{x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} \cdot RFPF_{\text{CH}_4[\text{NMC-FID}]} - x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} \cdot RF_{\text{CH}_4[\text{THC-FID}]}}{RFPF_{\text{CH}_4[\text{NMC-FID}]} - RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} \cdot RF_{\text{CH}_4[\text{THC-FID}]}}$$

Eq. 1065.660-2

Where:

x_{NMHC} = concentration of NMHC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$RF_{\text{CH}_4[\text{THC-FID}]}$ = response factor of THC FID to CH₄, according to § 1065.360(d).

$RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$ = ~~nonmethane cutter NMC~~ combined ~~C₂H₆ethane~~ response factor and penetration fraction, according to § 1065.365(d).

~~$RFPF_{\text{CH}_4[\text{NMC-FID}]}$ = NMC combined CH₄ response factor and penetration fraction, according to § 1065.365(d).~~

Example:

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = 150.3 \mu\text{mol/mol}$

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} = 20.5 \mu\text{mol/mol}$

$$RF_{PF_{C_2H_6[NMC-FID]}} = 0.019$$

$$RF_{PF_{CH_4[NMC-FID]}} = 1.000$$

$$RF_{CH_4[THC-FID]} = 1.05$$

$$x_{NMHC} = \frac{150.3 - 20.5 \cdot 1.05}{1 - 0.019 \cdot 1.05}$$

$$x_{NMHC} = 131.4 \mu\text{mol/mol}$$

(ii) Use the following equation for penetration fractions determined using an NMC configuration as outlined in § 1065.365(e):

$$x_{NMHC} = \frac{x_{THC[THC-FID]_{cor}} \cdot PF_{CH_4[NMC-FID]} - x_{THC[NMC-FID]_{cor}}}{PF_{CH_4[NMC-FID]} - PF_{C_2H_6[NMC-FID]}}$$

Eq. 1065.660-3

Where:

x_{NMHC} = concentration of NMHC.

$x_{THC[THC-FID]_{cor}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{CH_4[NMC-FID]}$ = ~~nonmethane cutter~~NMC CH_4 penetration fraction, according to § 1065.365(e).

$x_{THC[NMC-FID]_{cor}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the THC FID during sampling through the NMC.

$PF_{C_2H_6[NMC-FID]}$ = ~~nonmethane cutter ethane~~NMC C_2H_6 penetration fraction, according to § 1065.365(e).

Example:

$$x_{THC[THC-FID]_{cor}} = 150.3 \mu\text{mol/mol}$$

$$PF_{CH_4[NMC-FID]} = 0.990$$

$$x_{THC[NMC-FID]_{cor}} = 20.5 \mu\text{mol/mol}$$

$$PF_{C_2H_6[NMC-FID]} = 0.020$$

$$x_{NMHC} = \frac{150.3 \cdot 0.990 - 20.5}{0.990 - 0.020}$$

$$x_{NMHC} = 132.3 \mu\text{mol/mol}$$

(iii) Use the following equation for ~~penetration fractions determined using~~ an NMC configuration ~~as outlined described~~ in § 1065.365(f) ~~or for penetration fractions determined as a function of molar water concentration using an NMC configuration as outlined in § 1065.365(d)~~:

$$x_{NMHC} = \frac{x_{THC[THC-FID]_{cor}} \cdot PF_{CH_4[NMC-FID]} - x_{THC[NMC-FID]_{cor}} \cdot RF_{CH_4[THC-FID]}}{PF_{CH_4[NMC-FID]} - RF_{PF_{C_2H_6[NMC-FID]}} \cdot RF_{CH_4[THC-FID]}}$$

Eq. 1065.660-4

Where:

x_{NMHC} = concentration of NMHC.

$x_{THC[THC-FID]_{cor}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{CH_4[NMC-FID]}$ = ~~nonmethane cutter~~NMC CH_4 penetration fraction, according to § 1065.365(f).

$x_{THC[NMC-FID]_{cor}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the THC FID during sampling through the NMC.

$RF_{PF_{C_2H_6[NMC-FID]}}$ = ~~nonmethane cutter- CH_4~~ NMC combined C_2H_6 ~~ethane~~ response factor and penetration fraction, according to § 1065.365(f).

$RF_{CH_4[THC-FID]}$ = response factor of THC FID to CH_4 , according to § 1065.360(d).

Example:

$$x_{THC[THC-FID]_{cor}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$PF_{CH_4[NMC-FID]} = 0.990$$

$$x_{THC[NMC-FID]_{cor}} = 20.5 \text{ } \mu\text{mol/mol}$$

$$RF_{PF_{C_2H_6[NMC-FID]}} = 0.019$$

$$RF_{CH_4[THC-FID]} = 0.980$$

$$x_{NMHC} = \frac{150.3 \cdot 0.990 - 20.5 \cdot 0.980}{0.990 - 0.019 \cdot 0.980}$$

$$x_{NMHC} = 132.5 \text{ } \mu\text{mol/mol}$$

(3) For a GC-FID or FTIR, calculate x_{NMHC} using the THC analyzer's ~~methane- CH_4~~ response factor, $RF_{CH_4[THC-FID]}$, from § 1065.360, and the initial THC contamination and dry-to-wet corrected THC concentration, $x_{THC[THC-FID]_{cor}}$, as determined in paragraph (a) of this section as follows:

$$x_{NMHC} = x_{THC[THC-FID]_{cor}} - RF_{CH_4[THC-FID]} \cdot x_{CH_4}$$

Eq. 1065.660-5

Where:

x_{NMHC} = concentration of NMHC.

$x_{THC[THC-FID]_{cor}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID.

$RF_{CH_4[THC-FID]}$ = response factor of THC-FID to CH_4 .

x_{CH_4} = concentration of CH_4 , dry-to-wet corrected, as measured by the GC-FID or FTIR.

Example:

$$x_{THC[THC-FID]_{cor}} = 145.6 \text{ } \mu\text{mol/mol}$$

$$RF_{CH_4[THC-FID]} = 0.970$$

$$x_{CH_4} = 18.9 \text{ } \mu\text{mol/mol}$$

$$x_{NMHC} = 145.6 - 0.970 \cdot 18.9$$

$$x_{NMHC} = 127.3 \text{ } \mu\text{mol/mol}$$

(4) For an FTIR, calculate x_{NMHC} by summing the hydrocarbon species listed in § 1065.266(c) as follows:

$$x_{NMHC} = \sum_{i=1}^N (x_{HCi} - x_{HCi-init})$$

Eq. 1065.660-6

Where:

x_{NMHC} = concentration of NMHC.

$x_{\text{HC}i}$ = the C₁-equivalent concentration of hydrocarbon species *i* as measured by the FTIR, not corrected for initial contamination.

$x_{\text{HC}i\text{-init}}$ = the C₁-equivalent concentration of the initial system contamination (optional) of hydrocarbon species *i*, dry-to-wet corrected, as measured by the FTIR.

Example:

$x_{\text{C}_2\text{H}_6} = 4.9 \mu\text{mol/mol}$

$x_{\text{C}_2\text{H}_4} = 0.9 \mu\text{mol/mol}$

$x_{\text{C}_2\text{H}_2} = 0.8 \mu\text{mol/mol}$

$x_{\text{C}_3\text{H}_8} = 0.4 \mu\text{mol/mol}$

$x_{\text{C}_3\text{H}_6} = 0.5 \mu\text{mol/mol}$

$x_{\text{C}_4\text{H}_{10}} = 0.3 \mu\text{mol/mol}$

$x_{\text{CH}_2\text{O}} = 0.8 \mu\text{mol/mol}$

$x_{\text{C}_2\text{H}_4\text{O}} = 0.3 \mu\text{mol/mol}$

$x_{\text{CH}_2\text{O}_2} = 0.1 \mu\text{mol/mol}$

$x_{\text{CH}_4\text{O}} = 0.1 \mu\text{mol/mol}$

$x_{\text{NMHC}} = 4.9 + 0.9 + 0.8 + 0.4 + 0.5 + 0.3 + 0.8 + 0.3 + 0.1 + 0.1$

$x_{\text{NMHC}} = 9.1 \mu\text{mol/mol}$

(c) *NMNEHC determination.* Use one of the following methods to determine NMNEHC concentration, x_{NMNEHC} :

(1) Calculate x_{NMNEHC} based on the test fuel's ethane content as follows:

(i) If the content of your test fuel contains less than 0.010 mol/mol of ethane, you may omit the calculation of NMNEHC concentration and calculate the mass of NMNEHC as described in § 1065.650(c)(6)(i).

(ii) If the content of your fuel test contains at least 0.010 mol/mol of **ethane-C₂H₆**, you may omit the calculation of NMNEHC concentration and calculate the mass of NMNEHC as described in § 1065.650(c)(6)(ii).

(2) For a GC-FID, NMC FID, or FTIR, calculate x_{NMNEHC} using the THC analyzer's **CH₄methane** response factor, $RF_{\text{CH}_4[\text{THC-FID}]}$, and **C₂H₆ethane** response factor, $RF_{\text{C}_2\text{H}_6[\text{THC-FID}]}$, from § 1065.360, the initial contamination and dry-to-wet corrected THC concentration, $x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$, as determined in paragraph (a) of this section, the dry-to-wet corrected **methane-CH₄** concentration, x_{CH_4} , as determined in paragraph (d) of this section, and the dry-to-wet corrected **C₂H₆ethane** concentration, $x_{\text{C}_2\text{H}_6}$, as determined in paragraph (e) of this section as follows:

$$x_{\text{NMNEHC}} = x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} - RF_{\text{CH}_4[\text{THC-FID}]} \cdot x_{\text{CH}_4} - RF_{\text{C}_2\text{H}_6[\text{THC-FID}]} \cdot x_{\text{C}_2\text{H}_6}$$

Eq. 1065.660-7

Where:

x_{NMNEHC} = concentration of NMNEHC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID.

$RF_{\text{CH}_4[\text{THC-FID}]}$ = response factor of THC-FID to CH₄.

x_{CH_4} = concentration of CH₄, dry-to-wet corrected, as measured by the GC-FID, NMC FID, or FTIR.

$RF_{C_2H_6[THC-FID]}$ = response factor of THC-FID to C_2H_6 .

$x_{C_2H_6}$ = the C_1 -equivalent concentration of C_2H_6 , dry-to-wet corrected, as measured by the GC-FID or FTIR.

Example:

$$x_{THC[THC-FID]_{cor}} = 145.6 \mu\text{mol/mol}$$

$$RF_{CH_4[THC-FID]} = 0.970$$

$$x_{CH_4} = 18.9 \mu\text{mol/mol}$$

$$RF_{C_2H_6[THC-FID]} = 1.02$$

$$x_{C_2H_6} = 10.6 \mu\text{mol/mol}$$

$$x_{NMNEHC} = 145.6 - 0.970 \cdot 18.9 - 1.02 \cdot 10.6$$

$$x_{NMNEHC} = 116.5 \mu\text{mol/mol}$$

(3) For an FTIR, calculate x_{NMNEHC} by summing the hydrocarbon species listed in § 1065.266(c) as follows:

$$x_{NMNEHC} = \sum_{i=1}^N (x_{HCi} - x_{HCi-init})$$

Eq. 1065.660-8

Where:

x_{NMNEHC} = concentration of NMNEHC.

x_{HCi} = the C_1 -equivalent concentration of hydrocarbon species i as measured by the FTIR, not corrected for initial contamination.

$x_{HCi-init}$ = the C_1 -equivalent concentration of the initial system contamination (optional) of hydrocarbon species i , dry-to-wet corrected, as measured by the FTIR.

Example:

$$x_{C_2H_4} = 0.9 \mu\text{mol/mol}$$

$$x_{C_2H_2} = 0.8 \mu\text{mol/mol}$$

$$x_{C_3H_8} = 0.4 \mu\text{mol/mol}$$

$$x_{C_3H_6} = 0.5 \mu\text{mol/mol}$$

$$x_{C_4H_{10}} = 0.3 \mu\text{mol/mol}$$

$$x_{CH_2O} = 0.8 \mu\text{mol/mol}$$

$$x_{C_2H_4O} = 0.3 \mu\text{mol/mol}$$

$$x_{CH_2O_2} = 0.1 \mu\text{mol/mol}$$

$$x_{CH_4O} = 0.1 \mu\text{mol/mol}$$

$$x_{NMNEHC} = 0.9 + 0.8 + 0.4 + 0.5 + 0.3 + 0.8 + 0.3 + 0.1 + 0.1$$

$$x_{NMNEHC} = 4.2 \mu\text{mol/mol}$$

(d) *CH₄ determination.* Use one of the following methods to determine methane (CH₄) concentration, x_{CH_4} :

(1) For an nonmethane cutter (NMC)s, calculate x_{CH_4} using the nonmethane cutter NMC's methane penetration fractions, $PF_{CH_4[NMC-FID]}$, and the ethane response factors, and/or combined penetration fraction, $RPFF_{C_2H_6[NMC-FID]}$, froms and response factors as described in § 1065.365, the THC FID's CH₄methane response factor, $RF_{CH_4[THC-FID]}$, from § 1065.360, the initial THC contamination and dry-to-wet corrected THC concentration, $x_{THC[THC-FID]_{cor}}$,

as determined in paragraph (a) of this section, and the dry-to-wet corrected CH₄methane concentration, $x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$, optionally corrected for initial THC contamination as determined in paragraph (a) of this section.

(i) ~~If you need to account for penetration fractions determined as a function of molar water concentration, use Eq. 1065.660-11. Otherwise, u~~Use the following equation for ~~penetration fractions determined using~~ an NMC configuration as ~~outlined described~~ in § 1065.365(d):

$$x_{\text{CH}_4} = \frac{x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} - x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} \cdot RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}}{RFPF_{\text{CH}_4[\text{NMC-FID}]} - RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} \cdot RF_{\text{CH}_4[\text{THC-FID}]}}$$

Eq. 1065.660-9

Where:

x_{CH_4} = concentration of CH₄.

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$ = ~~the NMC~~ combined ~~ethane-C₂H₆~~ response factor and penetration fraction ~~of the nonmethane cutter~~, according to § 1065.365(d).

$RF_{\text{CH}_4[\text{THC-FID}]}$ = response factor of THC FID to CH₄, according to § 1065.360(d).

$RFPF_{\text{CH}_4[\text{NMC-FID}]}$ = NMC combined CH₄ response factor and penetration fraction, according to § 1065.365(d).

Example:

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} = 10.4 \text{ } \mu\text{mol/mol}$

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = 150.3 \text{ } \mu\text{mol/mol}$

$RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} = 0.019$

$RFPF_{\text{CH}_4[\text{NMC-FID}]} = 1.000$

$RF_{\text{CH}_4[\text{THC-FID}]} = 1.05$

$$x_{\text{CH}_4} = \frac{10.4 - 150.3 \cdot 0.019}{1 - 0.019 \cdot 1.05}$$

$x_{\text{CH}_4} = 7.69 \text{ } \mu\text{mol/mol}$

(ii) Use the following equation for ~~penetration fractions determined using~~ an NMC configuration as ~~outlined described~~ in § 1065.365(e):

$$x_{\text{CH}_4} = \frac{x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} - x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} \cdot PF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}}{RF_{\text{CH}_4[\text{THC-FID}]} \cdot (PF_{\text{CH}_4[\text{NMC-FID}]} - PF_{\text{C}_2\text{H}_6[\text{NMC-FID}]})}$$

Eq. 1065.660-10

Where:

x_{CH_4} = concentration of CH₄.

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{C_2H_6[NMC-FID]}$ = ~~nonmethane cutter ethane~~ NMC C_2H_6 penetration fraction, according to § 1065.365(e).

$RF_{CH_4[THC-FID]}$ = response factor of THC FID to CH_4 , according to § 1065.360(d).

$PF_{CH_4[NMC-FID]}$ = ~~nonmethane cutter~~ NMC CH_4 penetration fraction, according to § 1065.365(e).

Example:

$$x_{THC[NMC-FID]_{cor}} = 10.4 \text{ } \mu\text{mol/mol}$$

$$x_{THC[THC-FID]_{cor}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$PF_{C_2H_6[NMC-FID]} = 0.020$$

$$RF_{CH_4[THC-FID]} = 1.05$$

$$PF_{CH_4[NMC-FID]} = 0.990$$

$$x_{CH_4} = \frac{10.4 - 150.3 \cdot 0.020}{1.05 \cdot (0.990 - 0.020)}$$

$$x_{CH_4} = 7.25 \text{ } \mu\text{mol/mol}$$

(iii) Use the following equation for ~~penetration fractions determined using~~ an NMC configuration ~~as outlined described~~ in § 1065.365(f) ~~or for penetration fractions determined as a function of molar water concentration using an NMC configuration as outlined in § 1065.365(d)~~:

$$x_{CH_4} = \frac{x_{THC[NMC-FID]_{cor}} - x_{THC[THC-FID]_{cor}} \cdot RFPF_{C_2H_6[NMC-FID]}}{PF_{CH_4[NMC-FID]} - RFPF_{C_2H_6[NMC-FID]} \cdot RF_{CH_4[THC-FID]}}$$

Eq. 1065.660-11

Where:

x_{CH_4} = concentration of CH_4 .

$x_{THC[NMC-FID]_{cor}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$x_{THC[THC-FID]_{cor}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$RFPF_{C_2H_6[NMC-FID]}$ = the combined ~~C_2H_6 ethane~~ response factor and penetration fraction of the ~~nonmethane cutter~~ NMC, according to § 1065.365(f).

$PF_{CH_4[NMC-FID]}$ = ~~nonmethane cutter~~ NMC CH_4 penetration fraction, according to § 1065.365(f).

$RF_{CH_4[THC-FID]}$ = response factor of THC FID to CH_4 , according to § 1065.360(d).

Example:

$$x_{THC[NMC-FID]_{cor}} = 10.4 \text{ } \mu\text{mol/mol}$$

$$x_{THC[THC-FID]_{cor}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$RFPF_{C_2H_6[NMC-FID]} = 0.019$$

$$PF_{CH_4[NMC-FID]} = 0.990$$

$$RF_{CH_4[THC-FID]} = 1.05$$

$$x_{CH_4} = \frac{10.4 - 150.3 \cdot 0.019}{0.990 - 0.019 \cdot 1.05}$$

$$x_{CH_4} = 7.78 \text{ } \mu\text{mol/mol}$$

(2) For a GC-FID or FTIR, x_{CH_4} is the actual dry-to-wet corrected ~~methane-CH₄~~ concentration as measured by the analyzer.

(e) *C₂H₆ determination.* For a GC-FID or FTIR, $x_{C_2H_6}$ is the C₁-equivalent, dry-to-wet corrected ~~ethane-C₂H₆~~ concentration as measured by the analyzer.

§ 1065.665 THCE and NMHCE determination.

(a) If you measured an oxygenated hydrocarbon's mass concentration, first calculate its molar concentration in the exhaust sample stream from which the sample was taken (raw or diluted exhaust), and convert this into a C₁-equivalent molar concentration. Add these C₁-equivalent molar concentrations to the molar concentration of non-oxygenated total hydrocarbon (NOTHC). The result is the molar concentration of total hydrocarbon equivalent (THCE). Calculate THCE concentration using the following equations, noting that Eq. 1065.665-3 is required only if you need to convert your oxygenated hydrocarbon (OHC) concentration from mass to moles:

$$x_{THCE} = x_{NOTHC} + \sum_{i=1}^N (x_{OHCi} - x_{OHCi-init})$$

Eq. 1065.665-1

$$x_{NOTHC} = x_{THC[THC-FID]cor} - \sum_{i=1}^N \left((x_{OHCi} - x_{OHCi-init}) \cdot RF_{OHCi[THC-FID]} \right)$$

Eq. 1065.665-2

$$x_{OHCi} = \frac{\frac{m_{dexhOHCi}}{M_{OHCi}}}{\frac{m_{dexh}}{M_{dexh}}} = \frac{n_{dexhOHCi}}{n_{dexh}}$$

Eq. 1065.665-3

Where:

x_{THCE} = the sum of the C₁-equivalent concentrations of non-oxygenated hydrocarbon, alcohols, and aldehydes.

x_{NOTHC} = the sum of the C₁-equivalent concentrations of NOTHC.

x_{OHCi} = the C₁-equivalent concentration of oxygenated species *i* in diluted exhaust, not corrected for initial contamination.

$x_{OHCi-init}$ = the C₁-equivalent concentration of the initial system contamination (optional) of oxygenated species *i*, dry-to-wet corrected.

$x_{THC[THC-FID]cor}$ = the C₁-equivalent response to NOTHC and all OHC in diluted exhaust, HC contamination and dry-to-wet corrected, as measured by the THC-FID.

$RF_{OHCi[THC-FID]}$ = the response factor of the FID to species *i* relative to propane on a C₁-equivalent basis.

M_{dexh} = the molar mass of diluted exhaust as determine in § 1065.340.

$m_{dexhOHCi}$ = the mass of oxygenated species *i* in dilute exhaust.

M_{OHCi} = the C₁-equivalent molecular weight of oxygenated species *i*.

m_{dexh} = the mass of diluted exhaust

$n_{dexhOHCi}$ = the number of moles of oxygenated species *i* in total diluted exhaust flow.

n_{dexh} = the total diluted exhaust flow.

(b) If we require you to determine nonmethane hydrocarbon equivalent (NMHCE), use the following equation:

$$x_{\text{NMHCE}} = x_{\text{THCE}} - RF_{\text{CH}_4[\text{THC-FID}]} \cdot x_{\text{CH}_4}$$

Eq. 1065.665-4

Where:

x_{NMHCE} = the sum of the C₁-equivalent concentrations of nonoxygenated nonmethane hydrocarbon (NONMHC), alcohols, and aldehydes.

$RF_{\text{CH}_4[\text{THC-FID}]}$ = the response factor of THC-FID to CH₄.

x_{CH_4} = concentration of CH₄, HC contamination (optional) and dry-to-wet corrected, as measured by the gas chromatograph FID.

(c) The following example shows how to determine NMHCE emissions based on ethanol (C₂H₅OH), methanol (CH₃OH), acetaldehyde (C₂H₄O), and formaldehyde (CH₂O) as C₁-equivalent molar concentrations:

$$x_{\text{THC}[\text{THC-FID}]\text{cor}} = 145.6 \text{ } \mu\text{mol/mol}$$

$$x_{\text{CH}_4} = 18.9 \text{ } \mu\text{mol/mol}$$

$$x_{\text{C}_2\text{H}_5\text{OH}} = 100.8 \text{ } \mu\text{mol/mol}$$

$$x_{\text{CH}_3\text{OH}} = 1.1 \text{ } \mu\text{mol/mol}$$

$$x_{\text{C}_2\text{H}_4\text{O}} = 19.1 \text{ } \mu\text{mol/mol}$$

$$x_{\text{CH}_2\text{O}} = 1.3 \text{ } \mu\text{mol/mol}$$

$$RF_{\text{CH}_4[\text{THC-FID}]} = 1.07$$

$$RF_{\text{C}_2\text{H}_5\text{OH}[\text{THC-FID}]} = 0.76$$

$$RF_{\text{CH}_3\text{OH}[\text{THC-FID}]} = 0.74$$

$$RF_{\text{H}_2\text{H}_4\text{O}[\text{THC-FID}]} = 0.50$$

$$RF_{\text{CH}_2\text{O}[\text{THC-FID}]} = 0.0$$

$$x_{\text{NMHCE}} = x_{\text{THC}[\text{THC-FID}]\text{cor}} - (x_{\text{C}_2\text{H}_5\text{OH}} \cdot RF_{\text{C}_2\text{H}_5\text{OH}[\text{THC-FID}]} + x_{\text{CH}_3\text{OH}} \cdot RF_{\text{CH}_3\text{OH}[\text{THC-FID}]} + x_{\text{C}_2\text{H}_4\text{O}} \cdot RF_{\text{C}_2\text{H}_4\text{O}[\text{THC-FID}]} + x_{\text{CH}_2\text{O}} \cdot RF_{\text{CH}_2\text{O}[\text{THC-FID}]}) + x_{\text{C}_2\text{H}_5\text{OH}} + x_{\text{CH}_3\text{OH}} + x_{\text{C}_2\text{H}_4\text{O}} + x_{\text{CH}_2\text{O}} - (RF_{\text{CH}_4[\text{THC-FID}]} \cdot x_{\text{CH}_4})$$

$$x_{\text{NMHCE}} = 145.6 - (100.8 \cdot 0.76 + 1.1 \cdot 0.74 + 19.1 \cdot 0.50 + 1.3 \cdot 0) + 100.8 + 1.1 + 19.1 + 1.3 - (1.07 \cdot 18.9)$$

$$x_{\text{NMHCE}} = 160.71 \text{ } \mu\text{mol/mol}$$

§ 1065.667 Dilution air background emission correction.

(a) To determine the mass of background emissions to subtract from a diluted exhaust sample, first determine the total flow of dilution air, n_{dil} , over the test interval. This may be a measured quantity or a calculated quantity. Multiply the total flow of dilution air by the mean mole fraction (i.e., concentration) of a background emission. This may be a time-weighted mean or a flow-weighted mean (e.g., a proportionally sampled background). Finally, multiply by the molar mass, M , of the associated gaseous emission constituent. The product of n_{dil} and the mean molar concentration of a background emission and its molar mass, M , is the total background emission mass, m . In the case of PM, where the mean PM concentration is already in units of mass per mole of exhaust, multiply it by the total amount of dilution air flow, and the result is the total

background mass of PM, m_{PM} . Subtract total background mass from total mass to correct for background emissions.

(b) You may determine the total flow of dilution air by a direct flow measurement.

(c) You may determine the total flow of dilution air by subtracting the calculated raw exhaust molar flow as described in § 1065.655(g) from the measured dilute exhaust flow. This may be done by totaling continuous calculations or by using batch results.

(d) You may determine the total flow of dilution air from the measured dilute exhaust flow and a chemical balance of the fuel, DEF, intake air, and dilute exhaust as described in § 1065.655. For this paragraph (d), the molar flow of dilution air is calculated by multiplying the dilute exhaust flow by the mole fraction of dilution gas to dilute exhaust, $x_{dil/exh}$, from the dilute chemical balance. This may be done by totaling continuous calculations or by using batch results. For example, to use batch results, the total flow of dilution air is calculated by multiplying the total flow of diluted exhaust, n_{dexh} , by the flow-weighted mean mole fraction of dilution air in diluted exhaust, $\bar{x}_{dil/exh}$. Calculate $\bar{x}_{dil/exh}$ using flow-weighted mean concentrations of emissions in the chemical balance, as described in § 1065.655. The chemical balance in § 1065.655 assumes that your engine operates stoichiometrically, even if it is a lean-burn engine, such as a compression-ignition engine. Note that for lean-burn engines this assumption could result in an error in emission calculations. This error could occur because the chemical balance in § 1065.655 treats excess air passing through a lean-burn engine as if it was dilution air. If an emission concentration expected at the standard is about 100 times its dilution air background concentration, this error is negligible. However, if an emission concentration expected at the standard is similar to its background concentration, this error could be significant. If this error might affect your ability to show that your engines comply with applicable standards in this chapter, we recommend that you either determine the total flow of dilution air using one of the more accurate methods in paragraph (b) or (c) of this section, or remove background emissions from dilution air by HEPA filtration, chemical adsorption, or catalytic scrubbing. You might also consider using a partial-flow dilution technique such as a bag mini-diluter, which uses purified air as the dilution air.

(e) The following is an example of using the flow-weighted mean fraction of dilution air in diluted exhaust, $\bar{x}_{dil/exh}$, and the total mass of background emissions calculated using the total flow of diluted exhaust, n_{dexh} , as described in § 1065.650(c):

$$m_{bkgnd} = \bar{x}_{dil/exh} \cdot m_{bkgnddexh}$$

Eq. 1065.667-1

$$m_{bkgnddexh} = M \cdot \bar{x}_{bkgnd} \cdot n_{dexh}$$

Eq. 1065.667-2

Example:

$$M_{NOx} = 46.0055 \text{ g/mol}$$

$$\bar{x}_{bkgnd} = 0.05 \text{ } \mu\text{mol/mol} = 0.05 \cdot 10^{-6} \text{ mol/mol}$$

$$n_{dexh} = 23280.5 \text{ mol}$$

$$\bar{x}_{dil/exh} = 0.843 \text{ mol/mol}$$

$$m_{bkgndNOxdexh} = 46.0055 \cdot 0.05 \cdot 10^{-6} \cdot 23280.5$$

$$m_{bkgndNOxdexh} = 0.0536 \text{ g}$$

$$m_{bkgndNOx} = 0.843 \cdot 0.0536$$

$$m_{\text{bkgn dNO}_x} = 0.0452 \text{ g}$$

(f) The following is an example of using the fraction of dilution air in diluted exhaust, $x_{\text{dil/exh}}$, and the mass rate of background emissions calculated using the flow rate of diluted exhaust, \dot{n}_{dexh} , as described in § 1065.650(c):

$$\dot{m}_{\text{bkgn d}} = x_{\text{dil/exh}} \cdot \dot{m}_{\text{bkgn ddexh}}$$

$$\text{Eq. 1065.667-3}$$

$$\dot{m}_{\text{bkgn ddexh}} = M \cdot x_{\text{bkgn d}} \cdot \dot{n}_{\text{dexh}}$$

$$\text{Eq. 1065.667-4}$$

Example:

$$M_{\text{NO}_x} = 46.0055 \text{ g/mol}$$

$$x_{\text{bkgn d}} = 0.05 \text{ } \mu\text{mol/mol} = 0.05 \cdot 10^{-6} \text{ mol/mol}$$

$$\dot{n}_{\text{dexh}} = 23280.5 \text{ mol/s}$$

$$x_{\text{dil/exh}} = 0.843 \text{ mol/mol}$$

$$\dot{m}_{\text{bkgn dNO}_x \text{ dexh}} = 46.0055 \cdot 0.05 \cdot 10^{-6} \cdot 23280.5$$

$$\dot{m}_{\text{bkgn dNO}_x \text{ dexh}} = 0.0536 \text{ g/hr}$$

$$\dot{m}_{\text{bkgn dNO}_x} = 0.843 \cdot 0.0536$$

$$\dot{m}_{\text{bkgn dNO}_x} = 0.0452 \text{ g/hr}$$

§ 1065.670 NO_x intake-air humidity and temperature corrections.

See the standard-setting part to determine if you may correct NO_x emissions for the effects of intake-air humidity or temperature. Use the NO_x intake-air humidity and temperature corrections specified in the standard-setting part instead of the NO_x intake-air humidity correction specified in this part 1065. If the standard-setting part does not prohibit correcting NO_x emissions for intake-air humidity according to this part 1065, correct NO_x concentrations for intake-air humidity as described in this section. See § 1065.650(c)(1) for the proper sequence for applying the NO_x intake-air humidity and temperature corrections. You may use a time-weighted mean intake air humidity to calculate this correction if your intake air humidity remains within a tolerance of ± 0.0025 mol/mol of the mean value over the test interval. For intake-air humidity correction, use one of the following approaches:

(a) For compression-ignition engines operating on carbon-containing fuels and lean-burn combustion engines operating on fuels other than carbon-containing fuels, correct for intake-air humidity using the following equation:

$$x_{\text{NO}_x \text{ cor}} = x_{\text{NO}_x \text{ uncor}} \cdot (9.953 \cdot x_{\text{H}_2\text{O}} + 0.832)$$

$$\text{Eq. 1065.670-1}$$

Example:

$$x_{\text{NO}_x \text{ uncor}} = 700.5 \text{ } \mu\text{mol/mol}$$

$$x_{\text{H}_2\text{O}} = 0.022 \text{ mol/mol}$$

$$x_{\text{NO}_x \text{ cor}} = 700.5 \cdot (9.953 \cdot 0.022 + 0.832)$$

$$x_{\text{NO}_x \text{ cor}} = 736.2 \text{ } \mu\text{mol/mol}$$

(b) For spark-ignition engines operating on carbon-containing fuels and stoichiometric combustion engines operating on fuels other than carbon-containing fuels, correct for intake-air humidity using the following equation:

$$x_{\text{NOxcor}} = x_{\text{NOxuncor}} \cdot (18.840 \cdot x_{\text{H}_2\text{O}} + 0.68094)$$

Eq. 1065.670-2

Example:

$$x_{\text{NOxuncor}} = 154.7 \text{ } \mu\text{mol/mol}$$

$$x_{\text{H}_2\text{O}} = 0.022 \text{ mol/mol}$$

$$x_{\text{NOxcor}} = 154.7 \cdot (18.840 \cdot 0.022 + 0.68094)$$

$$x_{\text{NOxcor}} = 169.5 \text{ } \mu\text{mol/mol}$$

(c) Develop your own correction, based on good engineering judgment.

§ 1065.672 Drift correction.

(a) *Scope and frequency.* Perform the calculations in this section to determine if gas analyzer drift invalidates the results of a test interval. If drift does not invalidate the results of a test interval, correct that test interval's gas analyzer responses for drift according to this section. Use the drift-corrected gas analyzer responses in all subsequent emission calculations. Note that the acceptable threshold for gas analyzer drift over a test interval is specified in § 1065.550 for both laboratory testing and field testing.

(b) *Correction principles.* The calculations in this section utilize a gas analyzer's responses to reference zero and span concentrations of analytical gases, as determined sometime before and after a test interval. The calculations correct the gas analyzer's responses that were recorded during a test interval. The correction is based on an analyzer's mean responses to reference zero and span gases, and it is based on the reference concentrations of the zero and span gases themselves. Validate and correct for drift as follows:

(c) *Drift validation.* After applying all the other corrections—except drift correction—to all the gas analyzer signals, calculate brake-specific emissions according to § 1065.650. Then correct all gas analyzer signals for drift according to this section. Recalculate brake-specific emissions using all of the drift-corrected gas analyzer signals. Validate and report the brake-specific emission results before and after drift correction according to § 1065.550.

(d) *Drift correction.* Correct all gas analyzer signals as follows:

(1) Correct each recorded concentration, x_i , for continuous sampling or for batch sampling, \bar{x} .

(2) Correct for drift using the following equation:

$$x_{\text{idriftcorrected}} = x_{\text{refzero}} + (x_{\text{refspan}} - x_{\text{refzero}}) \cdot \frac{2x_i - (x_{\text{prezero}} + x_{\text{postzero}})}{(x_{\text{prespan}} + x_{\text{postspan}}) - (x_{\text{prezero}} + x_{\text{postzero}})}$$

Eq. 1065.672-1

Where:

$x_{\text{idriftcorrected}}$ = concentration corrected for drift.

x_{refzero} = reference concentration of the zero gas, which is usually zero unless known to be otherwise.

x_{refspan} = reference concentration of the span gas.

x_{prespan} = pre-test interval gas analyzer response to the span gas concentration.

x_{postspan} = post-test interval gas analyzer response to the span gas concentration.
 x_i or \bar{x} = concentration recorded during test, before drift correction.
 x_{prezero} = pre-test interval gas analyzer response to the zero gas concentration.
 x_{postzero} = post-test interval gas analyzer response to the zero gas concentration.

Example:

$x_{\text{refzero}} = 0 \text{ } \mu\text{mol/mol}$

$x_{\text{refspan}} = 1800.0 \text{ } \mu\text{mol/mol}$

$x_{\text{prespan}} = 1800.5 \text{ } \mu\text{mol/mol}$

$x_{\text{postspan}} = 1695.8 \text{ } \mu\text{mol/mol}$

x_i or $\bar{x} = 435.5 \text{ } \mu\text{mol/mol}$

$x_{\text{prezero}} = 0.6 \text{ } \mu\text{mol/mol}$

$x_{\text{postzero}} = -5.2 \text{ } \mu\text{mol/mol}$

$$x_{\text{idriftcorrected}} = 0 + (1800.0 - 0) \cdot \frac{2 \cdot 435.5 - (0.6 + (-5.2))}{(1800.5 + 1695.8) - (0.6 + (-5.2))}$$

$x_{\text{idriftcorrected}} = 450.2 \text{ } \mu\text{mol/mol}$

(3) For any pre-test interval concentrations, use the last concentration determined before the test interval. For some test intervals, the last pre-zero or pre-span might have occurred before one or more earlier test intervals.

(4) For any post-test interval concentrations, use the first concentration determined after the test interval. For some test intervals, the first post-zero or post-span might occur after one or more later test intervals.

(5) If you do not record any pre-test interval analyzer response to the span gas concentration, x_{prespan} , set x_{prespan} equal to the reference concentration of the span gas: $x_{\text{prespan}} = x_{\text{refspan}}$.

(6) If you do not record any pre-test interval analyzer response to the zero gas concentration, x_{prezero} , set x_{prezero} equal to the reference concentration of the zero gas: $x_{\text{prezero}} = x_{\text{refzero}}$.

(7) Usually the reference concentration of the zero gas, x_{refzero} , is zero: $x_{\text{refzero}} = 0 \text{ } \mu\text{mol/mol}$. However, in some cases you might know that x_{refzero} has a non-zero concentration. For example, if you zero a CO₂ analyzer using ambient air, you may use the default ambient air concentration of CO₂, which is 375 $\mu\text{mol/mol}$. In this case, $x_{\text{refzero}} = 375 \text{ } \mu\text{mol/mol}$. Note that when you zero an analyzer using a non-zero x_{refzero} , you must set the analyzer to output the actual x_{refzero} concentration. For example, if $x_{\text{refzero}} = 375 \text{ } \mu\text{mol/mol}$, set the analyzer to output a value of 375 $\mu\text{mol/mol}$ when the zero gas is flowing to the analyzer.

§ 1065.675 CLD quench verification calculations.

Perform CLD quench-check calculations as follows:

(a) Perform a CLD analyzer quench verification test as described in § 1065.370.

(b) Estimate the maximum expected mole fraction of water during emission testing, $x_{\text{H}_2\text{Oexp}}$.

Make this estimate where the humidified NO span gas was introduced in § 1065.370(e)(6). When estimating the maximum expected mole fraction of water, consider the maximum expected water content in intake air, fuel combustion products, and dilution air (if applicable). If you introduced the humidified NO span gas into the sample system upstream of a sample dryer during the verification test, you need not estimate the maximum expected mole fraction of water and you must set $x_{\text{H}_2\text{Oexp}}$ equal to $x_{\text{H}_2\text{Omeas}}$.

(c) Estimate the maximum expected CO₂ concentration during emission testing, $x_{\text{CO}_2\text{exp}}$. Make this estimate at the sample system location where the blended NO and CO₂ span gases are introduced according to § 1065.370(d)(10). When estimating the maximum expected CO₂ concentration, consider the maximum expected CO₂ content in fuel combustion products and dilution air.

(d) Calculate quench as follows:

$$\text{quench} = \left(\left(\frac{\frac{x_{\text{NOwet}}}{1 - x_{\text{H}_2\text{Omeas}}}}{x_{\text{NOdry}}} - 1 \right) \cdot \frac{x_{\text{H}_2\text{Oexp}}}{x_{\text{H}_2\text{Omeas}}} + \left(\frac{x_{\text{NOmeas}}}{x_{\text{NOact}}} - 1 \right) \cdot \frac{x_{\text{CO}_2\text{exp}}}{x_{\text{CO}_2\text{act}}} \right) \cdot 100 \%$$

Eq. 1065.675-1

Where:

quench = amount of CLD quench.

x_{NOdry} = concentration of NO upstream of a humidity generator, according to § 1065.370(e)(4).

x_{NOwet} = measured concentration of NO downstream of a humidity generator, according to § 1065.370(e)(9).

$x_{\text{H}_2\text{Oexp}}$ = maximum expected mole fraction of water during emission testing, according to paragraph (b) of this section.

$x_{\text{H}_2\text{Omeas}}$ = measured mole fraction of water during the quench verification, according to § 1065.370(e)(7).

x_{NOmeas} = measured concentration of NO when NO span gas is blended with CO₂ span gas, according to § 1065.370(d)(10).

x_{NOact} = actual concentration of NO when NO span gas is blended with CO₂ span gas, according to § 1065.370(d)(11) and calculated according to Eq. 1065.675-2.

$x_{\text{CO}_2\text{exp}}$ = maximum expected concentration of CO₂ during emission testing, according to paragraph (c) of this section.

$x_{\text{CO}_2\text{act}}$ = actual concentration of CO₂ when NO span gas is blended with CO₂ span gas, according to § 1065.370(d)(9).

$$x_{\text{NOact}} = \left(1 - \frac{x_{\text{CO}_2\text{act}}}{x_{\text{CO}_2\text{span}}} \right) \cdot x_{\text{NOspan}}$$

Eq. 1065.675-2

Where:

x_{NOspan} = the NO span gas concentration input to the gas divider, according to § 1065.370(d)(5).

$x_{\text{CO}_2\text{span}}$ = the CO₂ span gas concentration input to the gas divider, according to § 1065.370(d)(4).

Example:

$x_{\text{NOdry}} = 1800.0 \mu\text{mol/mol}$

$x_{\text{NOwet}} = 1739.6 \mu\text{mol/mol}$

$x_{\text{H}_2\text{Oexp}} = 0.030 \text{ mol/mol}$

$x_{\text{H}_2\text{Omeas}} = 0.030 \text{ mol/mol}$

$x_{\text{NOmeas}} = 1515.2 \mu\text{mol/mol}$

$x_{\text{NOspan}} = 3001.6 \mu\text{mol/mol}$

$x_{\text{CO}_2\text{exp}} = 3.2 \%$

$$x_{\text{CO}_2\text{span}} = 6.1 \%$$

$$x_{\text{CO}_2\text{act}} = 2.98 \%$$

$$x_{\text{NOact}} = \left(1 - \frac{2.98}{6.1}\right) \cdot 3001.6 = 1535.24459 \mu\text{mol/mol}$$

$$\text{quench} = \left(\left(\frac{1739.6}{1800.0} - 1 \right) \cdot \frac{0.030}{0.030} + \left(\frac{1515.2}{1535.24459} - 1 \right) \cdot \frac{3.2}{2.98} \right) \cdot 100 \%$$

$$\text{quench} = (-0.0036655 - 0.014020171) \cdot 100 \% = -1.7685671 \%$$

§ 1065.680 Adjusting emission levels to account for infrequently regenerating

aftertreatment devices.

This section describes how to calculate and apply emission adjustment factors for engines using aftertreatment technology with infrequent regeneration events that may occur during testing. These adjustment factors are typically calculated based on measurements conducted for the purposes of engine certification, and then used to adjust the results of testing related to demonstrating compliance with emission standards. For this section, “regeneration” means an intended event during which emission levels change while the system restores aftertreatment performance. For example, exhaust gas temperatures may increase temporarily to remove sulfur from an adsorber or SCR catalyst or to oxidize accumulated particulate matter in a trap. The duration of this event extends until the aftertreatment performance and emission levels have returned to normal baseline levels. Also, “infrequent” refers to regeneration events that are expected to occur on average less than once over a transient or ramped-modal duty cycle, or on average less than once per mode in a discrete-mode test.

(a) *Adjustment factors.* Apply adjustment factors based on whether there is active regeneration during a test segment. The test segment may be a test interval or a full duty cycle, as described in paragraph (b) of this section. For engines subject to standards over more than one duty cycle, you must develop adjustment factors under this section for each separate duty cycle. You must be able to identify active regeneration in a way that is readily apparent during all testing. All adjustment factors for regeneration are additive.

(1) If active regeneration does not occur during a test segment, apply an upward adjustment factor, *UAF*, that will be added to the measured emission rate for that test segment. Use the following equation to calculate *UAF*:

$$UAF_{[\text{cycle}]} = EF_{A[\text{cycle}]} - EF_{L[\text{cycle}]}$$

Eq. 1065.680-1

Where:

$EF_{A[\text{cycle}]}$ = the average emission factor over the test segment as determined in paragraph (a)(4) of this section.

$EF_{L[\text{cycle}]}$ = measured emissions over a complete test segment in which active regeneration does not occur.

Example:

$$EF_{\text{ARMC}} = 0.15 \text{ g/kW}\cdot\text{hr}$$

$$EF_{LRMC} = 0.11 \text{ g/kW}\cdot\text{hr}$$

$$UAF_{RMC} = 0.15 - 0.11 = 0.04 \text{ g/kW}\cdot\text{hr}$$

(2) If active regeneration occurs or starts to occur during a test segment, apply a downward adjustment factor, DAF , that will be subtracted from the measured emission rate for that test segment. Use the following equation to calculate DAF :

$$DAF_{[cycle]} = EF_{H[cycle]} - EF_{A[cycle]}$$

Eq. 1065.680-2

Where:

$EF_{H[cycle]}$ = measured emissions over the test segment from a complete regeneration event, or the average emission rate over multiple complete test segments with regeneration if the complete regeneration event lasts longer than one test segment.

Example:

$$EF_{ARMC} = 0.15 \text{ g/kW}\cdot\text{hr}$$

$$EF_{HRMC} = 0.50 \text{ g/kW}\cdot\text{hr}$$

$$DAF_{RMC} = 0.50 - 0.15 = 0.35 \text{ g/kW}\cdot\text{hr}$$

(3) Note that emissions for a given pollutant may be lower during regeneration, in which case EF_L would be greater than EF_H , and both UAF and DAF would be negative.

(4) Calculate the average emission factor, EF_A , as follows:

$$EF_{A[cycle]} = F_{[cycle]} \cdot EF_{H[cycle]} + (1.00 - F_{[cycle]}) \cdot EF_{L[cycle]}$$

Eq. 1065.680-3

Where:

$F_{[cycle]}$ = the frequency of the regeneration event during the test segment, expressed in terms of the fraction of equivalent test segments during which active regeneration occurs, as described in paragraph (a)(5) of this section.

Example:

$$F_{RMC} = 0.10$$

$$EF_{ARMC} = 0.10 \cdot 0.50 + (1.00 - 0.10) \cdot 0.11 = 0.15 \text{ g/kW}\cdot\text{hr}$$

(5) The frequency of regeneration, F , generally characterizes how often a regeneration event occurs within a series of test segments. Determine F using the following equation, subject to the provisions of paragraph (a)(6) of this section:

$$F_{[cycle]} = \frac{i_r[cycle]}{i_f[cycle] + i_r[cycle]}$$

Eq. 1065.680-4

Where:

$i_r[cycle]$ = the number of successive test segments required to complete an active regeneration, rounded up to the next whole number.

$i_f[cycle]$ = the number of test segments from the end of one complete regeneration event to the start of the next active regeneration, without rounding.

Example:

$$i_{\text{RMC}} = 2$$

$$i_{\text{RMC}} = 17.86$$

$$F_{\text{RMC}} = \frac{2}{17.86 + 2} = 0.10$$

- (6) Use good engineering judgment to determine i_r and i_t , as follows:
- (i) For engines that are programmed to regenerate after a specific time interval, you may determine the duration of a regeneration event and the time between regeneration events based on the engine's design parameters. For other engines, determine these values based on measurements from in-use operation or from running repetitive duty cycles in a laboratory.
 - (ii) For engines subject to standards over multiple duty cycles, such as for transient and steady-state testing, apply this same calculation to determine a value of F for each duty cycle.
 - (iii) Consider an example for an engine that is designed to regenerate its PM filter 500 minutes after the end of the last regeneration event, with the regeneration event lasting 30 minutes. If the RMC takes 28 minutes, $i_{\text{RMC}} = 2$ ($30 \div 28 = 1.07$, which rounds up to 2), and $i_{\text{RMC}} = 500 \div 28 = 17.86$.
- (b) Develop adjustment factors for different types of testing as follows:
- (1) *Discrete-mode testing.* Develop separate adjustment factors for each test mode (test interval) of a discrete-mode test. When measuring EF_H , if a regeneration event has started but is not complete when you reach the end of the sampling time for a test interval, extend the sampling period for that test interval until the regeneration event is complete.
 - (2) *Ramped-modal and transient testing.* Develop a separate set of adjustment factors for an entire ramped-modal cycle or transient duty cycle. When measuring EF_H , if a regeneration event has started but is not complete when you reach the end of the duty-cycle, start the next repeat test as soon as possible, allowing for the time needed to complete emission measurement and installation of new filters for PM measurement; in that case EF_H is the average emission level for the test segments that included regeneration.
 - (3) *Accounting for cold-start measurements.* For engines subject to cold-start testing requirements, incorporate cold-start operation into your analysis as follows:
 - (i) Determine the frequency of regeneration, F , in a way that incorporates the impact of cold-start operation in proportion to the cold-start weighting factor specified in the standard-setting part. You may use good engineering judgment to determine the effect of cold-start operation analytically.
 - (ii) Treat cold-start testing and hot-start testing together as a single test segment for adjusting measured emission results under this section. Apply the adjustment factor to the composite emission result.
 - (iii) You may apply the adjustment factor only to the hot-start test result if your aftertreatment technology does not regenerate during cold operation as represented by the cold-start transient duty cycle. If we ask for it, you must demonstrate this by engineering analysis or by test data.
- (c) If an engine has multiple regeneration strategies, determine and apply adjustment factors under this section separately for each type of regeneration.

§ 1065.690 Buoyancy correction for PM sample media.

(a) *General.* Correct PM sample media for their buoyancy in air if you weigh them on a balance. The buoyancy correction depends on the sample media density, the density of air, and the density of the calibration weight used to calibrate the balance. The buoyancy correction does not account for the buoyancy of the PM itself, because the mass of PM typically accounts for only (0.01 to 0.10) % of the total weight. A correction to this small fraction of mass would be at the most 0.010 %.

(b) *PM sample media density.* Different PM sample media have different densities. Use the known density of your sample media, or use one of the densities for some common sampling media, as follows:

(1) For PTFE-coated borosilicate glass, use a sample media density of 2300 kg/m³.

(2) For PTFE membrane (film) media with an integral support ring of polymethylpentene that accounts for 95 % of the media mass, use a sample media density of 920 kg/m³.

(3) For PTFE membrane (film) media with an integral support ring of PTFE, use a sample media density of 2144 kg/m³.

(c) *Air density.* Because a PM balance environment must be tightly controlled to an ambient temperature of (22 ±1) °C and humidity has an insignificant effect on buoyancy correction, air density is primarily a function of atmospheric pressure. Therefore you may use nominal constant values for temperature and humidity when determining the air density of the balance environment in Eq. 1065.690-2.

(d) *Calibration weight density.* Use the stated density of the material of your metal calibration weight. The example calculation in this section uses a density of 8000 kg/m³, but you should know the density of your weight from the calibration weight supplier or the balance manufacturer if it is an internal weight.

(e) *Correction calculation.* Correct the PM sample media for buoyancy using the following equations:

$$m_{\text{cor}} = m_{\text{uncor}} \cdot \left(\frac{1 - \frac{\rho_{\text{air}}}{\rho_{\text{weight}}}}{1 - \frac{\rho_{\text{air}}}{\rho_{\text{media}}}} \right)$$

Eq. 1065.690-1

Where:

m_{cor} = PM mass corrected for buoyancy.

m_{uncor} = PM mass uncorrected for buoyancy.

ρ_{air} = density of air in balance environment.

ρ_{weight} = density of calibration weight used to span balance.

ρ_{media} = density of PM sample media, such as a filter.

$$\rho_{\text{air}} = \frac{p_{\text{abs}} \cdot M_{\text{mix}}}{R \cdot T_{\text{amb}}}$$

Eq. 1065.690-2

Where:

p_{abs} = absolute pressure in balance environment.

M_{mix} = molar mass of air in balance environment.

R = molar gas constant.

T_{amb} = absolute ambient temperature of balance environment.

Example:

$p_{\text{abs}} = 99.980 \text{ kPa}$

$T_{\text{sat}} = T_{\text{dew}} = 9.5 \text{ }^\circ\text{C}$

Using Eq. 1065.645-1,

$p_{\text{H}_2\text{O}} = 1.1866 \text{ kPa}$

Using Eq. 1065.645-3,

$x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$

Using Eq. 1065.640-9,

$M_{\text{mix}} = 28.83563 \text{ g/mol}$

$R = 8.314472 \text{ J/(mol}\cdot\text{K)}$

$T_{\text{amb}} = 20 \text{ }^\circ\text{C}$

$$\rho_{\text{air}} = \frac{99.980 \cdot 28.83563}{8.314472 \cdot 293.15}$$

$\rho_{\text{air}} = 1.18282 \text{ kg/m}^3$

$m_{\text{uncorr}} = 100.0000 \text{ mg}$

$\rho_{\text{weight}} = 8000 \text{ kg/m}^3$

$\rho_{\text{media}} = 920 \text{ kg/m}^3$

$$m_{\text{cor}} = 100.0000 \cdot \left(\frac{1 - \frac{1.18282}{8000}}{1 - \frac{1.18282}{920}} \right)$$

$m_{\text{cor}} = 100.1139 \text{ mg}$

§ 1065.695 Data requirements.

(a) To determine the information we require from engine tests, refer to the standard-setting part and request from your EPA Program Officer the format used to apply for certification or demonstrate compliance. We may require different information for different purposes, such as for certification applications, approval requests for alternate procedures, selective enforcement audits, laboratory audits, production-line test reports, and field-test reports.

(b) See the standard-setting part and § 1065.25 regarding recordkeeping.

(c) We may ask you the following about your testing, and we may ask you for other information as allowed under the Act:

(1) What approved alternate procedures did you use? For example:

(i) Partial-flow dilution for proportional PM.

(ii) CARB test procedures.

(iii) ISO test procedures.

(2) What laboratory equipment did you use? For example, the make, model, and description of the following:

(i) Engine dynamometer and operator demand.

(ii) Probes, dilution, transfer lines, and sample preconditioning components.

- (iii) Batch storage media (such as the bag material or PM filter material).
- (3) What measurement instruments did you use? For example, the make, model, and description of the following:
- (i) Speed and torque instruments.
 - (ii) Flow meters.
 - (iii) Gas analyzers.
 - (iv) PM balance.
- (4) When did you conduct calibrations and performance checks and what were the results? For example, the dates and results of the following:
- (i) Linearity verification.
 - (ii) Interference checks.
 - (iii) Response checks.
 - (iv) Leak checks.
 - (v) Flow meter checks.
- (5) What engine did you test? For example, the following:
- (i) Manufacturer.
 - (ii) Family name on engine label.
 - (iii) Model.
 - (iv) Model year.
 - (v) Identification number.
- (6) How did you prepare and configure your engine for testing? Consider the following examples:
- (i) Dates, hours, duty cycle and fuel used for service accumulation.
 - (ii) Dates and description of scheduled and unscheduled maintenance.
 - (iii) Allowable pressure range of intake restriction.
 - (iv) Allowable pressure range of exhaust restriction.
 - (v) Charge air cooler volume.
 - (vi) Charge air cooler outlet temperature, specified engine conditions and location of temperature measurement.
 - (vii) Fuel temperature and location of measurement.
 - (viii) Any aftertreatment system configuration and description.
 - (ix) Any crankcase ventilation configuration and description (e.g., open, closed, PCV, crankcase scavenged).
 - (x) Number and type of preconditioning cycles.
- (7) How did you test your engine? For example:
- (i) Constant speed or variable speed.
 - (ii) Mapping procedure (step or sweep).
 - (iii) Continuous or batch sampling for each emission.
 - (iv) Raw or dilute sampling; any dilution-air background sampling.
 - (v) Duty cycle and test intervals.
 - (vi) Cold-start, hot-start, warmed-up running.
 - (vii) Absolute pressure, temperature, and dewpoint of intake and dilution air.
 - (viii) Simulated engine loads, curb idle transmission torque value.
 - (ix) Warm-idle speed value.
 - (x) Simulated vehicle signals applied during testing.
 - (xi) Bypassed governor controls during testing.

- (xii) Date, time, and location of test (e.g., dynamometer laboratory identification).
 - (xiii) Cooling medium for engine and charge air.
 - (xiv) Operating temperatures of coolant, head, and block.
 - (xv) Natural or forced cool-down and cool-down time.
 - (xvi) Canister loading.
- (8) How did you validate your testing? For example, results from the following:
- (i) Duty cycle regression statistics for each test interval.
 - (ii) Proportional sampling.
 - (iii) Drift.
 - (iv) Reference PM sample media in PM-stabilization environment.
 - (v) Carbon balance error verification, if performed.
- (9) How did you calculate results? For example, results from the following:
- (i) Drift correction.
 - (ii) Noise correction.
 - (iii) “Dry-to-wet” correction.
 - (iv) NMHC, CH₄, and contamination correction.
 - (v) [Chemical balance method—carbon-based or hydrogen-based chemical balance method.](#)
 - (vi) NO_x humidity correction.
 - (vii) Brake-specific emission formulation—total mass divided by total work, mass rate divided by power, or ratio of mass to work.
 - (viii) Rounding emission results.
- (10) What were the results of your testing? For example:
- (i) Maximum mapped power and speed at maximum power.
 - (ii) Maximum mapped torque and speed at maximum torque.
 - (iii) For constant-speed engines: no-load governed speed.
 - (iv) For constant-speed engines: test torque.
 - (v) For variable-speed engines: maximum test speed.
 - (vi) Speed versus torque map.
 - (vii) Speed versus power map.
 - (viii) Brake-specific emissions over the duty cycle and each test interval.
 - (ix) Brake-specific fuel consumption.
- (11) What fuel did you use? For example:
- (i) Fuel that met specifications of subpart H of this part.
 - (ii) Alternate fuel.
 - (iii) Oxygenated fuel.
- (12) How did you field test your engine? For example:
- (i) Data from paragraphs (c)(1), (3), (4), (5), and (9) of this section.
 - (ii) Probes, dilution, transfer lines, and sample preconditioning components.
 - (iii) Batch storage media (such as the bag material or PM filter material).
 - (iv) Continuous or batch sampling for each emission.
 - (v) Raw or dilute sampling; any dilution air background sampling.
 - (vi) Cold-start, hot-start, warmed-up running.
 - (vii) Intake and dilution air absolute pressure, temperature, dewpoint.
 - (viii) Curb idle transmission torque value.
 - (ix) Warm idle speed value, any enhanced-idle speed value.

- (x) Date, time, and location of test (e.g., identify the testing laboratory).
- (xi) Proportional sampling validation.
- (xii) Drift validation.
- (xiii) Operating temperatures of coolant, head, and block.
- (xiv) Vehicle make, model, model year, identification number.

Subpart H—Engine Fluids, Test Fuels, Analytical Gases and Other Calibration Standards

§ 1065.701 General requirements for test fuels.

(a) *General.* For all emission measurements, use test fuels that meet the specifications in this subpart, unless the standard-setting part directs otherwise. Section 1065.10(c)(1) does not apply with respect to test fuels. Note that the standard-setting parts generally require that you design your emission controls to function properly when using commercially available fuels, even if they differ from the test fuel. Where we specify multiple grades of a certain fuel type (such as diesel fuel with different sulfur concentrations), see the standard-setting part to determine which grade to use.

(b) *Fuels meeting alternate specifications.* We may allow you to use a different test fuel (such as California LEV III gasoline) if it does not affect your ability to show that your engines would comply with all applicable emission standards in this chapter using the test fuel specified in this subpart.

(c) *Fuels not specified in this subpart.* If you produce engines that run on a type of fuel (or mixture of fuels) that we do not specify in this subpart, you must get our written approval to establish the appropriate test fuel. See the standard-setting part for provisions related to fuels and fuel mixtures not specified in this subpart.

(1) For engines designed to operate on a single fuel, we will generally allow you to use the fuel if you show us all the following things are true:

- (i) Show that your engines will use only the designated fuel in service.
- (ii) Show that this type of fuel is commercially available.
- (iii) Show that operating the engines on the fuel we specify would be inappropriate, as in the following examples:

- (A) The engine will not run on the specified fuel.
- (B) The engine or emission controls will not be durable or work properly when operating with the specified fuel.
- (C) The measured emission results would otherwise be substantially unrepresentative of in-use emissions.

(2) For engines that are designed to operate on different fuel types, the provisions of paragraphs (c)(1)(ii) and (iii) of this section apply with respect to each fuel type.

(3) For engines that are designed to operate on different fuel types as well as continuous mixtures of those fuels, we may require you to test with either the worst-case fuel mixture or the most representative fuel mixture, unless the standard-setting part specifies otherwise.

(d) *Fuel specifications.* Specifications in this section apply as follows:

(1) Measure and calculate values as described in the appropriate reference procedure. Record and report final values expressed to at least the same number of decimal places as the applicable limit value. The right-most digit for each limit value is significant unless specified otherwise. For example, for a specified distillation temperature of 60 °C, determine the test fuel's value to at least the nearest whole number.

(2) The fuel parameters specified in this subpart depend on measurement procedures that are incorporated by reference. For any of these procedures, you may instead rely upon the procedures identified in 40 CFR part 1090 for measuring the same parameter. For example, we may identify different reference procedures for measuring gasoline parameters in 40 CFR 1090.1360.

(e) *Two-stroke fuel/oil mixing.* For two-stroke engines, use a fuel/oil mixture meeting the manufacturer’s specifications.

(f) *Service accumulation and field testing fuels.* If we do not specify a service-accumulation or field-testing fuel in the standard-setting part, use an appropriate commercially available fuel such as those meeting minimum specifications from the following table:

TABLE 1 OF § 1065.701—EXAMPLES OF SERVICE-ACCUMULATION AND FIELD-TESTING FUELS

Fuel category	Subcategory	Reference procedure ^a
Diesel	Light distillate and light blends with residual	ASTM D975
	Middle distillate	ASTM D6985
	Biodiesel (B100)	ASTM D6751
Intermediate and residual fuel	All	See § 1065.705
Gasoline	Automotive gasoline	ASTM D4814
	Automotive gasoline with ethanol concentration up to 10 volume %.	ASTM D4814
Alcohol	Ethanol (E51-83)	ASTM D5798
	Methanol (M70-M85)	ASTM D5797
Aviation fuel	Aviation gasoline	ASTM D910
	Gas turbine	ASTM D1655
	Jet B wide cut	ASTM D6615
Gas turbine fuel	General	ASTM D2880

^aIncorporated by reference; see § 1065.1010.

§ 1065.703 Distillate diesel fuel.

(a) Distillate diesel fuels for testing must be clean and bright, with pour and cloud points adequate for proper engine operation.

(b) There are three grades of #2 diesel fuel specified for use as a test fuel. See the standard-setting part to determine which grade to use. If the standard-setting part does not specify which grade to use, use good engineering judgment to select the grade that represents the fuel on which the engines will operate in use. The three grades are specified in Table 1 of this section.

TABLE 1 OF § 1065.703—TEST FUEL SPECIFICATIONS FOR DISTILLATE DIESEL FUEL

Property	Unit	Ultra Low Sulfur	Low Sulfur	High Sulfur	Reference Procedure ^a
Cetane Number	—	40-50	40-50	40-50	ASTM D613
Distillation range: Initial boiling point 10 pct. point 50 pct. point 90 pct. point Endpoint	°C	171-204 204-238 243-282 293-332 321-366	171-204 204-238 243-282 293-332 321-366	171-204 204-238 243-282 293-332 321-366	ASTM D86
Gravity	°API	32-37	32-37	32-37	ASTM D4052
Total sulfur	mg/kg	7-15	300-500	800-2500	ASTM D2622, ASTM D5453, or ASTM D7039
Aromatics, min. (Remainder shall be paraffins, naphthenes, and olefins)	g/kg	100	100	100	ASTM D5186
Flashpoint, min.	°C	54	54	54	ASTM D93
Kinematic Viscosity	mm ² /s	2.0-3.2	2.0-3.2	2.0-3.2	ASTM D445

^aIncorporated by reference, see § 1065.1010. See § 1065.701(d) for other allowed procedures.

(c) You may use the following nonmetallic additives with distillate diesel fuels:

- (1) Cetane improver.
- (2) Metal deactivator.
- (3) Antioxidant, dehazer.
- (4) Rust inhibitor.
- (5) Pour depressant.
- (6) Dye.
- (7) Dispersant.
- (8) Biocide.

§ 1065.705 Residual and intermediate residual fuel.

This section describes the specifications for fuels meeting the definition of residual fuel in 40 CFR 1090.80, including fuels marketed as intermediate fuel. Residual fuels for service accumulation and any testing must meet the following specifications:

- (a) The fuel must be a commercially available fuel that is representative of the fuel that will be used by the engine in actual use.
- (b) The fuel must be free of used lubricating oil. Demonstrate this by showing that the fuel meets at least one of the following specifications.
 - (1) Zinc is at or below 15 mg per kg of fuel based on the procedures specified in IP__470, IP__501, or ISO 8217 (incorporated by reference, [see-in](#) § 1065.1010).
 - (2) Phosphorus is at or below 15 mg per kg of fuel based on the procedures specified in IP__500, IP__501, or ISO 8217 (incorporated by reference, [see-in](#) § 1065.1010).
 - (3) Calcium is at or below 30 mg per kg of fuel based on the procedures specified in IP__470, IP__501, or ISO 8217 (incorporated by reference, [see-in](#) § 1065.1010).
- (c) The fuel must meet the specifications for one of the categories in the following table:

TABLE 1 OF § 1065.705–SERVICE ACCUMULATION AND TEST FUEL SPECIFICATIONS FOR RESIDUAL FUEL

Property	Unit	Category ISO-F-									Reference Procedure ^a	
		RMA 30	RMB 30	RMD 80	RME 180	RMF 180	RMG 380	RMH 380	RMK 380	RMH 700		RMK 700
Density at 15 °C, max.	kg/m ³	960.0	975.0	980.0	991.0		991.0		1010.0	991.0	1010.0	ISO 3675 or ISO 12185 (see also ISO 8217)
Kinematic viscosity at 50 °C, max.	mm ² /s	30.0		80.0	180.0		380.0		700.0			ISO 3104
Flash point, min.	°C	60		60	60		60		60			ISO 2719 (see also ISO 8217)
Pour point (upper) Winter quality, max. Summer quality, max.	°C	0 6	24 24	30 30	30 30		30 30		30 30			ISO 3016
Carbon residue, max.	(kg/kg) %	10		14	15	20	18	22	22			ISO 10370
Ash, max.	(kg/kg) %	0.10		0.10	0.10	0.15	0.15		0.15			ISO 6245
Water, max.	(m ³ /m ³) %	0.5		0.5	0.5		0.5		0.5			ISO 3733
Sulfur, max.	(kg/kg) %	3.50		4.00	4.50		4.50		4.50			ISO 8754 or ISO 14596 (see also ISO 8217)
Vanadium, max.	mg/kg	150		350	200	500	300	600	600			ISO 14597 or IP-501 or IP-470 (see also ISO 8217)
Total sediment potential, max.	(kg/kg) %	0.10		0.10	0.10		0.10		0.10			ISO 10307-2 (see also ISO 8217)
Aluminium plus silicon, max.	mg/kg	80		80	80		80		80			ISO 10478 or IP 501 or IP 470 (see also ISO 8217)

^aIncorporated by reference; see § 1065.1010. See § 1065.701(d) for other allowed procedures.

§ 1065.710 Gasoline.

(a) This section specifies test fuel properties for gasoline with ethanol (low-level blend only) and for gasoline without ethanol. Note that the “fuel type” for the fuels specified in paragraphs (b) and (c) of this section is considered to be gasoline. In contrast, fuels with higher ethanol concentrations, such as fuel containing 82 percent ethanol, are considered to be ethanol fuels rather than gasoline. We specify some test fuel parameters that apply uniquely for low-temperature testing and for testing at altitudes above 1,219 m. For all other testing, use the test fuel parameters specified for general testing. Unless the standard-setting part specifies otherwise, use the fuel specified in paragraph (c) of this section for general testing.

(b) The following specifications apply for a blended gasoline test fuel that has nominally 10 % ethanol (commonly called E10 test fuel):

(1) Prepare the blended test fuel from typical refinery gasoline blending components. You may not use pure compounds, except as follows:

(i) You may use neat ethanol as a blendstock.

(ii) You may adjust the test fuel’s vapor pressure by adding butane.

(iii) You may adjust the test fuel’s benzene content by adding benzene.

(iv) You may adjust the test fuel’s sulfur content by adding sulfur compounds that are representative of those found with in-use fuels.

(2) Table 1 of this section identifies limit values consistent with the units in the reference procedure for each fuel property. These values are generally specified in international units. Values presented in parentheses are for information only. Table 1 follows:

TABLE 1 OF § 1065.710—TEST FUEL SPECIFICATIONS FOR A LOW-LEVEL ETHANOL-GASOLINE BLEND

Property	Unit	SPECIFICATION			Reference Procedure ^a
		General Testing	Low-Temperature Testing	High Altitude Testing	
Antiknock Index (R+M)/2	-	87.0-88.4 ^b		Minimum, 87.0	ASTM D2699 and ASTM D2700
Sensitivity (R-M)	-	Minimum, 7.5			ASTM D2699 and ASTM D2700
Dry Vapor Pressure Equivalent (DVPE) ^{c,d}	kPa (psi)	60.0-63.4 (8.7-9.2)	77.2-81.4 (11.2-11.8)	52.4-55.2 (7.6-8.0)	ASTM D5191
Distillation ^d	°C (°F)	49-60 (120-140)	43-54 (110-130)	49-60 (120-140)	ASTM D86
10 % evaporated					
50 % evaporated	°C (°F)	88-99 (190-210)			
90 % evaporated	°C (°F)	157-168 (315-335)			
Evaporated final boiling point	°C (°F)	193-216 (380-420)			
Residue	milliliter	Maximum, 2.0			
Total Aromatic Hydrocarbons	volume %	21.0-25.0			ASTM D5769
C6 Aromatics (benzene)	volume %	0.5-0.7			
C7 Aromatics (toluene)	volume %	5.2-6.4			
C8 Aromatics	volume %	5.2-6.4			
C9 Aromatics	volume %	5.2-6.4			
C10+ Aromatics	volume %	4.4-5.6			
Olefins ^e	volume %	4.0-10.0			ASTM D6550
Ethanol blended	volume %	9.6-10.0			See paragraph (b)(3) of this section.
Ethanol confirmatory ^f	volume %	9.4-10.2			ASTM D4815 or ASTM D5599
Total Content of Oxygenates Other than Ethanol ^f	volume %	Maximum, 0.1			ASTM D4815 or ASTM D5599
Sulfur	mg/kg	8.0-11.0			ASTM D2622, ASTM D5453 or ASTM D7039
Lead	g/liter	Maximum, 0.0026			ASTM D3237
Phosphorus	g/liter	Maximum, 0.0013			ASTM D3231
Copper Corrosion	-	Maximum, No. 1			ASTM D130
Solvent-Washed Gum Content	mg/100 milliliter	Maximum, 3.0			ASTM D381
Oxidation Stability	minute	Minimum, 1000			ASTM D525

^aIncorporated by reference; see § 1065.1010. See § 1065.701(d) for other allowed procedures.

^bOctane specifications apply only for testing related to exhaust emissions. For engines or vehicles that require the use of premium fuel, as described in paragraph (d) of this section, the adjusted specification for antiknock index is a minimum value of 91.0; no maximum value applies. All other specifications apply for this high-octane fuel.

^cCalculate dry vapor pressure equivalent, DVPE, based on the measured total vapor pressure, p_T , using the following equation: $DVPE$ (kPa) = $0.956 \cdot p_T - 2.39$ or $DVPE$ (psi) = $0.956 \cdot p_T - 0.347$. DVPE is intended to be equivalent to Reid Vapor Pressure using a different test method.

^dParenthetical values are shown for informational purposes only.

^eASTM D6550 prescribes measurement of olefin concentration in mass %. Multiply this result by 0.857 and round to the first decimal place to determine the olefin concentration in volume %.

^fASTM D5599 prescribes concentration measurements for ethanol and other oxygenates in mass %. Convert results to volume % as specified in Section 14.3 of ASTM D4815.

(3) The ethanol-blended specification in Table 1 of this section is based on the volume % ethanol content of the fuel as determined during blending by the fuel supplier and as stated by the supplier at the time of fuel delivery. Use good engineering judgment to determine the volume % of ethanol based on the volume of each blendstock. We recommend using a flow-based or gravimetric procedure that has an accuracy and repeatability of $\pm 0.1\%$.

(c) The specifications of this paragraph (c) apply for testing with neat gasoline. This is sometimes called indolene or E0 test fuel. Gasoline for testing must have octane values that represent commercially available fuels for the appropriate application. Test fuel specifications apply as follows:

TABLE 2 OF § 1065.710—TEST FUEL SPECIFICATIONS FOR NEAT (E0) GASOLINE

Property	Unit	SPECIFICATION		Reference Procedure ^a
		General Testing	Low-Temperature Testing	
Distillation Range:				ASTM D86
Evaporated initial boiling point	°C	24-35 ^b	24-36	
10 % evaporated	°C	49-57	37-48	
50 % evaporated	°C	93-110	82-101	
90 % evaporated	°C	149-163	158-174	
Evaporated final boiling point	°C	Maximum, 213	Maximum, 212	
Total Aromatic Hydrocarbons	volume %	Maximum, 35	Maximum, 30.4	ASTM D1319 or ASTM D5769
Olefins ^c	volume %	Maximum, 10	Maximum, 17.5	ASTM D1319 or ASTM D6550
Lead	g/liter	Maximum, 0.013	Maximum, 0.013	ASTM D3237
Phosphorous	g/liter	Maximum, 0.0013	Maximum, 0.005	ASTM D3231
Total sulfur	mg/kg	Maximum, 80	Maximum, 80	ASTM D2622
Dry vapor pressure equivalent ^d	kPa	60.0-63.4 ^{b,e}	77.2-81.4	ASTM D5191

^aIncorporated by reference; see § 1065.1010. See § 1065.701(d) for other allowed procedures.

^bFor testing at altitudes above 1219 m, the specified initial boiling point range is (23.9 to 40.6) °C and the specified volatility range is (52.0 to 55.2) kPa.

^cASTM D6550 prescribes measurement of olefin concentration in mass %. Multiply this result by 0.857 and round to the first decimal place to determine the olefin concentration in volume %.

^dCalculate dry vapor pressure equivalent, *DVPE*, based on the measured total vapor pressure, p_T , in kPa using the following equation: $DVPE$ (kPa) = $0.956 \cdot p_T - 2.39$ or $DVPE$ (psi) = $0.956 \cdot p_T - 0.347$. *DVPE* is intended to be equivalent to Reid Vapor Pressure using a different test method.

^eFor testing unrelated to evaporative emissions, the specified range is (55.2 to 63.4) kPa.

(d) Use the high-octane gasoline specified in paragraph (b) of this section only for engines or vehicles for which the manufacturer conditions the warranty on the use of premium gasoline.

§ 1065.715 Natural gas.

(a) Except as specified in paragraph (b) of this section, natural gas for testing must meet the specifications in the following table:

TABLE 1 OF § 1065.715—TEST FUEL SPECIFICATIONS FOR NATURAL GAS

Property	Value ^a
Methane, CH ₄	Minimum, 0.87 mol/mol
Ethane, C ₂ H ₆	Maximum, 0.055 mol/mol
Propane, C ₃ H ₈	Maximum, 0.012 mol/mol
Butane, C ₄ H ₁₀	Maximum, 0.0035 mol/mol
Pentane, C ₅ H ₁₂	Maximum, 0.0013 mol/mol
C ₆ and higher	Maximum, 0.001 mol/mol
Oxygen	Maximum, 0.001 mol/mol
Inert gases (sum of CO ₂ and N ₂)	Maximum, 0.051 mol/mol

^aDemonstrate compliance with fuel specifications based on the reference procedures in ASTM D1945 (incorporated by reference, ~~see in~~ § 1065.1010), or on other measurement procedures using good engineering judgment. ~~See § 1065.701(d) for other allowed procedures.~~

(b) In certain cases you may use test fuel not meeting the specifications in paragraph (a) of this section, as follows:

- (1) You may use fuel that your in-use engines normally use, such as pipeline natural gas.
- (2) You may use fuel meeting alternate specifications if the standard-setting part allows it.
- (3) You may ask for approval to use fuel that does not meet the specifications in paragraph (a) of this section, but only if using the fuel would not adversely affect your ability to demonstrate compliance with the applicable standards in this chapter.

(c) When we conduct testing using natural gas, we will use fuel that meets the specifications in paragraph (a) of this section.

(d) At ambient conditions, natural gas must have a distinctive odor detectable down to a concentration in air not more than one-fifth the lower flammable limit.

§ 1065.720 Liquefied petroleum gas.

(a) Except as specified in paragraph (b) of this section, liquefied petroleum gas for testing must meet the specifications in the following table:

TABLE 1 TO PARAGRAPH (a) OF § 1065.720—TEST FUEL SPECIFICATIONS FOR LIQUEFIED PETROLEUM GAS

Property	Value	Reference procedure ^a
Propane, C ₃ H ₈	Minimum, 0.85 m ³ /m ³	ASTM D2163.
Vapor pressure at 38 °C	Maximum, 1400 kPa	ASTM D1267 or ASTM D2598. ^b
Butanes	Maximum, 0.05 m ³ /m ³	ASTM D2163.
Butenes	Maximum, 0.02 m ³ /m ³	ASTM D2163.
Pentenes and heavier	Maximum, 0.005 m ³ /m ³	ASTM D2163.
Propene	Maximum, 0.1 m ³ /m ³	ASTM D2163.
Residual matter (residue on evaporation of 100 ml oil stain observation)	Maximum, 0.05 ml pass ^c	ASTM D2158.
Corrosion, copper strip	Maximum, No. 1	ASTM D1838.
Sulfur	Maximum, 80 mg/kg	ASTM D6667.
Moisture content	pass	ASTM D2713.

^aIncorporated by reference; see § 1065.1010. See § 1065.701(d) for other allowed procedures.

^bIf these two test methods yield different results, use the results from ASTM D1267.

^cThe test fuel must not yield a persistent oil ring when you add 0.3 ml of solvent residue mixture to a filter paper in 0.1 ml increments and examine it in daylight after two minutes.

(b) In certain cases you may use test fuel not meeting the specifications in paragraph (a) of this section, as follows:

- (1) You may use fuel that your in-use engines normally use, such as commercial-quality liquefied petroleum gas.
- (2) You may use fuel meeting alternate specifications if the standard-setting part allows it.
- (3) You may ask for approval to use fuel that does not meet the specifications in paragraph (a) of this section, but only if using the fuel would not adversely affect your ability to demonstrate compliance with the applicable standards in this chapter.

(c) When we conduct testing using liquefied petroleum gas, we will use fuel that meets the specifications in paragraph (a) of this section.

(d) At ambient conditions, liquefied petroleum gas must have a distinctive odor detectable down to a concentration in air not more than one-fifth the lower flammable limit.

§ 1065.725 High-level ethanol-gasoline blends.

For testing vehicles capable of operating on a high-level ethanol-gasoline blend, create a test fuel as follows:

- (a) Add ethanol to an E10 fuel meeting the specifications described in § 1065.710 until the ethanol content of the blended fuel is between 80 and 83 volume %.
- (b) You may alternatively add ethanol to a gasoline base fuel with no ethanol if you can demonstrate that such a base fuel blended with the proper amount of ethanol would meet all the specifications for E10 test fuel described in § 1065.710, other than the ethanol content.
- (c) The ethanol used for blending must be either denatured fuel ethanol meeting the specifications in 40 CFR 1090.270, or fuel-grade ethanol with no denaturant. Account for the volume of any denaturant when calculating volumetric percentages.
- (d) The blended test fuel must have a dry vapor pressure equivalent between 41.5 and 45.1 kPa (6.0 and 6.5 psi) when measured using the procedure specified in § 1065.710. You may add commercial grade butane as needed to meet this specification.

§ 1065.735 Diesel exhaust fluid.

- (a) Use commercially available diesel exhaust fluid that represents the product that will be used in your in-use engines.
- (b) Diesel exhaust fluid for testing must generally conform to the specifications referenced in the definition of “diesel exhaust fluid” in § 1065.1001. Use marine-grade diesel exhaust fluid only for marine engines.

§ 1065.740 Lubricants.

- (a) Use commercially available lubricating oil that represents the oil that will be used in your engine in use.
- (b) You may use lubrication additives, up to the levels that the additive manufacturer recommends.

§ 1065.745 Coolants.

- (a) You may use commercially available antifreeze mixtures or other coolants that will be used in your engine in use.
- (b) For laboratory testing of liquid-cooled engines, you may use water with or without rust inhibitors.
- (c) For coolants allowed in paragraphs (a) and (b) of this section, you may use rust inhibitors and additives required for lubricity, up to the levels that the additive manufacturer recommends.

§ 1065.750 Analytical gases.

Analytical gases must meet the accuracy and purity specifications of this section, unless you can show that other specifications would not affect your ability to show that you comply with all applicable emission standards.

- (a) Subparts C, D, F, and J of this part refer to the following gas specifications:
 - (1) Use purified gases to zero measurement instruments and to blend with calibration gases. Use gases with contamination no higher than the highest of the following values in the gas cylinder or at the outlet of a zero-gas generator:
 - (i) 2 % contamination, measured relative to the flow-weighted mean concentration expected at the standard. For example, if you would expect a flow-weighted CO concentration of 100.0 $\mu\text{mol/mol}$, then you would be allowed to use a zero gas with CO contamination less than or equal to 2.000 $\mu\text{mol/mol}$.
 - (ii) Contamination as specified in the following table:

TABLE 1 OF § 1065.750—GENERAL SPECIFICATIONS FOR PURIFIED GASES^a

Constituent	Purified Air	Purified N ₂
THC (C ₁ -equivalent)	≤ 0.05 μmol/mol	≤ 0.05 μmol/mol
CO	≤ 1 μmol/mol	≤ 1 μmol/mol
CO ₂	≤ 10 μmol/mol	≤ 10 μmol/mol
O ₂	0.205 to 0.215 mol/mol	≤ 2 μmol/mol
NO _x	≤ 0.02 μmol/mol	≤ 0.02 μmol/mol
N ₂ O ^b	≤ 0.02 μmol/mol	≤ 0.02 μmol/mol
H ₂ ^c	≤ 1 μmol/mol	≤ 1 μmol/mol
NH ₃ ^d	≤ 1 μmol/mol	≤ 1 μmol/mol
H ₂ O ^e	≤ 5 μmol/mol	≤ 5 μmol/mol

^aWe do not require these levels of purity to be NIST-traceable.

^bThe N₂O limit applies only if the standard-setting part requires you to report N₂O or certify to an N₂O standard.

^cThe H₂ limit only applies for testing with H₂ fuel.

^dThe NH₃ limit only applies for testing with NH₃ fuel.

^eThe H₂O limit only applies for water measurement according to § 1065.257.

(2) Use the following gases with a FID analyzer:

(i) *FID fuel*. Use FID fuel with a stated H₂ concentration of (0.39 to 0.41) mol/mol, balance He or N₂, and a stated total hydrocarbon concentration of 0.05 μmol/mol or less. For GC-FIDs that measure methane (CH₄) using a FID fuel that is balance N₂, perform the CH₄ measurement as described in SAE J1151 (incorporated by reference, [see in § 1065.1010](#)).

(ii) *FID burner air*. Use FID burner air that meets the specifications of purified air in paragraph (a)(1) of this section. For field testing, you may use ambient air.

(iii) *FID zero gas*. Zero flame-ionization detectors with purified gas that meets the specifications in paragraph (a)(1) of this section, except that the purified gas O₂ concentration may be any value. Note that FID zero balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer zero gases that contain approximately the expected flow-weighted mean concentration of O₂ in the exhaust sample during testing.

(iv) *FID propane span gas*. Span and calibrate THC FID with span concentrations of propane, C₃H₈. Calibrate on a carbon number basis of one (C₁). For example, if you use a C₃H₈ span gas of concentration 200 μmol/mol, span a FID to respond with a value of 600 μmol/mol. Note that FID span balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer span gases that contain approximately the flow-weighted mean concentration of O₂ expected during testing. If the expected O₂ concentration in the exhaust sample is zero, we recommend using a balance gas of purified nitrogen.

(v) *FID CH₄ span gas*. If you always span and calibrate a CH₄ FID with a nonmethane cutter, then span and calibrate the FID with span concentrations of CH₄. Calibrate on a carbon number basis of one (C₁). For example, if you use a CH₄ span gas of concentration 200 μmol/mol, span a FID to respond with a value of 200 μmol/mol. Note that FID span balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer span gases that contain approximately the expected flow-weighted mean concentration of O₂ in the exhaust sample during testing. If the expected O₂ concentration in the exhaust sample is zero, we recommend using a balance gas of purified nitrogen.

(3) Use the following gas mixtures, with gases traceable within ± 1 % of the NIST-accepted gas standard value or other gas standards we approve:

- (i) CH₄, balance purified air and/or N₂ (as applicable).
- (ii) C₂H₆, balance purified air and/or N₂ (as applicable).
- (iii) C₃H₈, balance purified air and/or N₂ (as applicable).
- (iv) CO, balance purified N₂.
- (v) CO₂, balance purified N₂.
- (vi) NO, balance purified N₂.
- (vii) NO₂, balance purified air.
- (viii) O₂, balance purified N₂.
- (ix) C₃H₈, CO, CO₂, NO, balance purified N₂.
- (x) C₃H₈, CH₄, CO, CO₂, NO, balance purified N₂.
- (xi) N₂O, balance purified air and/or N₂ (as applicable).
- (xii) CH₄, C₂H₆, balance purified air and/or N₂ (as applicable).
- (xiii) CH₄, ~~CH₂O~~, CH₂O₂, C₂H₂, C₂H₄, C₂H₄O, C₂H₆, C₃H₈, C₃H₆, CH₄O, and C₄H₁₀.

You may omit individual gas constituents from this gas mixture. If your gas mixture contains oxygenated hydrocarbons, your gas mixture must be in balance purified N₂, otherwise you may use balance purified air.

(4) You may use gases for species other than those listed in paragraph (a)(3) of this section (such as methanol in air, which you may use to determine response factors), as long as they are traceable to within ± 3 % of the NIST-accepted value or other similar standards we approve, and meet the stability requirements of paragraph (b) of this section.

(5) You may generate your own calibration gases using a precision blending device, such as a gas divider, to dilute gases with purified N₂ or purified air. If your gas divider meets the specifications in § 1065.248, and the gases being blended meet the requirements of paragraphs (a)(1) and (3) of this section, the resulting blends are considered to meet the requirements of this paragraph (a).

(6) If you measure H₂O using an FTIR analyzer, generate H₂O calibration gases with a humidity generator using one of the options in this paragraph (a)(6). Use good engineering judgment to prevent condensation in the transfer lines, fittings, or valves from the humidity generator to the FTIR analyzer. Design your system so the wall temperatures in the transfer lines, fittings, and valves from the point where the mole fraction of H₂O in the humidified calibration gas, $x_{\text{H}_2\text{Oref}}$, is measured to the analyzer are at a temperature of (110 to 202) °C. Calibrate the humidity generator upon initial installation, within 370 days before verifying the H₂O measurement of the FTIR, and after major maintenance. Use the uncertainties from the calibration of the humidity generator's measurements and follow NIST Technical Note 1297 (incorporated by reference, see § 1065.1010) to verify that the amount of H₂O in the calibration gas, $x_{\text{H}_2\text{Oref}}$, is determined within ± 3 % uncertainty, $U_{x_{\text{H}_2\text{O}}}$. If the humidity generator requires assembly before use, after assembly follow the instrument manufacturer's instructions to check for leaks. You may generate the H₂O calibration gas using one of the following options:

- (i) Bubble gas that meets the requirements of paragraph (a)(1) of this section through distilled H₂O in a sealed vessel. Adjust the amount of H₂O in the calibration gas by changing the temperature of the H₂O in the sealed vessel. Determine absolute pressure, p_{abs} , and dewpoint, T_{dew} , of the humidified gas leaving the sealed vessel. Calculate the amount of H₂O in the calibration gas as described in § 1065.645(a) and (b). Calculate the

uncertainty of the amount of H₂O in the calibration gas, $U_{x_{H_2O}}$, using the following equations:

$$\frac{\partial x_{H_2O}}{\partial T_{dew}} = x_{H_2O} \cdot \left(\frac{6790.241 + 2.961487 \cdot 10^{4.76955 \cdot \left(1 - \frac{273.16}{T_{dew}}\right)}}{T_{dew}^2} - \frac{5.028}{T_{dew}} + 2.423229 \cdot 10^{-5} \cdot 10^{-8.2969 \cdot \left(\frac{T_{dew}}{273.16} - 1\right)} \right)$$

Eq. 1065.750-1

$$\frac{\partial x_{H_2O}}{\partial p_{abs}} = -1 \cdot \frac{x_{H_2O}}{p_{abs}}$$

Eq. 1065.750-2

$$U_{x_{H_2O}} = \sqrt{\left(\frac{\partial x_{H_2O}}{\partial p_{abs}} \cdot U_{p_{abs}}\right)^2 + \left(\frac{\partial x_{H_2O}}{\partial T_{dew}} \cdot U_{T_{dew}}\right)^2}$$

Eq. 1065.750-3

Where:

T_{dew} = saturation temperature of water at measured conditions.

$U_{T_{dew}}$ = expanded uncertainty ($k = 2$) of the measured saturation temperature of water at measured conditions.

p_{abs} = wet static absolute pressure at the location of the dewpoint measurement.

$U_{p_{abs}}$ = expanded uncertainty ($k = 2$) of the wet static absolute pressure at the location of the dewpoint measurement.

$\frac{\partial x_{H_2O}}{\partial T_{dew}}$ = partial derivative of x_{H_2O} with respect to T_{dew} .

$\frac{\partial x_{H_2O}}{\partial p_{abs}}$ = partial derivative of x_{H_2O} with respect to p_{abs} .

x_{H_2O} = amount of water in the calibration gas.

$U_{x_{H_2O}}$ = expanded uncertainty ($k = 2$) of the amount of H₂O in the calibration gas.

Example:

$$T_{dew} = 39.5 \text{ °C} = 312.65 \text{ K}$$

$$U_{T_{dew}} = 0.390292 \text{ K}$$

$$p_{abs} = 99.980 \text{ kPa}$$

$$U_{p_{abs}} = 1.15340 \text{ kPa}$$

Using Eq. 1065.645-1,

$$x_{H_2O} = 0.0718436 \text{ mol/mol}$$

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial T_{\text{dew}}} = 0.0718436 \cdot \left(\frac{6790.241 + 2.961487 \cdot 10^{4.76955 \cdot \left(1 - \frac{273.16}{312.65}\right)}}{312.65^2} - \frac{5.028}{312.65} + 2.423229 \cdot 10^{-5} \cdot 10^{-8.2969 \cdot \left(\frac{312.65}{273.16} - 1\right)} \right)$$

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial T_{\text{dew}}} = 0.00384409 \text{ (mol/mol)/K}$$

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial p_{\text{abs}}} = -1 \cdot \frac{0.0718436}{99.980}$$

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial p_{\text{abs}}} = -0.000718580 \text{ (mol/mol)/kPa}$$

$$U_{x_{\text{H}_2\text{O}}} = \sqrt{(-0.000718580 \cdot 1.15340)^2 + (0.00384409 \cdot 0.390292)^2}$$

$$U_{x_{\text{H}_2\text{O}}} = 0.00171402 \text{ mol/mol}$$

(ii) Use a device that introduces a measured flow of distilled H₂O as vapor into a measured flow of gas that meets the requirements of paragraph (a)(1) of this section. Determine the molar flows of gas and H₂O that are mixed to generate the calibration gas.

(A) Calculate the amount of H₂O in the calibration gas as follows:

$$x_{\text{H}_2\text{O}} = \frac{\dot{n}_{\text{H}_2\text{O}}}{\dot{n}_{\text{gas}} + \dot{n}_{\text{H}_2\text{O}}}$$

Eq. 1065.750-4

(B) Calculate the uncertainty of the amount of H₂O in the generated calibration gas,

U_{x_{H₂O}}, using the following equations:

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{gas}}} = -1 \cdot \frac{\dot{n}_{\text{H}_2\text{O}}}{(\dot{n}_{\text{gas}} + \dot{n}_{\text{H}_2\text{O}})^2}$$

Eq. 1065.750-5

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{H}_2\text{O}}} = \frac{\dot{n}_{\text{gas}}}{(\dot{n}_{\text{gas}} + \dot{n}_{\text{H}_2\text{O}})^2}$$

Eq. 1065.750-6

$$U_{x_{\text{H}_2\text{O}}} = \sqrt{\left(\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{gas}}} \cdot U_{\dot{n}_{\text{gas}}}\right)^2 + \left(\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{H}_2\text{O}}} \cdot U_{\dot{n}_{\text{H}_2\text{O}}}\right)^2}$$

Eq. 1065.750-7

Where:

\dot{n}_{gas} = molar flow of gas entering the humidity generator.

$U_{\dot{n}_{\text{gas}}}$ = expanded uncertainty (k=2) of the molar flow of gas entering the humidity generator.

$\dot{n}_{\text{H}_2\text{O}}$ = molar flow of H₂O entering the humidity generator, mol/s.

$U_{\dot{n}_{\text{H}_2\text{O}}}$ = expanded uncertainty (k=2) of the molar flow of H₂O entering the humidity generator.

$\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{gas}}}$ = partial derivative of $x_{\text{H}_2\text{O}}$ with respect to \dot{n}_{gas} .

$\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{H}_2\text{O}}}$ = partial derivative of $x_{\text{H}_2\text{O}}$ with respect to $\dot{n}_{\text{H}_2\text{O}}$.

$x_{\text{H}_2\text{O}}$ = amount of H₂O in the calibration gas.

$U_{x_{\text{H}_2\text{O}}}$ = expanded uncertainty (k=2) of the amount of H₂O in the generated calibration gas.

(C) The following example is a solution for $U_{x_{\text{H}_2\text{O}}}$ using the equations in paragraph

(a)(6)(ii)(B) of this section:

$\dot{n}_{\text{H}_2\text{O}} = 0.00138771 \text{ mol/s}$

$U_{\dot{n}_{\text{gas}}} = 0.000226137 \text{ mol/s}$

$\dot{n}_{\text{gas}} = 0.0148680 \text{ mol/s}$

$U_{\dot{n}_{\text{H}_2\text{O}}} = 0.0000207436 \text{ mol/s}$

$$x_{\text{H}_2\text{O}} = \frac{0.00138771}{0.0148680 + 0.00138771}$$

$x_{\text{H}_2\text{O}} = 0.0853676 \text{ mol/mol}$

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{gas}}} = -1 \cdot \frac{0.00138771}{(0.0148680 + 0.00138771)^2}$$

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{gas}}} = -5.25155 \text{ (mol/mol)/(mol/s)}$$

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{H}_2\text{O}}} = \frac{0.0148680}{(0.0148680 + 0.00138771)^2}$$

$$\frac{\partial x_{\text{H}_2\text{O}}}{\partial \dot{n}_{\text{H}_2\text{O}}} = 56.2653 \text{ (mol/mol)/(mol/s)}$$

$$U_{x_{\text{H}_2\text{O}}} = \sqrt{(-5.25155 \cdot 0.000226137)^2 + (56.2653 \cdot 0.0000207436)^2}$$

$$U_{x_{\text{H}_2\text{O}}} = 0.00166510 \text{ mol/mol}$$

(b) Record the concentration of any calibration gas standard and its expiration date specified by the gas supplier.

(1) Do not use any calibration gas standard after its expiration date, except as allowed by paragraph (b)(2) of this section.

- (2) Calibration gases may be relabeled and used after their expiration date as follows:
- (i) Alcohol/carbonyl calibration gases used to determine response factors according to subpart I of this part may be relabeled as specified in subpart I of this part.
 - (ii) Other gases may be relabeled and used after the expiration date only if we approve it in advance.

(c) Transfer gases from their source to analyzers using components that are dedicated to controlling and transferring only those gases. For example, do not use a regulator, valve, or transfer line for zero gas if those components were previously used to transfer a different gas mixture. We recommend that you label regulators, valves, and transfer lines to prevent contamination. Note that even small traces of a gas mixture in the dead volume of a regulator, valve, or transfer line can diffuse upstream into a high-pressure volume of gas, which would contaminate the entire high-pressure gas source, such as a compressed-gas cylinder.

(d) To maintain stability and purity of gas standards, use good engineering judgment and follow the gas standard supplier's recommendations for storing and handling zero, span, and calibration gases. For example, it may be necessary to store bottles of condensable gases in a heated environment.

§ 1065.790 Mass standards.

(a) *PM balance calibration weights.* Use PM balance calibration weights that are certified as NIST-traceable within ± 0.1 % uncertainty. Make sure your highest calibration weight has no more than ten times the mass of an unused PM-sample medium.

(b) *Dynamometer, fuel mass scale, and DEF mass scale calibration weights.* Use dynamometer and mass scale calibration weights that are certified as NIST-traceable within ± 0.1 % uncertainty.

Subpart I—Testing with Oxygenated Fuels

§ 1065.801 Applicability.

(a) This subpart applies for testing with oxygenated fuels. Unless the standard-setting part specifies otherwise, the requirements of this subpart do not apply for fuels that contain less than 25 % oxygenated compounds by volume. For example, you generally do not need to follow the requirements of this subpart for tests performed using a fuel containing 10 % ethanol and 90 % gasoline, but you must follow these requirements for tests performed using a fuel containing 85 % ethanol and 15 % gasoline.

(b) Section 1065.805 applies for all other testing that requires measurement of any alcohols or carbonyls.

(c) This subpart specifies sampling procedures and calculations that are different than those used for non-oxygenated fuels. All other test procedures of this part 1065 apply for testing with oxygenated fuels.

§ 1065.805 Sampling system.

(a) Dilute engine exhaust, and use batch sampling to collect proportional flow-weighted dilute samples of the applicable alcohols and carbonyls. You may not use raw sampling for alcohols and carbonyls.

- (b) You may collect background samples for correcting dilution air for background concentrations of alcohols and carbonyls.
- (c) Maintain sample temperatures within the dilution tunnel, probes, and sample lines high enough to prevent aqueous condensation up to the point where a sample is collected to prevent loss of the alcohols and carbonyls by dissolution in condensed water. Use good engineering judgment to ensure that surface reactions of alcohols and carbonyls do not occur, as surface decomposition of methanol has been shown to occur at temperatures greater than 120 °C in exhaust from methanol-fueled engines.
- (d) You may bubble a sample of the exhaust through water to collect alcohols for later analysis. You may also use a photoacoustic analyzer to quantify ethanol and methanol in an exhaust sample as described in § 1065.269.
- (e) Sample the exhaust through cartridges impregnated with 2,4-dinitrophenylhydrazine to collect carbonyls for later analysis. If the standard-setting part specifies a duty cycle that has multiple test intervals (such as multiple engine starts or an engine-off soak phase), you may proportionally collect a single carbonyl sample for the entire duty cycle. For example, if the standard-setting part specifies a six-to-one weighting of hot-start to cold-start emissions, you may collect a single carbonyl sample for the entire duty cycle by using a hot-start sample flow rate that is six times the cold-start sample flow rate.
- (f) You may sample alcohols or carbonyls using "California Non-Methane Organic Gas Test Procedures" (incorporated by reference, [see-in](#) § 1065.1010). If you use this method, follow its calculations to determine the mass of the alcohol/carbonyl in the exhaust sample, but follow subpart G of this part for all other calculations (40 CFR part 1066, subpart G, for vehicle testing).
- (g) Use good engineering judgment to sample other oxygenated hydrocarbon compounds in the exhaust.

§ 1065.845 Response factor determination.

Since FID analyzers generally have an incomplete response to alcohols and carbonyls, determine each FID analyzer's alcohol/carbonyl response factor ($RF_{\text{OHC}[\text{THC-FID}]}$) after FID optimization to subtract those responses from the FID reading. Use the most recently determined alcohol/carbonyl response factors to compensate for alcohol/carbonyl response. You are not required to determine the response factor for a compound unless you will subtract its response to compensate for a response.

(a) You may generate response factors as described in paragraph (b) of this section, or you may use the following default response factors, consistent with good engineering judgment:

TABLE 1 OF § 1065.845—DEFAULT VALUES FOR THC FID
RESPONSE FACTOR RELATIVE TO PROPANE ON A C₁-EQUIVALENT BASIS

Compound	Response factor (RF)
acetaldehyde	0.50
ethanol	0.75
formaldehyde	0.00
methanol	0.63
propanol	0.85

- (b) Determine the alcohol/carbonyl response factors as follows:
- (1) Select a C₃H₈ span gas that meets the specifications of § 1065.750. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O₂ expected during testing. Record the C₃H₈ concentration of the gas.
 - (2) Select or prepare an alcohol/carbonyl calibration gas that meets the specifications of § 1065.750 and has a concentration typical of the peak concentration expected at the hydrocarbon standard. Record the calibration concentration of the gas.
 - (3) Start and operate the FID analyzer according to the manufacturer's instructions.
 - (4) Confirm that the FID analyzer has been calibrated using C₃H₈. Calibrate on a carbon number basis of one (C₁). For example, if you use a C₃H₈ span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol.
 - (5) Zero the FID. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O₂ expected during testing.
 - (6) Span the FID with the C₃H₈ span gas that you selected under paragraph (a)(1) of this section.
 - (7) Introduce at the inlet of the FID analyzer the alcohol/carbonyl calibration gas that you selected under paragraph (a)(2) of this section.
 - (8) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the analyzer and to account for its response.
 - (9) While the analyzer measures the alcohol/carbonyl concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these values.
 - (10) Divide the mean measured concentration by the recorded span concentration of the alcohol/carbonyl calibration gas on a C₁-equivalent basis. The result is the FID analyzer's response factor for alcohol/carbonyl, $RF_{\text{OHC}_i[\text{THC-FID}]}$ on a C₁-equivalent basis.
- (c) Alcohol/carbonyl calibration gases must remain within ±2 % of the labeled concentration. You must demonstrate the stability based on a quarterly measurement procedure with a precision of ±2 % percent or another method that we approve. Your measurement procedure may incorporate multiple measurements. If the true concentration of the gas changes deviates by more than ±2 %, but less than ±10 %, the gas may be relabeled with the new concentration.

§ 1065.850 Calculations.

Use the calculations specified in § 1065.665 to determine THCE or NMHCE and the calculations specified in 40 CFR 1066.635 to determine NMOG.

Subpart J—Field Testing and Portable Emission Measurement Systems

§ 1065.901 Applicability.

(a) *Field testing.* This subpart specifies procedures for field-testing engines to determine brake-specific emissions and mass rate emissions using portable emission measurement systems (PEMS). These procedures are designed primarily for in-field measurements of engines that

remain installed in vehicles or equipment the field. Field-test procedures apply to your engines only as specified in the standard-setting part.

(b) *Laboratory testing*. You may use PEMS for any testing in a laboratory or similar environment without restriction or prior approval if the PEMS meets all applicable specifications for laboratory testing. You may also use PEMS for any testing in a laboratory or similar environment if we approve it in advance, subject to the following provisions:

- (1) Follow the laboratory test procedures specified in this part 1065, according to § 1065.905(e).
- (2) Do not apply any PEMS-related field-testing adjustments or measurement allowances to laboratory emission results or standards.
- (3) Do not use PEMS for laboratory measurements if it prevents you from demonstrating compliance with the applicable standards in this chapter. Some of the PEMS requirements in this part 1065 are less stringent than the corresponding laboratory requirements. Depending on actual PEMS performance, you might therefore need to account for some additional measurement uncertainty when using PEMS for laboratory testing. If we ask, you must show us by engineering analysis that any additional measurement uncertainty due to your use of PEMS for laboratory testing is offset by the extent to which your engine's emissions are below the applicable standards in this chapter. For example, you might show that PEMS versus laboratory uncertainty represents 5 % of the standard, but your engine's deteriorated emissions are at least 20 % below the standard for each pollutant.

§ 1065.905 General provisions.

(a) *General*. Unless the standard-setting part specifies deviations from the provisions of this subpart, field testing and laboratory testing with PEMS must conform to the provisions of this subpart. Use good engineering judgment when testing with PEMS to ensure proper function of the instruments under test conditions. For example, this may require additional maintenance or calibration for field testing or may require verification after moving the PEMS unit.

(b) *Field-testing scope*. Field testing conducted under this subpart may include any normal in-use operation of an engine.

(c) *Field testing and the standard-setting part*. This subpart J specifies procedures for field-testing various categories of engines. See the standard-setting part for specific provisions for a particular type of engine. Before using this subpart's procedures for field testing, read the standard-setting part to answer at least the following questions:

- (1) How many engines must I test in the field?
- (2) How many times must I repeat a field test on an individual engine?
- (3) How do I select vehicles for field testing?
- (4) What maintenance steps may I take before or between tests?
- (5) What data are needed for a single field test on an individual engine?
- (6) What are the limits on ambient conditions for field testing? Note that the ambient condition limits in § 1065.520 do not apply for field testing. Field testing may occur at any ambient temperature, pressure, and humidity unless otherwise specified in the standard-setting part.
- (7) Which exhaust constituents do I need to measure?
- (8) How do I account for crankcase emissions?
- (9) Which engine and ambient parameters do I need to measure?

(10) How do I process the data recorded during field testing to determine if my engine meets field-testing standards? How do I determine individual test intervals? Note that “test interval” is defined in subpart K of this part 1065.

(11) Should I warm up the test engine before measuring emissions, or do I need to measure cold-start emissions during a warm-up segment of in-use operation?

(12) Do any unique specifications apply for test fuels?

(13) Do any special conditions invalidate parts of a field test or all of a field test?

(14) Does any special measurement allowance apply to field-test emission results or standards, based on using PEMS for field-testing versus using laboratory equipment and instruments for laboratory testing?

(15) Do results of initial field testing trigger any requirement for additional field testing or laboratory testing?

(16) How do I report field-testing results?

(d) *Field testing and this part 1065.* Use the following specifications for field testing:

(1) Use the applicability and general provisions of subpart A of this part.

(2) Use equipment specifications in § 1065.101 and in the sections from § 1065.140 to the end of subpart B of this part, with the exception of § 1065.140(e)(1) and (4), § 1065.170(c)(1)(vi), and § 1065.195(c). Section 1065.910 identifies additional equipment that is specific to field testing.

(i) For PM samples, configure dilution systems as follows:

(A) Use good engineering judgment to control dilution air temperature. If you choose to directly and actively control dilution air temperature, set the temperature to 25 °C.

(B) Control sample temperature to a (32 to 62) °C tolerance, as measured anywhere within 20 cm upstream or downstream of the PM storage media (such as a filter or oscillating crystal), where the tolerance applies only during sampling.

(C) Maintain filter face velocity to a (5 to 100) cm/s tolerance for flow-through media. Compliance with this provision can be verified by engineering analysis. This provision does not apply for non-flow-through media.

(ii) For inertial PM balances, there is no requirement to control the stabilization environment temperature or dewpoint.

(3) Use measurement instruments in subpart C of this part, except as specified in § 1065.915.

(4) Use calibrations and verifications in subpart D of this part, except as specified in § 1065.920. Section 1065.920 also specifies additional calibrations and verifications for field testing.

(5) Use the provisions of the standard-setting part for selecting and maintaining engines in the field instead of the specifications in subpart E of this part.

(6) Use the procedures in §§ 1065.930 and 1065.935 to start and run a field test. If you use a gravimetric balance for PM, weigh PM samples according to §§ 1065.590 and 1065.595.

(7) Use the calculations in subpart G of this part to calculate emissions over each test interval. Note that “test interval” is defined in subpart K of this part 1065, and that the standard setting part indicates how to determine test intervals for your engine. Section 1065.940 specifies additional calculations for field testing. Use any calculations specified in the standard-setting part to determine if your engines meet the field-testing standards. The standard-setting part may also contain additional calculations that determine when further field testing is required.

(8) Use a typical in-use fuel meeting the specifications of § 1065.701(d).

- (9) Use the lubricant and coolant specifications in § 1065.740 and § 1065.745.
- (10) Use the analytical gases and other calibration standards in § 1065.750 and § 1065.790.
- (11) If you are testing with oxygenated fuels, use the procedures specified for testing with oxygenated fuels in subpart I of this part.
- (12) Apply the definitions and reference materials in subpart K of this part.

(e) *Laboratory testing using PEMS*. You may use PEMS for testing in a laboratory as described in § 1065.901(b). Use the following procedures and specifications when using PEMS for laboratory testing:

- (1) Use the applicability and general provisions of subpart A of this part.
- (2) Use equipment specifications in subpart B of this part. Section 1065.910 specifies additional equipment specific to testing with PEMS.
- (3) Use measurement instruments in subpart C of this part, except as specified in § 1065.915.
- (4) Use calibrations and verifications in subpart D of this part, except as specified in § 1065.920. Section 1065.920 also specifies additional calibration and verifications for PEMS.
- (5) Use the provisions of § 1065.401 for selecting engines for testing. Use the provisions of subpart E of this part for maintaining engines, except as specified in the standard-setting part.
- (6) Use the procedures in subpart F of this part and in the standard-setting part to start and run a laboratory test.
- (7) Use the calculations in subpart G of this part to calculate emissions over the applicable duty cycle. Section 1065.940 specifies additional calculations for testing with PEMS.
- (8) Use a fuel meeting the specifications of subpart H of this part, as specified in the standard-setting part.
- (9) Use the lubricant and coolant specifications in § 1065.740 and § 1065.745.
- (10) Use the analytical gases and other calibration standards in § 1065.750 and § 1065.790.
- (11) If you are testing with oxygenated fuels, use the procedures specified for testing with oxygenated fuels in subpart I of this part.
- (12) Apply the definitions and reference materials in subpart K of this part.

(f) *Summary*. The following table summarizes the requirements of paragraphs (d) and (e) of this section:

TABLE 1 OF § 1065.905—SUMMARY OF TESTING REQUIREMENTS SPECIFIED OUTSIDE OF THIS SUBPART J

Subpart	Applicability for field testing^a	Applicability for laboratory or similar testing with PEMS without restriction^a	Applicability for laboratory or similar testing with PEMS with restrictions^a
A: Applicability and general provisions	Use all.	Use all.	Use all.
B: Equipment for testing	Use §§ 1065.101 and 1065.140 through the end of subpart B of this part, except §§ 1065.140(e)(1) and (4), 1065.170(c)(1)(vi), and 1065.195(c). Section 1065.910 specifies equipment specific to field testing.	Use all.	Use all. Section 1065.910 specifies equipment specific to laboratory testing with PEMS.
C: Measurement instruments	Use all. Section 1065.915 allows deviations.	Use all except § 1065.295(c).	Use all except § 1065.295(c). Section 1065.915 allows deviations.
D: Calibrations and verifications	Use all except §§ 1065.308 and 1065.309. Section 1065.920 allows deviations, but also has additional specifications.	Use all.	Use all. Section 1065.920 allows deviations, but also has additional specifications.
E: Test engine selection, maintenance, and durability	Do not use. Use standard-setting part.	Use all.	Use all.
F: Running an emission test in the laboratory	Use §§ 1065.590 and 1065.595 for PM §§ 1065.930 and 1065.935 to start and run a field test.	Use all.	Use all.
G: Calculations and data requirements	Use all. Section 1065.940 has additional calculation instructions	Use all.	Use all. Section 1065.940 has additional calculation instructions
H: Fuels, engine fluids, analytical gases, and other calibration materials	Use all.	Use all.	Use all.
I: Testing with oxygenated fuels	Use all.	Use all.	Use all.
K: Definitions and reference materials	Use all.	Use all.	Use all.

^aRefer to paragraphs (d) and (e) of this section for complete specifications.

§ 1065.910 PEMS auxiliary equipment for field testing.

For field testing you may use various types of auxiliary equipment to attach PEMS to a vehicle or engine and to power PEMS.

(a) When you use PEMS, you may route engine intake air or exhaust through a flow meter.

Route the engine intake air or exhaust as follows:

(1) *Flexible connections.* Use short flexible connectors where necessary.

(i) You may use flexible connectors to enlarge or reduce the pipe diameters to match that of your test equipment.

(ii) We recommend that you use flexible connectors that do not exceed a length of three times their largest inside diameter.

(iii) We recommend that you use four-ply silicone-fiberglass fabric with a temperature rating of at least 315 °C for flexible connectors. You may use connectors with a spring-steel wire helix for support and you may use NomexTM coverings or linings for durability. You may also use any other nonreactive material with equivalent permeation-resistance and durability, as long as it seals tightly.

(iv) Use stainless-steel hose clamps to seal flexible connectors, or use clamps that seal equivalently.

(v) You may use additional flexible connectors to connect to flow meters.

(2) *Tubing.* We recommend using rigid 300 series stainless steel tubing to connect between flexible connectors. Tubing may be straight or bent to accommodate vehicle geometry. You may use “T” or “Y” fittings to join multiple connections, or you may cap or plug redundant flow paths if the engine manufacturer recommends it.

(3) *Flow restriction.* Use flow meters, connectors, and tubing that do not increase flow restriction so much that it exceeds the manufacturer’s maximum specified value. You may verify this at the maximum exhaust flow rate by measuring pressure at the manufacturer-specified location with your system connected. You may also perform an engineering analysis to verify an acceptable configuration, taking into account the maximum exhaust flow rate expected, the field test system’s flexible connectors, and the tubing’s characteristics for pressure drops versus flow.

(b) Locate the PEMS to minimize the effects of the following parameters or place the PEMS in an environmental enclosure that minimizes the effect of these parameters on the emission measurement:

(1) Ambient temperature changes.

(2) Electromagnetic radiation.

(3) Mechanical shock and vibration.

(c) Use mounting hardware as required for securing flexible connectors, ambient sensors, and other equipment. Use structurally sound mounting points such as vehicle frames, trailer hitch receivers, walk spaces, and payload tie-down fittings. We recommend mounting hardware such as clamps, suction cups, and magnets that are specifically designed for your application. We also recommend considering mounting hardware such as commercially available bicycle racks, trailer hitches, and luggage racks where applicable.

(d) Field testing may require portable electrical power to run your test equipment. Power your equipment, as follows:

(1) You may use electrical power from the vehicle, equipment, or vessel, up to the highest power level, such that all the following are true:

- (i) The power system is capable of safely supplying power, such that the power demand for testing does not overload the power system.
- (ii) The engine emissions do not change significantly as a result the power demand for testing.
- (iii) The power demand for testing does not increase output from the engine by more than 1 % of its maximum power.

(2) You may install your own portable power supply. For example, you may use batteries, fuel cells, a portable generator, or any other power supply to supplement or replace your use of vehicle power. You may connect an external power source directly to the vehicle's, vessel's, or equipment's power system; however, you must not supply power to the vehicle's power system in excess of 1 % of the engine's maximum power.

§ 1065.915 PEMS instruments.

(a) *Instrument specifications.* We recommend that you use PEMS that meet the specifications of subpart C of this part. For unrestricted use of PEMS in a laboratory or similar environment, use a PEMS that meets the same specifications as each lab instrument it replaces. For field testing or for testing with PEMS in a laboratory or similar environment, under the provisions of § 1065.905(b), the specifications in the following table apply instead of the specifications in Table 1 of § 1065.205:

TABLE 1 OF § 1065.915—RECOMMENDED MINIMUM PEMS MEASUREMENT INSTRUMENT PERFORMANCE

Measurement	Measured quantity symbol	Rise time, t_{10-90} , and Fall time, t_{90-10}	Recording update frequency	Accuracy ^a	Repeatability ^a	Noise ^a
Engine speed transducer	f_n	1 s	1 Hz means	5 % of pt. or 1 % of max.	2 % of pt. or 1 % of max.	0.5 % of max
Engine torque estimator, BSFC (This is a signal from an engine's ECM)	T or BSFC	1 s	1 Hz means	8 % of pt. or 5 % of max.	2 % of pt. or 1 % of max.	1 % of max.
General pressure transducer (not a part of another instrument)	p	5 s	1 Hz	5 % of pt. or 5 % of max.	2 % of pt. or 0.5 % of max.	1 % of max
Atmospheric pressure meter	p_{atmos}	50 s	0.1 Hz	250 Pa	200 Pa	100 Pa
General temperature sensor (not a part of another instrument)	T	5 s	1 Hz	1 % of pt. K or 5 K	0.5 % of pt. K or 2 K	0.5 % of max 0.5 K
General dewpoint sensor	T_{dew}	50 s	0.1 Hz	3 K	1 K	1 K
Exhaust flow meter	\dot{V}	1 s	1 Hz means	5 % of pt. or 3 % of max.	2 % of pt.	2 % of max.
Dilution air, inlet air, exhaust, and sample flow meters	\dot{V}	1 s	1 Hz means	2.5 % of pt. or 1.5 % of max.	1.25 % of pt. or 0.75 % of max.	1 % of max.
Continuous gas analyzer	x	5 s	1 Hz	4 % of pt. or 4 % of meas.	2 % of pt. or 2 % of meas.	1 % of max.
Gravimetric PM balance	m_{PM}	—	—	See § 1065.790	0.5 μg	—
Inertial PM balance	m_{PM}	—	—	4 % of pt. or 4 % of meas.	2 % of pt. or 2 % of meas.	1 % of max

^aAccuracy, repeatability, and noise are all determined with the same collected data, as described in § 1065.305, and based on absolute values. “pt.” refers to the overall flow-weighted mean value expected at the standard; “max.” refers to the peak value expected at the standard over any test interval, not the maximum of the instrument's range; “meas” refers to the actual flow-weighted mean measured over any test interval.

(b) *Redundant measurements.* For all PEMS described in this subpart, you may use data from multiple instruments to calculate test results for a single test. If you use redundant systems, use good engineering judgment to use multiple measured values in calculations or to disregard individual measurements. Note that you must keep your results from all measurements, as described in § 1065.25. This requirement applies whether or not you actually use the measurements in your calculations.

(c) *Field-testing ambient effects on PEMS.* We recommend that you use PEMS that are only minimally affected by ambient conditions such as temperature, pressure, humidity, physical orientation, mechanical shock and vibration, electromagnetic radiation, and ambient hydrocarbons. Follow the PEMS manufacturer's instructions for proper installation to isolate PEMS from ambient conditions that affect their performance. If a PEMS is inherently affected by ambient conditions that you cannot control, you may monitor those conditions and adjust the PEMS signals to compensate for the ambient effect. The standard-setting part may also specify the use of one or more field-testing adjustments or measurement allowances that you apply to results or standards to account for ambient effects on PEMS.

(d) *ECM signals.* You may use signals from the engine's electronic control module (ECM) in place of values measured by individual instruments within a PEMS, subject to the following provisions:

(1) *Recording ECM signals.* If your ECM updates a broadcast signal more or less frequently than 1 Hz, process data as follows:

(i) If your ECM updates a broadcast signal more frequently than 1 Hz, use PEMS to sample and record the signal's value more frequently. Calculate and record the 1 Hz mean of the more frequently updated data.

(ii) If your ECM updates a broadcast signal less frequently than 1 Hz, use PEMS to sample and record the signal's value at the most frequent rate. Linearly interpolate between recorded values and record the interpolated values at 1 Hz.

(iii) Optionally, you may use PEMS to electronically filter the ECM signals to meet the rise time and fall time specifications in Table 1 of this section. Record the filtered signal at 1 Hz.

(2) *Omitting ECM signals.* Replace any discontinuous or irrational ECM data with linearly interpolated values from adjacent data.

(3) *Aligning ECM signals with other data.* You must perform time-alignment and dispersion of ECM signals, according to PEMS manufacturer instructions and using good engineering judgment.

(4) *ECM signals for determining test intervals.* You may use any combination of ECM signals, with or without other measurements, to determine the start-time and end-time of a test interval.

(5) *ECM signals for determining brake-specific emissions.* You may use any combination of ECM signals, with or without other measurements, to estimate engine speed, torque, brake-specific fuel consumption (BSFC, in units of mass of fuel per kW-hr), and fuel rate for use in brake-specific emission calculations. We recommend that the overall performance of any speed, torque, or BSFC estimator should meet the performance specifications in Table 1 of this section. We recommend using one of the following methods:

(i) *Speed*. Use the engine speed signal directly from the ECM. This signal is generally accurate and precise. You may develop your own speed algorithm based on other ECM signals.

(ii) *Torque*. Use one of the following:

(A) *ECM torque*. Use the engine-torque signal directly from the ECM, if broadcast. Determine if this signal is proportional to indicated torque or brake torque. If it is proportional to indicated torque, subtract friction torque from indicated torque and record the result as brake torque. Friction torque may be a separate signal broadcast from the ECM or you may have to determine it from laboratory data as a function of engine speed.

(B) *ECM %-load*. Use the %-load signal directly from the ECM, if broadcast. Determine if this signal is proportional to indicated torque or brake torque. If it is proportional to indicated torque, subtract the minimum %-load value from the %-load signal. Multiply this result by the maximum brake torque at the corresponding engine speed. Maximum brake torque versus speed information is commonly published by the engine manufacturer.

(C) *Your algorithms*. You may develop and use your own combination of ECM signals to determine torque.

(iii) *BSFC*. Use one of the following:

(A) Use ECM engine speed and ECM fuel flow signals to interpolate brake-specific fuel consumption data, which might be available from an engine laboratory as a function of ECM engine speed and ECM fuel signals.

(B) Use a single BSFC value that approximates the BSFC value over a test interval (as defined in subpart K of this part). This value may be a nominal BSFC value for all engine operation determined over one or more laboratory duty cycles, or it may be any other BSFC that you determine. If you use a nominal BSFC, we recommend that you select a value based on the BSFC measured over laboratory duty cycles that best represent the range of engine operation that defines a test interval for field-testing. You may use the methods of this paragraph (d)(5)(iii)(B) only if it does not adversely affect your ability to demonstrate compliance with applicable standards.

(C) You may develop and use your own combination of ECM signals to determine BSFC.

(iv) *ECM fuel rate*. Use the fuel rate signal directly from the ECM and chemical balance to determine the molar flow rate of exhaust. Use § 1065.655(d) to determine the carbon mass fraction of fuel. You may alternatively develop and use your own combination of ECM signals to determine fuel mass flow rate.

(v) *Other ECM signals*. You may ask to use other ECM signals for determining brake-specific emissions, such as ECM air flow. We must approve the use of such signals in advance.

(6) *Permissible deviations*. ECM signals may deviate from the specifications of this part 1065, but the expected deviation must not prevent you from demonstrating that you meet the applicable standards in this chapter. For example, your emission results may be sufficiently below an applicable standard, such that the deviation would not significantly change the result. As another example, a very low engine-coolant temperature may define a logical statement that determines when a test interval may start. In this case, even if the ECM's

sensor for detecting coolant temperature was not very accurate or repeatable, its output would never deviate so far as to significantly affect when a test interval may start.

§ 1065.920 PEMS calibrations and verifications.

(a) *Subsystem calibrations and verifications.* Use all the applicable calibrations and verifications in subpart D of this part, including the linearity verifications in § 1065.307, to calibrate and verify PEMS. Note that a PEMS does not have to meet the system-response and updating-recording verifications of § 1065.308 and § 1065.309 if it meets the overall verification described in paragraph (b) of this section or if it measures PM using any method other than that described in § 1065.170(c)(1). This section does not apply to ECM signals. Note that because the regulations of this part require you to use good engineering judgment, it may be necessary to perform additional verifications and analysis. It may also be necessary to limit the range of conditions under which the PEMS can be used or to include specific additional maintenance to ensure that it functions properly under the test conditions. As provided in 40 CFR 1068.5, we will deem your system to not meet the requirements of this section if we determine that you did not use good engineering judgment to verify the measurement equipment. We may also deem your system to meet these requirements only under certain test conditions. If we ask for it, you must send us a summary of your verifications. We may also ask you to provide additional information or analysis to support your conclusions.

(b) *Overall verification.* This paragraph (b) specifies methods and criteria for verifying the overall performance of systems not fully compliant with requirements that apply for laboratory testing. Maintain records to show that the particular make, model, and configuration of your PEMS meets this verification. You may rely on data and other information from the PEMS manufacturer. However, we recommend that you generate your own records to show that your specific PEMS meets this verification. If you upgrade or change the configuration of your PEMS, your record must show that your new configuration meets this verification. The verification required by this section consists of operating an engine over a duty cycle in the laboratory and statistically comparing data generated and recorded by the PEMS with data simultaneously generated and recorded by laboratory equipment as follows:

- (1) Mount an engine on a dynamometer for laboratory testing. Prepare the laboratory and PEMS for emission testing, as described in this part, to get simultaneous measurements. We recommend selecting an engine with emission levels close to the applicable duty-cycle standards, if possible.
- (2) Select or create a duty cycle that has all the following characteristics:
 - (i) Engine operation that represents normal in-use speeds, loads, and degree of transient activity. Consider using data from previous field tests to generate a cycle.
 - (ii) A duration of (6 to 9) hours.
- (3) Starting with a warmed-up engine, run a valid emission test with the duty cycle from paragraph (b)(2) of this section. The laboratory and PEMS must both meet applicable validation requirements, such as drift validation, hydrocarbon contamination validation, and proportional validation.
- (4) Determine the brake-specific emissions and mass rate emissions, as applicable, for each test interval for both laboratory and the PEMS measurements, as follows:
 - (i) For both laboratory and PEMS measurements, use identical values to determine the beginning and end of each test interval.

- (ii) For both laboratory and PEMS measurements, use identical values to determine total work over each test interval.
- (iii) If the standard-setting part specifies the use of a measurement allowance for field testing, also apply the measurement allowance during calibration using good engineering judgment. If the measurement allowance is normally added to the standard, this means you must subtract the measurement allowance from measured PEMS emission results.
- (iv) Round results to the same number of significant digits as the standard.
- (5) For each test interval and emission, subtract the lab result from the PEMS result.
- (6) The PEMS passes the verification of this paragraph (b) if any one of the following are true for each constituent:
 - (i) 91 % or more of the differences are zero or less than zero.
 - (ii) The entire set of test-interval results passes the 95 % confidence alternate-procedure statistics for field testing (*t*-test and *F*-test) specified in § 1065.12.

§ 1065.925 PEMS preparation for field testing.

Take the following steps to prepare PEMS for field testing:

- (a) Verify that ambient conditions at the start of the test are within the limits specified in the standard-setting part. Continue to monitor these values to determine if ambient conditions exceed the limits during the test.
- (b) Install a PEMS and any accessories needed to conduct a field test.
- (c) Power the PEMS and allow pressures, temperatures, and flows to stabilize to their operating set points.
- (d) Bypass or purge any gaseous sampling PEMS instruments with ambient air until sampling begins to prevent system contamination from excessive cold-start emissions.
- (e) Conduct calibrations and verifications.
- (f) Operate any PEMS dilution systems at their expected flow rates using a bypass.
- (g) If you use a gravimetric balance to determine whether an engine meets an applicable PM standard, follow the procedures for PM sample preconditioning and tare weighing as described in § 1065.590. Operate the PM-sampling system at its expected flow rates using a bypass.
- (h) Verify the amount of contamination in the PEMS HC sampling system before the start of the field test as follows:
 - (1) Select the HC analyzer range for measuring the maximum concentration expected at the HC standard.
 - (2) Zero the HC analyzer using a zero gas or ambient air introduced at the analyzer port. When zeroing a FID, use the FID's burner air that would be used for in-use measurements (generally either ambient air or a portable source of burner air).
 - (3) Span the HC analyzer using span gas introduced at the analyzer port.
 - (4) Overflow zero or ambient air at the HC probe inlet or into a tee near the probe outlet.
 - (5) Measure the HC concentration in the sampling system:
 - (i) For continuous sampling, record the mean HC concentration as overflow zero air flows.
 - (ii) For batch sampling, fill the sample medium and record its mean concentration.
 - (6) Record this value as the initial HC concentration, x_{THCinit} , and use it to correct measured values as described in § 1065.660.

(7) If the initial HC concentration exceeds the greater of the following values, determine the source of the contamination and take corrective action, such as purging the system or replacing contaminated portions:

- (i) 2 % of the flow-weighted mean concentration expected at the standard or measured during testing.
- (ii) 2 $\mu\text{mol/mol}$.

(8) If corrective action does not resolve the deficiency, you may use a contaminated HC system if it does not prevent you from demonstrating compliance with the applicable emission standards.

§ 1065.930 Engine starting, restarting, and shutdown.

Unless the standard-setting part specifies otherwise, start, restart, and shut down the test engine for field testing as follows:

- (a) Start or restart the engine as described in the owners manual.
- (b) If the engine does not start after 15 seconds of cranking, stop cranking and determine the reason it failed to start. However, you may crank the engine longer than 15 seconds, as long as the owners manual or the service-repair manual describes the longer cranking time as normal.
- (c) Respond to engine stalling with the following steps:
 - (1) If the engine stalls during a required warm-up before emission sampling begins, restart the engine and continue warm-up.
 - (2) If the engine stalls at any other time after emission sampling begins, restart the engine and continue testing.
- (d) Shut down and restart the engine according to the manufacturer's specifications, as needed during normal operation in-use, but continue emission sampling until the field test is complete.

§ 1065.935 Emission test sequence for field testing.

- (a) Time the start of field testing as follows:
 - (1) If the standard-setting part requires only hot-stabilized emission measurements, operate the engine in-use until the engine coolant, block, or head absolute temperature is within ± 10 % of its mean value for the previous 2 min or until an engine thermostat controls engine temperature with coolant or air flow.
 - (2) If the standard-setting part requires hot-start emission measurements, shut down the engine after at least 2 min at the temperature tolerance specified in paragraph (a)(1) of this section. Start the field test within 20 min of engine shutdown.
 - (3) If the standard-setting part requires cold-start emission measurements, proceed to the steps specified in paragraph (b) of this section.
- (b) Take the following steps before emission sampling begins:
 - (1) For batch sampling, connect clean storage media, such as evacuated bags or tare-weighted PM sample media.
 - (2) Operate the PEMS according to the instrument manufacturer's instructions and using good engineering judgment.
 - (3) Operate PEMS heaters, dilution systems, sample pumps, cooling fans, and the data-collection system.
 - (4) Pre-heat or pre-cool PEMS heat exchangers in the sampling system to within their tolerances for operating temperatures.

- (5) Allow all other PEMS components such as sample lines, filters, and pumps to stabilize at operating temperature.
 - (6) Verify that no significant vacuum-side leak exists in the PEMS, as described in § 1065.345.
 - (7) Adjust PEMS flow rates to desired levels, using bypass flow if applicable.
 - (8) Zero and span all PEMS gas analyzers using NIST-traceable gases that meet the specifications of § 1065.750.
- (c) Start testing as follows:
- (1) Before the start of the first test interval, zero or re-zero any PEMS electronic integrating devices, as needed.
 - (2) If the engine is already running and warmed up and starting is not part of field testing, start the field test by simultaneously starting to sample exhaust, record engine and ambient data, and integrate measured values using a PEMS.
 - (3) If engine starting is part of field testing, start field testing by simultaneously starting to sample from the exhaust system, record engine and ambient data, and integrate measured values using a PEMS. Then start the engine.
- (d) Continue the test as follows:
- (1) Continue to sample exhaust, record data and integrate measured values throughout normal in-use operation of the engine.
 - (2) Between each test interval, zero or re-zero any electronic integrating devices, and reset batch storage media, as needed.
 - (3) The engine may be stopped and started, but continue to sample emissions throughout the entire field test.
 - (4) Conduct periodic verifications such as zero and span verifications on PEMS gas analyzers and use these to correct for drift according to paragraph (g) of this section. Do not include data recorded during verifications in emission calculations. Conduct the verifications as follows:
 - (i) For PEMS gas analyzers used to determine NTE emission values, perform verifications as recommended by the PEMS manufacturer or as indicated by good engineering judgment.
 - (ii) For PEMS gas analyzers used to determine bin emission values, perform zero verifications at least hourly using purified air. Perform span verification at the end of the shift-day or more frequently as recommended by the PEMS manufacturer or as indicated by good engineering judgment.
 - (5) You may periodically condition and analyze batch samples in-situ, including PM samples; for example you may condition an inertial PM balance substrate if you use an inertial balance to measure PM.
 - (6) You may have personnel monitoring and adjusting the PEMS during a test, or you may operate the PEMS unattended.
- (e) Stop testing as follows:
- (1) Continue sampling as needed to get an appropriate amount of emission measurement, according to the standard setting part. If the standard-setting part does not describe when to stop sampling, develop a written protocol before you start testing to establish how you will stop sampling. You may not determine when to stop testing based on emission results.

(2) At the end of the field test, allow the sampling systems' response times to elapse and then stop sampling. Stop any integrators and indicate the end of the test cycle on the data-collection medium.

(3) You may shut down the engine before or after you stop sampling.

(f) For any proportional batch sample, such as a bag sample or PM sample, verify for each test interval whether or not proportional sampling was maintained according to § 1065.545. Void the sample for any test interval that did not maintain proportional sampling according to § 1065.545.

(g) Take the following steps after emission sampling is complete:

(1) As soon as practical after emission sampling, analyze any gaseous batch samples.

(2) If you used dilution air, either analyze background samples or assume that background emissions were zero. Refer to § 1065.140 for dilution-air specifications.

(3) After quantifying all exhaust gases, record mean analyzer values after stabilizing a zero gas to each analyzer, then record mean analyzer values after stabilizing the span gas to the analyzer. Stabilization may include time to purge an analyzer of any sample gas and any additional time to account for analyzer response. Use these recorded values, including pre-test verifications and any zero verifications during testing, to correct for drift as described in § 1065.550.

(4) Verify PEMS gas analyzers used to determine NTE emission values as follows:

(i) Invalidate any data that does not meet the range criteria in § 1065.550. Note that it is acceptable that analyzers exceed 100 % of their ranges when measuring emissions between test intervals, but not during test intervals. You do not have to retest an engine if the range criteria are not met.

(ii) Invalidate any data that does not meet the drift criterion in § 1065.550. For HC, invalidate any data if the difference between the uncorrected and the corrected brake-specific HC emission values are not within ± 10 % of the uncorrected results or the applicable standard, whichever is greater. For data that does meet the drift criterion, correct those test intervals for drift according to § 1065.672 and use the drift corrected results in emissions calculations.

(5) Verify PEMS gas analyzers used to determine bin emission values as follows:

(i) Invalidate data from a whole shift-day if more than 1 % of recorded 1 Hz data exceeds 100 % of the selected gas analyzer range. For analyzer outputs exceeding 100 % of range, calculate emission results using the reported value. You must retest an engine if the range criteria are not met.

(ii) Invalidate any data for periods in which the ~~CO₂, H₂, O₂, H₂O, and NH₃~~ ~~and~~ ~~and~~ CO₂, H₂, O₂, H₂O, and NH₃ gas analyzers do not meet the drift criterion in § 1065.550. For HC, invalidate data if the difference between the uncorrected and the corrected brake-specific HC emission values are not within ± 10 % of the uncorrected results or the applicable standard, whichever is greater. For data that do meet the drift criterion, correct the data for drift according to § 1065.672 and use the drift-corrected results in emissions calculations.

(iii) For PEMS NO_x analyzers used to determine bin emission values, invalidate data for the engine over the entire shift-day if any data do not meet the following drift limits instead of meeting the drift criteria specified in § 1065.550:

(A) The allowable analyzer zero-drift between successive zero verifications is ± 2.5 ppm. The analyzer zero-drift limit over the shift-day is ± 10 ppm.

(B) The allowable analyzer span-drift limit is ± 4 % of the measured span value between successive span verifications.

(6) Unless you weighed PM in-situ, such as by using an inertial PM balance, place any used PM samples into covered or sealed containers and return them to the PM-stabilization environment and weigh them as described in § 1065.595.

§ 1065.940 Emission calculations.

(a) Perform emission calculations as described in § 1065.650 to calculate brake-specific emissions for each test interval using any applicable information and instructions in the standard-setting part.

(b) You may use a fixed molar mass for the diluted exhaust mixture for field testing. Determine this fixed value by engineering analysis.

Subpart K—Definitions and Other Reference Information

§ 1065.1001 Definitions.

The definitions in this section apply to this part. The definitions apply to all subparts unless we note otherwise. All undefined terms have the meaning the Act gives them. The definitions follow:

300 series stainless steel means any stainless steel alloy with a Unified Numbering System for Metals and Alloys number designated from S30100 to S39000. For all instances in this part where we specify 300 series stainless steel, such parts must also have a smooth inner-wall construction. We recommend an average roughness, R_a , no greater than 4 μm .

Accuracy means the absolute difference between a reference quantity and the arithmetic mean of ten mean measurements of that quantity. Determine instrument accuracy, repeatability, and noise from the same data set. We specify a procedure for determining accuracy in § 1065.305.

Act means the Clean Air Act, as amended, 42 U.S.C. 7401-7671q.

Adjustable parameter means any device, system, or element of design that someone can adjust (including those which are difficult to access) and that, if adjusted, may affect emissions or engine performance during emission testing or normal in-use operation. This includes, but is not limited to, parameters related to injection timing and fueling rate. In some cases, this may exclude a parameter that is difficult to access if it cannot be adjusted to affect emissions without significantly degrading engine performance, or if it will not be adjusted in a way that affects emissions during in-use operation.

Aerodynamic diameter means the diameter of a spherical water droplet that settles at the same constant velocity as the particle being sampled.

Aftertreatment means relating to a catalytic converter, particulate filter, or any other system, component, or technology mounted downstream of the exhaust valve (or exhaust port) whose design function is to decrease emissions in the engine exhaust before it is exhausted to the environment. Exhaust-gas recirculation (EGR) and turbochargers are not aftertreatment.

Allowed procedures means procedures that we either specify in this part 1065 or in the standard-

setting part or approve under § 1065.10.

Alternate procedures means procedures allowed under § 1065.10(c)(7).

Applicable standard means an emission standard to which an engine is subject; or a family emission limit to which an engine is certified under an emission credit program in the standard-setting part.

Aqueous condensation means the precipitation of water-containing constituents from a gas phase to a liquid phase. Aqueous condensation is a function of humidity, pressure, temperature, and concentrations of other constituents such as sulfuric acid. These parameters vary as a function of engine intake-air humidity, dilution-air humidity, engine air-to-fuel ratio, and fuel composition—including the amount of hydrogen and sulfur in the fuel.

Atmospheric pressure means the wet, absolute, atmospheric static pressure. Note that if you measure atmospheric pressure in a duct, you must ensure that there are negligible pressure losses between the atmosphere and your measurement location, and you must account for changes in the duct's static pressure resulting from the flow.

Auto-ranging means a gas analyzer function that automatically changes the analyzer digital resolution to a larger range of concentrations as the concentration approaches 100 % of the analyzer's current range. Auto-ranging does not mean changing an analog amplifier gain within an analyzer.

Auxiliary emission-control device means any element of design that senses temperature, motive speed, engine RPM, transmission gear, or any other parameter for the purpose of activating, modulating, delaying, or deactivating the operation of any part of the emission-control system.

Average means the arithmetic mean of a sample.

Brake power has the meaning given in the standard-setting part. If it is not defined in the standard-setting part, brake power means the usable power output of the engine, not including power required to fuel, lubricate, or heat the engine, circulate coolant to the engine, or to operate aftertreatment devices. If the engine does not power these accessories during a test, subtract the work required to perform these functions from the total work used in brake-specific emission calculations. Subtract engine fan work from total work only for air-cooled engines.

C₁-equivalent means a convention of expressing HC concentrations based on the total number of carbon atoms present, such that the C₁-equivalent of a molar HC concentration equals the molar concentration multiplied by the mean number of carbon atoms in each HC molecule. For example, the C₁-equivalent of 10 µmol/mol of propane (C₃H₈) is 30 µmol/mol. C₁-equivalent molar values may be denoted as "ppmC" in the standard-setting part. Molar mass may also be expressed on a C₁ basis. Note that calculating HC masses from molar concentrations and molar masses is only valid where they are each expressed on the same carbon basis.

Calibration means the process of setting a measurement system's response so that its output agrees with a range of reference signals. Contrast with "verification".

Calibration gas means a purified gas mixture used to calibrate gas analyzers. Calibration gases must meet the specifications of § 1065.750. Note that calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analyzers and sample handling components might refer to either calibration gases or span gases.

Carbon-containing fuel means an engine fuel that is characterized by compounds containing carbon. For example, gasoline, diesel, alcohol, liquefied petroleum gas, and natural gas are carbon-containing fuels.

Certification means relating to the process of obtaining a certificate of conformity for an engine family that complies with the emission standards and requirements in the standard-setting part.

Compression-ignition means relating to a type of reciprocating, internal-combustion engine that is not a spark-ignition engine.

Confidence interval means the range associated with a probability that a quantity will be considered statistically equivalent to a reference quantity.

Constant-speed engine means an engine whose certification is limited to constant-speed operation. Engines whose constant-speed governor function is removed or disabled are no longer constant-speed engines.

Constant-speed operation means engine operation with a governor that automatically controls the operator demand to maintain engine speed, even under changing load. Governors do not always maintain speed exactly constant. Typically speed can decrease (0.1 to 10) % below the speed at zero load, such that the minimum speed occurs near the engine's point of maximum power.

Coriolis meter means a flow-measurement instrument that determines the mass flow of a fluid by sensing the vibration and twist of specially designed flow tubes as the flow passes through them. The twisting characteristic is called the Coriolis effect. According to Newton's Second Law of Motion, the amount of sensor tube twist is directly proportional to the mass flow rate of the fluid flowing through the tube. See § 1065.220.

Dewpoint means a measure of humidity stated as the equilibrium temperature at which water condenses under a given pressure from moist air with a given absolute humidity. Dewpoint is specified as a temperature in °C or K, and is valid only for the pressure at which it is measured. See § 1065.645 to determine water vapor mole fractions from dewpoints using the pressure at which the dewpoint is measured.

Diesel exhaust fluid (DEF) means a liquid reducing agent (other than the engine fuel) used in conjunction with selective catalytic reduction to reduce NO_x emissions. *Diesel exhaust fluid* is generally understood to be an aqueous solution of urea conforming to the specifications of ISO 18611 or ISO 22241.

Discrete-mode means relating to a discrete-mode type of steady-state test, as described in the standard-setting part.

Dispersion means either:

- (1) The broadening and lowering of a signal due to any fluid capacitance, fluid mixing, or electronic filtering in a sampling system. (Note: To adjust a signal so its dispersion matches that of another signal, you may adjust the system's fluid capacitance, fluid mixing, or electronic filtering.)
- (2) The mixing of a fluid, especially as a result of fluid mechanical forces or chemical diffusion.

Dilution ratio (DR) means the amount of diluted exhaust per amount of undiluted exhaust.

Drift means the difference between a zero or calibration signal and the respective value reported by a measurement instrument immediately after it was used in an emission test, as long as you zeroed and spanned the instrument just before the test.

Dual-fuel has the meaning given in the standard-setting part.

Duty cycle means one of the following:

- (1) A series of speed and torque values (or power values) that an engine must follow during a laboratory test. Duty cycles are specified in the standard-setting part. A single duty cycle may consist of one or more test intervals. A series of speed and torque values meeting the definition of this paragraph (1) may also be considered a test cycle. For example, a duty cycle may be a ramped-modal cycle, which has one test interval; a cold-start plus hot-start transient cycle, which has two test intervals; or a discrete-mode cycle, which has one test interval for each mode.
- (2) A set of weighting factors and the corresponding speed and torque values, where the weighting factors are used to combine the results of multiple test intervals into a composite result.

Electric power generation application means an application whose purpose is to generate a precise frequency of electricity, which is characterized by an engine that controls engine speed very precisely. This would generally not apply to welders or portable home generators.

Electronic control module means an engine's electronic device that uses data from engine sensors to control engine parameters.

Emission-control system means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from an engine.

Emission-data engine means an engine that is tested for certification. This includes engines tested to establish deterioration factors.

Emission-related maintenance means maintenance that substantially affects emissions or is likely to substantially affect emission deterioration.

Engine family means a group of engines with similar emission characteristics throughout the useful life, as specified in the standard-setting part.

Engine governed speed means the engine operating speed when it is controlled by the installed

governor. *Enhanced-idle* means a mode of engine idle operation where idle speed is elevated above warm idle speed as determined by the electronic control module, for example during engine warm-up or to increase exhaust temperature.

EPA Program Officer means the Director, Compliance Division, U.S. Environmental Protection Agency, 2000 Traverwood Dr., Ann Arbor, MI 48105.

Exhaust-gas recirculation means a technology that reduces emissions by routing exhaust gases that had been exhausted from the combustion chamber(s) back into the engine to be mixed with incoming air before or during combustion. The use of valve timing to increase the amount of residual exhaust gas in the combustion chamber(s) that is mixed with incoming air before or during combustion is not considered exhaust-gas recirculation for the purposes of this part.

Fall time, t_{90-10} , means the time interval of a measurement instrument's response after any step decrease to the input between the following points:

- (1) The point at which the response has fallen 10 % of the total amount it will fall in response to the step change.
- (2) The point at which the response has fallen 90 % of the total amount it will fall in response to the step change.

Flexible-fuel has the meaning given in the standard-setting part.

Flow-weighted mean means the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust flow rate, divided by the sum of the recorded flow rates. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration, because the CVS system itself flow-weights the bag concentration.

Fuel type means a general category of fuels such as gasoline or LPG. There can be multiple grades within a single type of fuel, such as all-season and winter-grade gasoline.

Good engineering judgment means judgments made consistent with generally accepted scientific and engineering principles and all available relevant information. See 40 CFR 1068.5 for the administrative process we use to evaluate good engineering judgment.

HEPA filter means high-efficiency particulate air filters that are rated to achieve a minimum initial particle-removal efficiency of 99.97 % using ASTM F1471 (incorporated by reference, [see 49 CFR § 1065.1010](#)).

High-idle speed means the engine speed at which an engine governor function controls engine speed with operator demand at maximum and with zero load applied. "Warm high-idle speed" is the high-idle speed of a warmed-up engine.

High-speed governor means any device, system, or element of design that modulates the engine output torque for the purpose of limiting the maximum engine speed.

Hydraulic diameter means the diameter of a circle whose area is equal to the area of a noncircular cross section of tubing, including its wall thickness. The wall thickness is included only for the purpose of facilitating a simplified and nonintrusive measurement.

Hydrocarbon (HC) means THC, THCE, NMHC, NMNEHC, NMOG, or NMHCE, as applicable. Hydrocarbon generally means the hydrocarbon group on which the emission standards are based for each type of fuel and engine.

Identification number means a unique specification (for example, a model number/serial number combination) that allows someone to distinguish a particular engine from other similar engines.

Idle speed means the engine speed at which an engine governor function controls engine speed with operator demand at minimum and with minimum load applied (greater than or equal to zero). For engines without a governor function that controls idle speed, idle speed means the manufacturer-declared value for lowest engine speed possible with minimum load. This definition does not apply for operation designated as “high-idle speed.” “Warm idle speed” is the idle speed of a warmed-up engine.

Intermediate speed has the meaning given in § 1065.610.

Lean-burn engine means an engine with a nominal air fuel ratio substantially leaner than stoichiometric. For example, diesel-fueled engines are typically lean-burn engines, and gasoline-fueled engines are lean-burn engines if they have an air-to-fuel mass ratio above 14.7:1.

Linearity means the degree to which measured values agree with respective reference values. Linearity is quantified using a linear regression of pairs of measured values and reference values over a range of values expected or observed during testing. Perfect linearity would result in an intercept, a_0 , equal to zero, a slope, a_1 , of one, a coefficient of determination, r^2 , of one, and a standard error of the estimate, *SEE*, of zero. The term "linearity" is not used in this part to refer to the shape of a measurement instrument's unprocessed response curve, such as a curve relating emission concentration to voltage output. A properly performing instrument with a nonlinear response curve will meet linearity specifications.

Manufacturer has the meaning given in section 216(1) of the Act. In general, this term includes any person who manufactures an engine or vehicle for sale in the United States or otherwise introduces a new nonroad engine into commerce in the United States. This includes importers who import engines or vehicles for resale.

Maximum test speed has the meaning given in § 1065.610.

Maximum test torque has the meaning given in § 1065.610.

Measurement allowance means a specified adjustment in the applicable emission standard or a measured emission value to reflect the relative quality of the measurement. See the standard-setting part to determine whether any measurement allowances apply for your testing. Measurement allowances generally apply only for field testing and are intended to account for reduced accuracy or precision that result from using field-grade measurement systems.

Mode means one of the following:

- (1) A distinct combination of engine speed and load for steady-state testing.
- (2) A continuous combination of speeds and loads specifying a transition during a ramped-modal test.
- (3) A distinct operator demand setting, such as would occur when testing locomotives or constant-speed engines.

Neat means fuel that is free from mixture or dilution with other fuels. For example, hydrogen or natural gas fuel used without diesel pilot fuel are neat.

NIST-accepted means relating to a value that has been assigned or named by NIST.

NIST-traceable means relating to a standard value that can be related to NIST-stated references through an unbroken chain of comparisons, all having stated uncertainties, as specified in NIST Technical Note 1297 (incorporated by reference, [see in](#) § 1065.1010). Allowable uncertainty limits specified for NIST-traceability refer to the propagated uncertainty specified by NIST.

Noise means the precision of 30 seconds of updated recorded values from a measurement instrument as it quantifies a zero or reference value. Determine instrument noise, repeatability, and accuracy from the same data set. We specify a procedure for determining noise in § 1065.305.

No-load means a dynamometer setting of zero torque.

Nonmethane hydrocarbons (NMHC) means the sum of all hydrocarbon species except methane. Refer to § 1065.660 for NMHC determination.

Nonmethane hydrocarbon equivalent (NMHCE) means the sum of the carbon mass contributions of non-oxygenated nonmethane hydrocarbons, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust nonmethane hydrocarbon from petroleum-fueled engines. The hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

Nonmethane nonethane hydrocarbons (NMNEHC) means the sum of all hydrocarbon species except methane and ethane. Refer to § 1065.660 for NMNEHC determination.

Nonroad means relating to nonroad engines.

Nonroad engine has the meaning we give in 40 CFR 1068.30. In general this means all internal-combustion engines except motor vehicle engines, stationary engines, engines used solely for competition, or engines used in aircraft.

Open crankcase emissions means any flow from an engine's crankcase that is emitted directly into the environment. Crankcase emissions are not "open crankcase emissions" if the engine is designed to always route all crankcase emissions back into the engine (for example, through the intake system or an aftertreatment system) such that all the crankcase emissions, or their products, are emitted into the environment only through the engine exhaust system.

Operator demand means an engine operator's input to control engine output. The "operator" may be a person (i.e., manual), or a governor (i.e., automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor setpoint or signal. Output means engine power, P , which is the product of engine speed, f_n , and engine torque, T .

Oxides of nitrogen means NO and NO₂ as measured by the procedures specified in § 1065.270. Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO₂, such that you use an effective molar mass for all oxides of nitrogen equivalent to that of NO₂.

Oxygenated fuels means fuels composed of at least 25 % oxygen-containing compounds, such as ethanol or methanol. Testing engines that use oxygenated fuels generally requires the use of the sampling methods in subpart I of this part. However, you should read the standard-setting part and subpart I of this part to determine appropriate sampling methods.

Partial pressure means the pressure, p , attributable to a single gas in a gas mixture. For an ideal gas, the partial pressure divided by the total pressure is equal to the constituent's molar concentration, x .

Percent (%) means a representation of exactly 0.01. Numbers expressed as percentages in this part (such as a tolerance of ± 2 %) have infinite precision, so 2 % and 2.000000000 % have the same meaning. This means that where we specify some percentage of a total value, the calculated value has the same number of significant digits as the total value. For example, 2 % of a span value where the span value is 101.3302 is 2.026604.

Portable emission measurement system (PEMS) means a measurement system consisting of portable equipment that can be used to generate brake-specific emission measurements during field testing or laboratory testing.

Precision means two times the standard deviation of a set of measured values of a single zero or reference quantity. See also the related definitions of *noise* and *repeatability* in this section.

Procedures means all aspects of engine testing, including the equipment specifications, calibrations, calculations and other protocols and specifications needed to measure emissions, unless we specify otherwise.

Proving ring is a device used to measure static force based on the linear relationship between stress and strain in an elastic material. It is typically a steel alloy ring, and you measure the deflection (strain) of its diameter when a static force (stress) is applied across its diameter.

PTFE means polytetrafluoroethylene, commonly known as Teflon™.

Purified air means air meeting the specifications for purified air in § 1065.750. Purified air may be produced by purifying ambient air. The purification may occur at the test site or at another location (such as at a gas supplier's facility). Alternatively, purified air may be synthetically generated, using good engineering judgment, from purified oxygen and nitrogen. The addition of other elements normally present in purified ambient air (such as Ar) is not required.

Ramped-modal means relating to a ramped-modal type of steady-state test, as described in the standard-setting part.

Rechargeable Energy Storage System (RESS) means engine or equipment the components of a hybrid engine or vehicle that store recovered energy for later use to propel the vehicle or accomplish a different primary function. Examples of RESS include the battery system or a hydraulic accumulator, such as the battery system in a hybrid ~~electric~~ vehicle.

Recommend has the meaning given in § 1065.201.

Regression statistics means any of the regression statistics specified in § 1065.602.

Regulated pollutant means an exhaust constituent for which an emission standard or a reporting requirement applies.

Repeatability means the precision of ten mean measurements of a reference quantity. Determine instrument repeatability, accuracy, and noise from the same data set. We specify a procedure for determining repeatability in § 1065.305.

Revoke has the meaning given in 40 CFR 1068.30.

Rise time, t_{10-90} , means the time interval of a measurement instrument's response after any step increase to the input between the following points:

- (1) The point at which the response has risen 10 % of the total amount it will rise in response to the step change.
- (2) The point at which the response has risen 90 % of the total amount it will rise in response to the step change.

Roughness (or average roughness, R_a) means the size of finely distributed vertical surface deviations from a smooth surface, as determined when traversing a surface. It is an integral of the absolute value of the roughness profile measured over an evaluation length.

Round means to apply the rounding convention specified in § 1065.20(e), unless otherwise specified.

Scheduled maintenance means adjusting, repairing, removing, disassembling, cleaning, or replacing components or systems periodically to keep a part or system from failing, malfunctioning, or wearing prematurely. It also may mean actions you expect are necessary to correct an overt indication of failure or malfunction for which periodic maintenance is not appropriate.

Shared atmospheric pressure meter means an atmospheric pressure meter whose output is used as the atmospheric pressure for an entire test facility that has more than one dynamometer test cell.

Shared humidity measurement means a humidity measurement that is used as the humidity for an entire test facility that has more than one dynamometer test cell.

Span means to adjust an instrument so that it gives a proper response to a calibration standard that represents between 75 % and 100 % of the maximum value in the instrument range or expected range of use.

Span gas means a purified gas mixture used to span gas analyzers. Span gases must meet the specifications of § 1065.750. Note that calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analyzers and sample handling components might refer to either calibration gases or span gases.

Spark-ignition means relating to a gasoline-fueled engine or any other type of engine with a spark plug (or other sparking device) and with operating characteristics significantly similar to the theoretical Otto combustion cycle. Spark-ignition engines usually use a throttle to regulate intake air flow to control power during normal operation.

Special procedures means procedures allowed under § 1065.10(c)(2).

Specified procedures means procedures we specify in this part 1065 or the standard-setting part. Other procedures allowed or required by § 1065.10(c) are not specified procedures.

Standard deviation has the meaning given in § 1065.602. Note this is the standard deviation for a non-biased sample.

Standard-setting part means the part in the Code of Federal Regulations that defines emission standards for a particular engine. See § 1065.1(a).

Steady-state means relating to emission tests in which engine speed and load are held at a finite set of nominally constant values. Steady-state tests are generally either discrete-mode tests or ramped-modal tests.

Stoichiometric means relating to the particular ratio of air and fuel such that if the fuel were fully oxidized, there would be no remaining fuel or oxygen. For example, stoichiometric combustion in a gasoline-fueled engine typically occurs at an air-to-fuel mass ratio of about 14.7:1.

Storage medium means a particulate filter, sample bag, or any other storage device used for batch sampling.

Test engine means an engine in a test sample.

Test interval means a duration of time over which you determine mass of emissions. For example, the standard-setting part may specify a complete laboratory duty cycle as a cold-start test interval, plus a hot-start test interval. As another example, a standard-setting part may specify a field-test interval, such as a “not-to-exceed” (NTE) event, as a duration of time over which an engine operates within a certain range of speed and torque. In cases where multiple test intervals occur over a duty cycle, the standard-setting part may specify additional calculations that weight and combine results to arrive at composite values for comparison against the applicable standards in this chapter.

Test sample means the collection of engines selected from the population of an engine family for emission testing.

Tolerance means the interval in which at least 95 % of a set of recorded values of a certain quantity must lie. Use the specified recording frequencies and time intervals to determine if a quantity is within the applicable tolerance. The concept of tolerance is intended to address random variability. You may not take advantage of the tolerance specification to incorporate a bias into a measurement.

Total hydrocarbon (THC) means the combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon, expressed as a hydrocarbon with a hydrogen-to-carbon mass ratio of 1.85:1.

Total hydrocarbon equivalent (THCE) means the sum of the carbon mass contributions of non-oxygenated hydrocarbons, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust hydrocarbon from petroleum-fueled engines. The hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

Transformation time, t_{50} , means the overall system response time to any step change in input, generally the average of the time to reach 50 % response to a step increase, t_{0-50} , or to a step decrease, t_{100-50} .

t_{0-50} means the time interval of a measurement system's response after any step increase to the input between the following points:

- (1) The point at which the step change is initiated at the sample probe.
- (2) The point at which the response has risen 50 % of the total amount it will rise in response to the step change.

t_{100-50} means the time interval of a measurement system's response after any step decrease to the input between the following points:

- (1) The point at which the step change is initiated at the sample probe.
- (2) The point at which the response has fallen 50 % of the total amount it will fall in response to the step change.

Uncertainty means uncertainty with respect to NIST-traceability. See the definition of NIST-traceable in this section.

United States means the States, the District of Columbia, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, Guam, American Samoa, and the U.S. Virgin Islands.

Useful life means the period during which a new engine is required to comply with all applicable emission standards. The standard-setting part defines the specific useful-life periods for individual engines.

Variable-speed engine means an engine that is not a constant-speed engine.

Vehicle means any vehicle, vessel, or type of equipment using engines to which this part applies.

For purposes of this part, the term “vehicle” may include nonmotive machines or equipment such as a pump or generator.

Verification means to evaluate whether or not a measurement system’s outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance. Contrast with “calibration”.

We (us, our) means the Administrator of the Environmental Protection Agency and any authorized representatives.

Work has the meaning given in § 1065.110.

Zero means to adjust an instrument so it gives a zero response to a zero calibration standard, such as purified nitrogen or purified air for measuring concentrations of emission constituents.

Zero gas means a gas that yields a zero response in an analyzer. This may either be purified nitrogen, purified air, a combination of purified air and purified nitrogen. For field testing, *zero gas* may include ambient air.

§ 1065.1005 Symbols, abbreviations, acronyms, and units of measure.

The procedures in this part generally follow the International System of Units (SI), as detailed in NIST Special Publication 811, which we incorporate by reference in § 1065.1010. See § 1065.20 for specific provisions related to these conventions. This section summarizes the way we use symbols, units of measure, and other abbreviations.

(a) *Symbols for quantities.* This part uses the following symbols and units of measure for various quantities:

TABLE 1 OF § 1065.1005—SYMBOLS FOR QUANTITIES

Symbol	Quantity	Unit	Unit symbol	Units in terms of SI base units
α	atomic hydrogen-to-carbon ratio	mole per mole	mol/mol	1.
A	area	square meter	m ²	m ² .
a_0	intercept of least squares regression			
a_1	slope of least squares regression			
a_g	acceleration of Earth’s gravity	meter per square second	m/s ²	m·s ⁻² .
β	ratio of diameters	meter per meter	m/m	1.
β	atomic oxygen-to-carbon ratio	mole per mole	mol/mol	1.
$C_{\#}$	number of carbon atoms in a molecule			
c	power-specific carbon mass error coefficient	gram per kilowatt-hour	g/(kW·hr)	3.6 ⁻¹ ·10 ⁻⁹ ·m ⁻² ·s ² .
C_d	discharge coefficient			
C_f	flow coefficient			
δ	atomic nitrogen-to-carbon ratio	mole per mole	mol/mol	1.
d	diameter	meter	m	m.
d	power-specific carbon mass rate absolute error coefficient	gram per kilowatt-hour	g/(kW·hr)	3.6 ⁻¹ ·10 ⁻⁹ ·m ⁻² ·s ² .
DR	dilution ratio	mole per mole	mol/mol	1.

ε	error between a quantity and its reference			
ϵ	difference or error quantity			
e	brake-specific emission or fuel consumption	gram per kilowatt hour	g/(kW·hr)	$3.6^{-1} \cdot 10^{-9} \cdot \text{m}^{-2} \cdot \text{s}^2$.
F	F-test statistic			
f	frequency	hertz	Hz	s^{-1} .
f_n	angular speed (shaft)	revolutions per minute	r/min	$\pi \cdot 30^{-1} \cdot \text{s}^{-1}$.
γ	ratio of specific heats	(joule per kilogram kelvin) per (joule per kilogram kelvin)	(J/(kg·K))/(J/(kg·K))	1.
γ	atomic sulfur-to-carbon ratio	mole per mole	mol/mol	1.
K	correction factor			1.
K_v	calibration coefficient		$\text{m}^4 \cdot \text{s} \cdot \text{K}^{0.5} / \text{kg}$	$\text{m}^4 \cdot \text{kg}^{-1} \cdot \text{s} \cdot \text{K}^{0.5}$.
κ	opacity			
l	length	meter	m	m.
L	limit			
μ	viscosity, dynamic	pascal second	Pa·s	$\text{m}^{-1} \cdot \text{kg} \cdot \text{s}^{-1}$.
M	molar mass ^a	gram per mole	g/mol	$10^{-3} \cdot \text{kg} \cdot \text{mol}^{-1}$.
m	mass	kilogram	kg	kg.
\dot{m}	mass rate	kilogram per second	kg/s	$\text{kg} \cdot \text{s}^{-1}$.
ν	viscosity, kinematic	meter squared per second	m^2/s	$\text{m}^2 \cdot \text{s}^{-1}$.
N	total number in series			
n	amount of substance	mole	mol	mol.
\dot{n}	amount of substance rate	mole per second	mol/s	$\text{mol} \cdot \text{s}^{-1}$.
P	power	kilowatt	kW	$10^3 \cdot \text{m}^2 \cdot \text{kg} \cdot \text{s}^{-3}$.
PF	penetration fraction			
p	pressure	pascal	Pa	$\text{m}^{-1} \cdot \text{kg} \cdot \text{s}^{-2}$.
ρ	mass density	kilogram per cubic meter	kg/m^3	$\text{m}^{-3} \cdot \text{kg}$.
Δp	differential static pressure	pascal	Pa	$\text{m}^{-1} \cdot \text{kg} \cdot \text{s}^{-2}$.
r	ratio of pressures	pascal per pascal	Pa/Pa	1.
r^2	coefficient of determination			
Ra	average surface roughness	micrometer	μm	$10^{-6} \cdot \text{m}$.
$Re^\#$	Reynolds number			
RF	response factor			
RH	relative humidity			
σ	non-biased standard deviation			
S	Sutherland constant	kelvin	K	K.
SEE	standard error of the estimate			
T	absolute temperature	kelvin	K	K.
T	Celsius temperature	degree Celsius	°C	$\text{K} - 273.15$.
T	torque (moment of force)	newton meter	N·m	$\text{m}^2 \cdot \text{kg} \cdot \text{s}^{-2}$.
θ	plane angle	degrees	°	rad.
t	time	second	s	s.
Δt	time interval, period, 1/frequency	second	s	s.
V	volume	cubic meter	m^3	m^3 .

\dot{V}	volume rate	cubic meter per second	m ³ /s	m ³ ·s ⁻¹ .
W	work	kilowatt-hour	kW·hr	3.6·10 ⁶ ·m ² ·kg·s ⁻² .
w_c	carbon mass fraction	gram per gram	g/g	1.
x	amount of substance mole fraction ^b	mole per mole	mol/mol	1.
\bar{x}	flow-weighted mean concentration	mole per mole	mol/mol	1.
y	generic variable			
Z	compressibility factor			

^aSee paragraph (f)(2) of this section for the values to use for molar masses. Note that in the cases of NO_x and HC, the regulations specify effective molar masses based on assumed speciation rather than actual speciation.

^bNote that mole fractions for THC, THCE, NMHC, NMHCE, and NOTHC are expressed on a C₁-equivalent basis.

(b) *Symbols for chemical species.* This part uses the following symbols for chemical species and exhaust constituents:

TABLE 2 OF § 1065.1005—SYMBOLS FOR CHEMICAL SPECIES AND EXHAUST CONSTITUENTS

Symbol	Species
Ar	argon.
C	carbon.
CH ₂ O	formaldehyde.
CH ₂ O ₂	formic acid.
CH ₃ OH	methanol.
CH ₄	methane.
C ₂ H ₄ O	acetaldehyde.
C ₂ H ₅ OH	ethanol.
C ₂ H ₆	ethane.
C ₃ H ₇ OH	propanol.
C ₃ H ₈	propane.
C ₄ H ₁₀	butane.
C ₅ H ₁₂	pentane.
CO	carbon monoxide.
CO ₂	carbon dioxide.
H	atomic hydrogen.
H ₂	molecular hydrogen.
H ₂ O	water.
H ₂ SO ₄	sulfuric acid.
HC	hydrocarbon.
He	helium.
⁸⁵ Kr	krypton 85.
N ₂	molecular nitrogen.
NH ₃	ammonia.
NMHC	nonmethane hydrocarbon.
NMHCE	nonmethane hydrocarbon equivalent.
NMNEHC	nonmethane-nonethane hydrocarbon.
NO	nitric oxide.
NO ₂	nitrogen dioxide.
NO _x	oxides of nitrogen.
N ₂ O	nitrous oxide.
NMOG	nonmethane organic gases.
NONMHC	non-oxygenated nonmethane hydrocarbon.
NOTHC	non-oxygenated total hydrocarbon.
O ₂	molecular oxygen.
OHC	oxygenated hydrocarbon.
²¹⁰ Po	polonium 210.
PM	particulate matter.
S	sulfur.
SVOC	semi-volatile organic compound.
THC	total hydrocarbon.
THCE	total hydrocarbon equivalent.
ZrO ₂	zirconium dioxide.

(c) *Prefixes.* This part uses the following prefixes for units and unit symbols:

TABLE 3 OF § 1065.1005—PREFIXES

Symbol	Prefix name	Factor
μ	micro	10 ⁻⁶
m	milli	10 ⁻³
c	centi	10 ⁻²
k	kilo	10 ³
M	mega	10 ⁶

(d) *Superscripts*. This part uses the following superscripts for modifying quantity symbols:

TABLE 4 OF § 1065.1005—SUPERSCRIPTS

Superscript	Meaning
overbar (such as \bar{y})	arithmetic mean.
overdot (such as \dot{y})	quantity per unit time.

(e) *Subscripts*. This part uses the following subscripts for modifying quantity symbols:

TABLE 5 OF § 1065.1005—SUBSCRIPTS

Subscript	Meaning
a	absolute (e.g., absolute difference or error).
abs	absolute quantity.
act	actual condition.
air	air, dry.
amb	ambient.
atmos	atmospheric.
bkgnd	background.
C	carbon mass.
cal	calibration quantity.
CFV	critical flow venturi.
comb	combined.
comp	composite value.
cor	corrected quantity.
dil	dilution air.
dew	dewpoint.
dexh	diluted exhaust.
dry	dry condition.
dutycycle	duty cycle.
ε	related to a difference or error quantity.
exh	raw exhaust.
exp	expected quantity.
fluid	fluid stream.
fn	feedback speed.
frict	friction.
fuel	fuel consumption.
hi,idle	condition at high-idle.
i	an individual of a series.
idle	condition at idle.
in	quantity in.

init	initial quantity, typically before an emission test.
int	intake air.
j	an individual of a series.
mapped	conditions over which an engine can operate.
max	the maximum (i.e., peak) value expected at the standard over a test interval; not the maximum of an instrument range.
meas	measured quantity.
media	PM sample media.
mix	mixture of diluted exhaust and air.
norm	normalized.
out	quantity out.
P	power.
part	partial quantity.
PDP	positive-displacement pump.
post	after the test interval.
pre	before the test interval.
prod	stoichiometric product.
r	relative (e.g., relative difference or error).
rate	rate (divided by time).
record	record rate.
ref	reference quantity.
rev	revolution.
sat	saturated condition.
s	slip.
span	span quantity.
SSV	subsonic venturi.
std	standard condition.
stroke	engine strokes per power stroke.
T	torque.
test	test quantity.
test.alt	alternate test quantity.
uncor	uncorrected quantity.
vac	vacuum side of the sampling system.
weight	calibration weight.
zero	zero quantity.

(f) *Constants.* (1) This part uses the following constants for the composition of dry air:

TABLE 6 OF § 1065.1005—CONSTANTS

Symbol	Quantity	mol/mol
x_{Arair}	amount of argon in dry air	0.00934
x_{CO2air}	amount of carbon dioxide in dry air	0.000375
x_{N2air}	amount of nitrogen in dry air	0.78084
x_{O2air}	amount of oxygen in dry air	0.209445

(2) This part uses the following molar masses or effective molar masses of chemical species:

TABLE 7 OF § 1065.1005—MOLAR MASSES

Symbol	Quantity	g/mol ($10^{-3} \cdot \text{kg} \cdot \text{mol}^{-1}$)
M_{air}	molar mass of dry air ^a	28.96559
M_{Ar}	molar mass of argon	39.948
M_{C}	molar mass of carbon	12.0107
$M_{\text{CH}_3\text{OH}}$	molar mass of methanol	32.04186
$M_{\text{C}_2\text{H}_5\text{OH}}$	molar mass of ethanol	46.06844
$M_{\text{C}_2\text{H}_4\text{O}}$	molar mass of acetaldehyde	44.05256
$M_{\text{CH}_4\text{N}_2\text{O}}$	molar mass of urea	60.05526
$M_{\text{C}_2\text{H}_6}$	molar mass of ethane	30.06904
$M_{\text{C}_3\text{H}_8}$	molar mass of propane	44.09562
$M_{\text{C}_3\text{H}_7\text{OH}}$	molar mass of propanol	60.09502
M_{CO}	molar mass of carbon monoxide	28.0101
M_{CH_4}	molar mass of methane	16.0425
M_{CO_2}	molar mass of carbon dioxide	44.0095
M_{H}	molar mass of atomic hydrogen	1.00794
M_{H_2}	molar mass of molecular hydrogen	2.01588
$M_{\text{H}_2\text{O}}$	molar mass of water	18.01528
$M_{\text{CH}_2\text{O}}$	molar mass of formaldehyde	30.02598
M_{He}	molar mass of helium	4.002602
M_{N}	molar mass of atomic nitrogen	14.0067
M_{N_2}	molar mass of molecular nitrogen	28.0134
M_{NH_3}	molar mass of ammonia	17.03052
M_{NMHC}	effective C_1 molar mass of nonmethane hydrocarbon ^b	13.875389
M_{NMHCE}	effective C_1 molar mass of nonmethane hydrocarbon equivalent ^b	13.875389
M_{NMNEHC}	effective C_1 molar mass of nonmethane-nonethane hydrocarbon ^b	13.875389
M_{NO_x}	effective molar mass of oxides of nitrogen ^c	46.0055
$M_{\text{N}_2\text{O}}$	molar mass of nitrous oxide	44.0128
M_{O}	molar mass of atomic oxygen	15.9994
M_{O_2}	molar mass of molecular oxygen	31.9988
M_{S}	molar mass of sulfur	32.065
M_{THC}	effective C_1 molar mass of total hydrocarbon ^b	13.875389
M_{THCE}	effective C_1 molar mass of total hydrocarbon equivalent ^b	13.875389

^aSee paragraph (f)(1) of this section for the composition of dry air.

^bThe effective molar masses of THC, THCE, NMHC, NMHCE, and NMNEHC are defined on a C_1 basis and are based on an atomic hydrogen-to-carbon ratio, α , of 1.85 (with β , γ , and δ equal to zero).

^cThe effective molar mass of NO_x is defined by the molar mass of nitrogen dioxide, NO_2 .

(3) This part uses the following molar gas constant for ideal gases:

TABLE 8 OF § 1065.1005—MOLAR GAS CONSTANT FOR IDEAL GASES

Symbol	Quantity	J/(mol·K) ($\text{m}^2 \cdot \text{kg} \cdot \text{s}^{-2} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$)
R	molar gas constant	8.314472

(4) This part uses the following ratios of specific heats for dilution air and diluted exhaust:

TABLE 9 OF § 1065.1005—RATIOS OF SPECIFIC HEATS FOR DILUTION AIR AND DILUTED EXHAUST

Symbol	Quantity	[J/(kg·K)]/[J/(kg·K)]
γ_{air}	ratio of specific heats for intake air or dilution air	1.399
γ_{dil}	ratio of specific heats for diluted exhaust	1.399
γ_{exh}	ratio of specific heats for raw exhaust	1.385

(g) *Other acronyms and abbreviations.* This part uses the following additional abbreviations and acronyms:

TABLE 10 OF § 1065.1005—OTHER ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
ABS	acrylonitrile-butadiene-styrene.
ASTM	ASTM International.
BMD	bag mini-diluter.
BSFC	brake-specific fuel consumption.
CARB	California Air Resources Board.
CFR	Code of Federal Regulations.
CFV	critical-flow venturi.
CI	compression-ignition.
CITT	Curb Idle Transmission Torque.
CLD	chemiluminescent detector.
CVS	constant-volume sampler.
DEF	diesel exhaust fluid.
DF	deterioration factor.
ECM	electronic control module.
EFC	electronic flow control.
e.g.	exempli gratia, for example.
EGR	exhaust gas recirculation.
EPA	Environmental Protection Agency.
FEL	Family Emission Limit.
FID	flame-ionization detector.
FTIR	Fourier transform infrared.
GC	gas chromatograph.
GC-ECD	gas chromatograph with an electron-capture detector.
GC-FID	gas chromatograph with a flame ionization detector.
HEPA	high-efficiency particulate air.
IBP	initial boiling point.
IBR	incorporated by reference.
i.e.	id est, in other words.
ISO	International Organization for Standardization.
LPG	liquefied petroleum gas.
MPD	magnetopneumatic detection.
NDIR	nondispersive infrared.
NDUV	nondispersive ultraviolet.
NIST	National Institute for Standards and Technology.

NMC	nonmethane cutter.
PDP	positive-displacement pump.
PEMS	portable emission measurement system.
PFD	partial-flow dilution.
PLOT	porous layer open tubular.
PMD	paramagnetic detection.
PMP	Polymethylpentene.
pt.	a single point at the mean value expected at the standard.
psi	pounds per square inch.
PTFE	polytetrafluoroethylene (commonly known as Teflon™).
RE	rounding error.
RESS	rechargeable energy storage system.
RFPF	response factor penetration fraction.
RMC	ramped-modal cycle.
rms	root-mean square.
RTD	resistive temperature detector.
SAW	surface acoustic wave.
SEE	standard error of the estimate.
SSV	subsonic venturi.
SI	spark-ignition.
THC-FID	total hydrocarbon flame ionization detector.
TINV	inverse student <i>t</i> -test function in Microsoft Excel.
UCL	upper confidence limit.
UFM	ultrasonic flow meter.
U.S.C.	United States Code.

§ 1065.1010 Incorporation by reference.

Certain material is incorporated by reference into this part with the approval of the Director of the Federal Register under 5 U.S.C. 552(a) and 1 CFR part 51. To enforce any edition other than that specified in this section, EPA must publish a document in the *Federal Register* and the material must be available to the public. All approved incorporation by reference (IBR) material is available for inspection at EPA and at the National Archives and Records Administration (NARA). Contact EPA at: U.S. EPA, Air and Radiation Docket Center, WJC West Building, Room 3334, 1301 Constitution Ave. NW, Washington, DC 20004; www.epa.gov/dockets; (202) 202-1744. For information on inspecting this material at NARA, visit www.archives.gov/federal-register/cfr/ibr-locations.html or email fr.inspection@nara.gov. The material may be obtained from the following sources:

(a) *ASTM material*. The following standards are available from ASTM International, 100 Barr Harbor Dr., P.O. Box C700, West Conshohocken, PA 19428–2959, (877) 909–ASTM, or <http://www.astm.org>:

(1) ASTM D86-12, Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure, approved December 1, 2012 (“ASTM D86”), IBR approved for §§ 1065.703(b) and 1065.710(b) and (c).

(2) ASTM D93-13, Standard Test Methods for Flash Point by Pensky- Martens Closed Cup Tester, approved July 15, 2013 (“ASTM D93”), IBR approved for § 1065.703(b).

- (3) ASTM D130-12, Standard Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test, approved November 1, 2012 (“ASTM D130”), IBR approved for § 1065.710(b).
- (4) ASTM D381-12, Standard Test Method for Gum Content in Fuels by Jet Evaporation, approved April 15, 2012 (“ASTM D381”), IBR approved for § 1065.710(b).
- (5) ASTM D445-12, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity), approved April 15, 2012 (“ASTM D445”), IBR approved for § 1065.703(b).
- (6) ASTM D525-12a, Standard Test Method for Oxidation Stability of Gasoline (Induction Period Method), approved September 1, 2012 (“ASTM D525”), IBR approved for § 1065.710(b).
- (7) ASTM D613-13, Standard Test Method for Cetane Number of Diesel Fuel Oil, approved December 1, 2013 (“ASTM D613”), IBR approved for § 1065.703(b).
- (8) ASTM D910-13a, Standard Specification for Aviation Gasolines, approved December 1, 2013 (“ASTM D910”), IBR approved for § 1065.701(f).
- (9) ASTM D975-13a, Standard Specification for Diesel Fuel Oils, approved December 1, 2013 (“ASTM D975”), IBR approved for § 1065.701(f).
- (10) ASTM D1267-12, Standard Test Method for Gage Vapor Pressure of Liquefied Petroleum (LP) Gases (LP-Gas Method), approved November 1, 2012 (“ASTM D1267”), IBR approved for § 1065.720(a).
- (11) ASTM D1319-13, Standard Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption, approved May 1, 2013 (“ASTM D1319”), IBR approved for § 1065.710(c).
- (12) ASTM D1655-13a, Standard Specification for Aviation Turbine Fuels, approved December 1, 2013 (“ASTM D1655”), IBR approved for § 1065.701(f).
- (13) ASTM D1837-11, Standard Test Method for Volatility of Liquefied Petroleum (LP) Gases, approved October 1, 2011 (“ASTM D1837”), IBR approved for § 1065.720(a).
- (14) ASTM D1838-12a, Standard Test Method for Copper Strip Corrosion by Liquefied Petroleum (LP) Gases, approved December 1, 2012 (“ASTM D1838”), IBR approved for § 1065.720(a).
- (15) ASTM D1945-03 (Reapproved 2010), Standard Test Method for Analysis of Natural Gas by Gas Chromatography, approved January 1, 2010 (“ASTM D1945”), IBR approved for § 1065.715(a).
- (16) ASTM D2158-11, Standard Test Method for Residues in Liquefied Petroleum (LP) Gases, approved January 1, 2011 (“ASTM D2158”), IBR approved for § 1065.720(a).
- (17) ASTM D2163-07, Standard Test Method for Determination of Hydrocarbons in Liquefied Petroleum (LP) Gases and Propane/Propene Mixtures by Gas Chromatography, approved December 1, 2007 (“ASTM D2163”), IBR approved for § 1065.720(a).
- (18) ASTM D2598-12, Standard Practice for Calculation of Certain Physical Properties of Liquefied Petroleum (LP) Gases from Compositional Analysis, approved November 1, 2012 (“ASTM D2598”), IBR approved for § 1065.720(a).
- (19) ASTM D2622-16, Standard Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry, approved January 1, 2016 (“ASTM D2622”), IBR approved for §§ 1065.703(b) and 1065.710(b) and (c).

- (20) ASTM D2699-13b, Standard Test Method for Research Octane Number of Spark-Ignition Engine Fuel, approved October 1, 2013 (“ASTM D2699”), IBR approved for § 1065.710(b).
- (21) ASTM D2700-13b, Standard Test Method for Motor Octane Number of Spark-Ignition Engine Fuel, approved October 1, 2013 (“ASTM D2700”), IBR approved for § 1065.710(b).
- (22) ASTM D2713-13, Standard Test Method for Dryness of Propane (Valve Freeze Method), approved October 1, 2013 (“ASTM D2713”), IBR approved for § 1065.720(a).
- (23) ASTM D2880-13b, Standard Specification for Gas Turbine Fuel Oils, approved November 15, 2013 (“ASTM D2880”), IBR approved for § 1065.701(f).
- (24) ASTM D2986-95a, Standard Practice for Evaluation of Air Assay Media by the Monodisperse DOP (Dioctyl Phthalate) Smoke Test, approved September 10, 1995 (“ASTM D2986”), IBR approved for § 1065.170(c). (Note: This standard was withdrawn by ASTM.)
- (25) ASTM D3231-13, Standard Test Method for Phosphorus in Gasoline, approved June 15, 2013 (“ASTM D3231”), IBR approved for § 1065.710(b) and (c).
- (26) ASTM D3237-12, Standard Test Method for Lead in Gasoline By Atomic Absorption Spectroscopy, approved June 1, 2012 (“ASTM D3237”), IBR approved for § 1065.710(b) and (c).
- (27) ASTM D4052-11, Standard Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter, approved October 15, 2011 (“ASTM D4052”), IBR approved for § 1065.703(b).
- (28) ASTM D4629-12, Standard Test Method for Trace Nitrogen in Liquid Petroleum Hydrocarbons by Syringe/Inlet Oxidative Combustion and Chemiluminescence Detection, approved April 15, 2012 (“ASTM D4629”), IBR approved for § 1065.655(e).
- (29) ASTM D4814-13b, Standard Specification for Automotive Spark-Ignition Engine Fuel, approved December 1, 2013 (“ASTM D4814”), IBR approved for § 1065.701(f).
- (30) ASTM D4815-13, Standard Test Method for Determination of MTBE, ETBE, TAME, DIPE, tertiary-Amyl Alcohol and C₁ to C₄ Alcohols in Gasoline by Gas Chromatography, approved October 1, 2013 (“ASTM D4815”), IBR approved for § 1065.710(b).
- (31) ASTM D5186-03 (Reapproved 2009), Standard Test Method for Determination of the Aromatic Content and Polynuclear Aromatic Content of Diesel Fuels and Aviation Turbine Fuels By Supercritical Fluid Chromatography, approved April 15, 2009 (“ASTM D5186”), IBR approved for § 1065.703(b).
- (32) ASTM D5191-13, Standard Test Method for Vapor Pressure of Petroleum Products (Mini Method), approved December 1, 2013 (“ASTM D5191”), IBR approved for § 1065.710(b) and (c).
- (33) ASTM D5291-10, Standard Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Petroleum Products and Lubricants, approved May 1, 2010 (“ASTM D5291”), IBR approved for § 1065.655(e).
- (34) ASTM D5453-19a, Standard Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence, approved July 1, 2019 (“ASTM D5453”), IBR approved for §§ 1065.703(b) and 1065.710(b).
- (35) ASTM D5599-00 (Reapproved 2010), Standard Test Method for Determination of Oxygenates in Gasoline by Gas Chromatography and Oxygen Selective Flame Ionization Detection, approved October 1, 2010 (“ASTM D5599”), IBR approved for §§ 1065.655(e) and 1065.710(b).

(36) ASTM D5762-12 Standard Test Method for Nitrogen in Petroleum and Petroleum Products by Boat-Inlet Chemiluminescence, approved April 15, 2012 (“ASTM D5762”), IBR approved for § 1065.655(e).

(37) ASTM D5769-10, Standard Test Method for Determination of Benzene, Toluene, and Total Aromatics in Finished Gasolines by Gas Chromatography/Mass Spectrometry, approved May 1, 2010 (“ASTM D5769”), IBR approved for § 1065.710(b).

(38) ASTM D5797-13, Standard Specification for Fuel Methanol (M70- M85) for Automotive Spark-Ignition Engines, approved June 15, 2013 (“ASTM D5797”), IBR approved for § 1065.701(f).

(39) ASTM D5798-13a, Standard Specification for Ethanol Fuel Blends for Flexible Fuel Automotive Spark-Ignition Engines, approved June 15, 2013 (“ASTM D5798”), IBR approved for § 1065.701(f).

(40) ASTM D6348-12^{e1}, Standard Test Method for Determination of Gaseous Compounds by Extractive Direct Interface Fourier Transform Infrared (FTIR) Spectroscopy, approved February 1, 2012 (“ASTM D6348”), IBR approved for §§ [1065.257\(ba\)](#), [1065.266\(bc\)](#), and [1065.275\(b\)](#), and [1065.277\(b\)](#).

(41) ASTM D6550-10, Standard Test Method for Determination of Olefin Content of Gasolines by Supercritical-Fluid Chromatography, approved October 1, 2010 (“ASTM D6550”), IBR approved for § 1065.710(b).

(42) ASTM D6615-11a, Standard Specification for Jet B Wide-Cut Aviation Turbine Fuel, approved October 1, 2011 (“ASTM D6615”), IBR approved for § 1065.701(f).

(43) ASTM D6667-14 (Reapproved 2019), Standard Test Method for Determination of Total Volatile Sulfur in Gaseous Hydrocarbons and Liquefied Petroleum Gases by Ultraviolet Fluorescence, approved May 1, 2019 (“ASTM D6667”), IBR approved for § 1065.720(a).

(44) ASTM D6751-12, Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels, approved August 1, 2012 (“ASTM D6751”), IBR approved for § 1065.701(f).

(45) ASTM D6985-04a, Standard Specification for Middle Distillate Fuel Oil—Military Marine Applications, approved November 1, 2004 (“ASTM D6985”), IBR approved for § 1065.701(f). (Note: This standard was withdrawn by ASTM.)

(46) ASTM D7039-15a (Reapproved 2020), Standard Test Method for Sulfur in Gasoline, Diesel Fuel, Jet Fuel, Kerosine, Biodiesel, Biodiesel Blends, and Gasoline-Ethanol Blends by Monochromatic Wavelength Dispersive X-ray Fluorescence Spectrometry, approved May 1, 2020 (“ASTM D7039”), IBR approved for §§ 1065.703(b) and 1065.710(b).

(47) ASTM F1471-09, Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air Filter System, approved March 1, 2009 (“ASTM F1471”), IBR approved for § 1065.1001.

(b) *California Air Resources Board material.* The following documents are available from the California Air Resources Board, Haagen-Smit Laboratory, 9528 Telstar Ave., El Monte, CA 91731–2908, (800) 242–4450, or <http://www.arb.ca.gov>:

(1) California Non-Methane Organic Gas Test Procedures, Amended July 30, 2002, Mobile Source Division, California Air Resources Board, IBR approved for § 1065.805(f).

(2) [Reserved]

(c) *Institute of Petroleum material.* The following documents are available from the Energy Institute, 61 New Cavendish St., London, W1G 7AR, UK, or by calling +44–(0)20–7467–7100, or at <http://www.energyinst.org>:

(1) IP-470, 2005, Determination of aluminum, silicon, vanadium, nickel, iron, calcium, zinc, and sodium in residual fuels by atomic absorption spectrometry, IBR approved for § 1065.705(b).

(2) IP-500, 2003, Determination of the phosphorus content of residual fuels by ultra-violet spectrometry, IBR approved for § 1065.705(b).

(3) IP-501, 2005, Determination of aluminum, silicon, vanadium, nickel, iron, sodium, calcium, zinc and phosphorus in residual fuel oil by ashing, fusion and inductively coupled plasma emission spectrometry, IBR approved for § 1065.705(b).

(d) *ISO material*. The following standards are available from the International Organization for Standardization, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, 41-22-749-01-11, or <http://www.iso.org>:

(1) ISO 2719:2002, Determination of flash point—Pensky-Martens closed cup method (“ISO 2719”), IBR approved for § 1065.705(c).

(2) ISO 3016:1994, Petroleum products—Determination of pour point (“ISO 3016”), IBR approved for § 1065.705(c).

(3) ISO 3104:1994/Cor 1:1997, Petroleum products—Transparent and opaque liquids—Determination of kinematic viscosity and calculation of dynamic viscosity (“ISO 3104”), IBR approved for § 1065.705(c).

(4) ISO 3675:1998, Crude petroleum and liquid petroleum products— Laboratory determination of density— Hydrometer method (“ISO 3675”), IBR approved for § 1065.705(c).

(5) ISO 3733:1999, Petroleum products and bituminous materials— Determination of water—Distillation method (“ISO 3733”), IBR approved for § 1065.705(c).

(6) ISO 6245:2001, Petroleum products—Determination of ash (“ISO 6245”), IBR approved for § 1065.705(c).

(7) ISO 8217:2012(E), Petroleum products—Fuels (class F)—Specifications of marine fuels, Fifth edition, August 15, 2012 (“ISO 8217”), IBR approved for § 1065.705(b) and (c).

(8) ISO 8754:2003, Petroleum products—Determination of sulfur content—Energy-dispersive X-ray Fluorescence spectrometry (“ISO 8754”), IBR approved for § 1065.705(c).

(9) ISO 10307-2(E):2009, Petroleum products—Total sediment in residual fuel oils—Part 2: Determination using standard procedures for ageing, Second Ed., February 1, 2009 (“ISO 10307”), as modified by ISO 10307-2:2009/Cor.1:2010(E), Technical Corrigendum 1, published May 15, 2010, IBR approved for § 1065.705(c).

(10) ISO 10370:1993/Cor 1:1996, Petroleum products—Determination of carbon residue—Micro method (“ISO 10370”), IBR approved for § 1065.705(c).

(11) ISO 10478:1994, Petroleum products—Determination of aluminium and silicon in fuel oils—Inductively coupled plasma emission and atomic absorption spectroscopy methods (“ISO 10478”), IBR approved for § 1065.705(c).

(12) ISO 12185:1996/Cor 1:2001, Crude petroleum and petroleum products—Determination of density—Oscillating U-tube method (“ISO 12185”), IBR approved for § 1065.705(c).

(13) ISO 14596:2007, Petroleum products—Determination of sulfur content—Wavelength-dispersive X-ray fluorescence spectrometry (“ISO 14596”), IBR approved for § 1065.705(c).

(14) ISO 14597:1997, Petroleum products—Determination of vanadium and nickel content—Wavelength dispersive X-ray fluorescence spectrometry (“ISO 14597”), IBR approved for § 1065.705(c).

(15) ISO 14644–1:1999, Cleanrooms and associated controlled environments (“ISO 14644”), IBR approved for § 1065.190(b).

(e) *NIST material*. The following documents are available from National Institute of Standards and Technology, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, (301) 975-6478, or www.nist.gov:

(1) NIST Special Publication 811, 2008 Edition, Guide for the Use of the International System of Units (SI), March 2008, IBR approved for §§ 1065.20(a) and 1065.1005.

(2) NIST Technical Note 1297, 1994 Edition, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, IBR approved for §§ [1065.365\(g\)](#), [1065.750\(a\)](#), and 1065.1001.

(f) *SAE International material*. The following standards are available from SAE International, 400 Commonwealth Dr., Warrendale, PA 15096–0001; (724) 776–4841; or <http://www.sae.org>:

(1) SAE 770141, Optimization of Flame Ionization Detector for Determination of Hydrocarbon in Diluted Automotive Exhausts, Glenn D. Reschke, 1977, (“SAE 770141”); IBR approved for § 1065.360(c).

(2) SAE J1151, Methane Measurement Using Gas Chromatography, stabilized September 2011, (“SAE J1151”); IBR approved for §§ 1065.267(b); 1065.750(a).

Subpart L—Methods for Unregulated and Special Pollutants and Additional Procedures

§ 1065.1101 Applicability.

This subpart specifies procedures that may be used to measure emission constituents that are not measured (or not separately measured) by the test procedures in the other subparts of this part. These procedures are included to facilitate consistent measurement of unregulated pollutants for purposes other than compliance with emission standards. Unless otherwise specified in the standard-setting part, use of these procedures is optional and does not replace any requirements in the rest of this part.

SEMI-VOLATILE ORGANIC COMPOUNDS

§ 1065.1103 General provisions for SVOC measurement.

The provisions of §§ 1065.1103 through 1065.1111 specify procedures for measuring semi-volatile organic compounds (SVOC) along with PM. These sections specify how to collect a sample of the SVOCs during exhaust emission testing, as well as how to use wet chemistry techniques to extract SVOCs from the sample media for analysis. Note that the precise method you use will depend on the category of SVOCs being measured. For example, the method used to measure polynuclear aromatic hydrocarbons (PAHs) will differ slightly from the method used to measure dioxins. Follow standard analytic chemistry methods for any aspects of the analysis that are not specified.

(a) Laboratory cleanliness is especially important throughout SVOC testing. Thoroughly clean all sampling system components and glassware before testing to avoid sample contamination. For the purposes of this subpart, the sampling system is defined as sample pathway from the sample probe inlet to the downstream most point where the sample is captured (in this case the condensate trap).

- (b) We recommend that media blanks be analyzed for each batch of sample media (sorbent, filters, etc.) prepared for testing. Blank sorbent modules (i.e., field blanks) should be stored in a sealed environment and should periodically accompany the test sampling system throughout the course of a test, including sampling system and sorbent module disassembly, sample packaging, and storage. Use good engineering judgment to determine the frequency with which you should generate field blanks. The field blank sample should be close to the sampler during testing.
- (c) We recommend the use of isotope dilution techniques, including the use of isotopically labeled surrogate, internal, alternate, and injection standards.
- (d) If your target analytes degrade when exposed to ultraviolet radiation, such as nitropolynuclear aromatic hydrocarbons (nPAHs), perform these procedures in the dark or with ultraviolet filters installed over the lights.
- (e) The following definitions and abbreviations apply for SVOC measurements:
- (1) Soxhlet extraction means the extraction method invented by Franz von Soxhlet, in which the sample is placed in a thimble and rinsed repeatedly with a recycle of the extraction solvent.
 - (2) XAD-2 means a hydrophobic crosslinked polystyrene copolymer resin adsorbent known commercially as Amberlite® XAD®-2, or an equivalent adsorbent like XAD-4.
 - (3) Semi-volatile organic compound (SVOC) means an organic compound that is sufficiently volatile to exist in vapor form in engine exhaust, but that readily condenses to liquid or solid form under atmospheric conditions. Most SVOCs have at least 14 carbon atoms per molecule or they have a boiling point between (240 and 400) °C. SVOCs include dioxin, quinone, PAH, and nitro-PAH compounds. They may be a natural byproduct of combustion or they may be created post-combustion. Note that SVOCs may be included in measured values of hydrocarbons and/or PM using the procedures specified in this part.
 - (4) Kuderna-Danish concentrator means laboratory glassware known by this name that consists of an air-cooled condenser on top of an extraction bulb.
 - (5) Dean-Stark trap means laboratory glassware known by this name that uses a reflux condenser to collect water from samples extracted under reflux.
 - (6) PUF means polyurethane foam.
 - (7) Isotopically labeled means relating to a compound in which either all the hydrogen atoms are replaced with the atomic isotope hydrogen-2 (deuterium) or one of the carbon atoms at a defined position in the molecule is replaced with the atomic isotope carbon-13.

§ 1065.1105 Sampling system design.

- (a) *General.* We recommend that you design your SVOC batch sampler to extract sample from undiluted emissions to maximize the sampled SVOC quantity. If you dilute your sample, we recommend using annular dilution. If you dilute your sample, but do not use annular dilution, you must precondition your sampling system to reach equilibrium with respect to loss and re-entrainment of SVOCs to the wall of the sampling system. To the extent practical, adjust sampling times based on the emission rate of target analytes from the engine to obtain analyte concentrations above the detection limit. In some instances you may need to run repeat test cycles without replacing the sample media or disassembling the batch sampler.
- (b) *Sample probe, transfer lines, and sample media holder design and construction.* The sampling system should consist of a sample probe, transfer line, PM filter holder, cooling coil, sorbent module, and condensate trap. Construct sample probes, transfer lines, and sample media holders that have inside surfaces of nickel, titanium or another nonreactive material capable of

withstanding raw exhaust gas temperatures. Seal all joints in the hot zone of the system with gaskets made of nonreactive material similar to that of the sampling system components. You may use teflon gaskets in the cold zone. We recommend locating all components as close to probes as practical to shorten sampling system length and minimize the surface exposed to engine exhaust.

(c) *Sample system configuration.* This paragraph (c) specifies the components necessary to collect SVOC samples, along with our recommended design parameters. Where you do not follow our recommendations, use good engineering judgment to design your sampling system so it does not result in loss of SVOC during sampling. The sampling system should contain the following components in series in the order listed:

(1) Use a sample probe similar to the PM sample probe specified in subpart B of this part.

(2) Use a PM filter holder similar to the holder specified in subpart B of this part, although you will likely need to use a larger size to accommodate the high sample flow rates. We recommend using a 110 mm filter for testing spark ignition engines or engines that utilize exhaust aftertreatment for PM removal and a 293 mm filter for other engines. If you are not analyzing separately for SVOCs in gas and particle phases, you do not have to control the temperature of the filter holder. Note that this differs from normal PM sampling procedures, which maintain the filter at a much lower temperature to capture a significant fraction of exhaust SVOC on the filter. In this method, SVOCs that pass through the filter will be collected on the downstream sorbent module. If you are collecting SVOCs in gas and particle phases, control your filter face temperature according to § 1065.140(e)(4).

(3) Use good engineering judgment to design a cooling coil that will drop the sample temperature to approximately 5 °C. Note that downstream of the cooling coil, the sample will be a mixture of vapor phase hydrocarbons in CO₂, air, and a primarily aqueous liquid phase.

(4) Use a hydrophobic sorbent in a sealed sorbent module. Note that this sorbent module is intended to be the final stage for collecting the SVOC sample and should be sized accordingly. We recommend sizing the module to hold 40 g of XAD-2 along with PUF plugs at either end of the module, noting that you may vary the mass of XAD used for testing based on the anticipated SVOC emission concentration and sample flow rate.

(5) Include a condensate trap to separate the aqueous liquid phase from the gas stream. We recommend using a peristaltic pump to remove water from the condensate trap over the course of the test to prevent build-up of the condensate. Note that for some tests it may be appropriate to collect this water for analysis.

(d) *Sampler flow control.* For testing using the recommended filter and sorbent module sizes, we recommend targeting an average sample flow rate of 70 liters per minute to maximize SVOC collection. The sampler must be designed to maintain proportional sampling throughout the test. Verify proportional sampling after an emission test as described in § 1065.545.

(e) *Water bath.* Design the sample system with a water bath in which the cooling coil, sorbent module, and condensate trap will be submerged. Use a heat exchanger or ice to maintain the bath temperature at (3 to 7) °C.

§ 1065.1107 Sample media and sample system preparation; sample system assembly.

This section describes the appropriate types of sample media and the cleaning procedure required to prepare the media and wetted sample surfaces for sampling.

(a) *Sample media.* The sampling system uses two types of sample media in series: the first to simultaneously capture the PM and associated particle phase SVOCs, and a second to capture SVOCs that remain in the gas phase, as follows:

(1) For capturing PM, we recommend using pure quartz filters with no binder if you are not analyzing separately for SVOCs in gas and particle phases. If you are analyzing separately, you must use polytetrafluoroethylene (PTFE) filters with PTFE support. Select the filter diameter to minimize filter change intervals, accounting for the expected PM emission rate, sample flow rate. Note that when repeating test cycles to increase sample mass, you may replace the filter without replacing the sorbent or otherwise disassembling the batch sampler. In those cases, include all filters in the extraction.

(2) For capturing gaseous SVOCs, utilize XAD-2 resin with or without PUF plugs. Note that two PUF plugs are typically used to contain the XAD-2 resin in the sorbent module.

(b) *Sample media and sampler preparation.* Prepare pre-cleaned PM filters and pre-cleaned PUF plugs/XAD-2 as needed. Store sample media in containers protected from light and ambient air if you do not use them immediately after cleaning. Use the following preparation procedure, or an analogous procedure with different solvents and extraction times:

(1) Pre-clean the filters via Soxhlet extraction with methylene chloride for 24 hours and dry over dry nitrogen in a low-temperature vacuum oven.

(2) Pre-clean PUF and XAD-2 with a series of Soxhlet extractions: 8 hours with water, 22 hours with methanol, 22 hours with methylene chloride, and 22 hours with toluene, followed by drying with nitrogen.

(3) Clean sampler components, including the probe, filter holder, condenser, sorbent module, and condensate collection vessel by rinsing three times with methylene chloride and then three times with toluene. Prepare pre-cleaned aluminum foil for capping the probe inlet of the sampler after the sampling system has been assembled.

(c) *Sorbent spiking.* Use good engineering judgment to verify the extent to which your extraction methods recover SVOCs absorbed on the sample media. We recommend spiking the XAD-2 resin with a surrogate standard before testing with a carbon-13 or hydrogen-2 isotopically labeled standard for each of the class of analytes targeted for analysis. Perform this spiking as follows:

(1) Insert the lower PUF plug into the bottom of the sorbent module.

(2) Add half of one portion of XAD-2 resin to the module and spike the XAD-2 in the module with the standard.

(3) Wait 1 hour for the solvent from the standard(s) to evaporate, add the remaining 20 g of the XAD-2 resin to the module, and then insert a PUF plug in the top of the sorbent module.

(4) Cover the inlet and outlet of the sorbent module with pre-cleaned aluminum foil.

(d) *Sampling system assembly.* After preparing the sample media and the sampler, assemble the condensate trap, cooling coil, filter holder with filter, sample probe, and sorbent module, then lower the assembly into the reservoir. Cover the probe inlet with pre-cleaned aluminum foil.

§ 1065.1109 Post-test sampler disassembly and sample extraction.

This section describes the process for disassembling and rinsing the sampling system and extracting and cleaning up the sample.

(a) *Sampling system disassembly.* Disassemble the sampling system in a clean environment as follows after the test:

(1) Remove the PM filter, PUF plugs, and all the XAD-2 from the sampling system and store them at or below 5 °C until analysis.

(2) Rinse sampling system wetted surfaces upstream of the condensate trap with acetone followed by toluene (or a comparable solvent system), ensuring that all the solvent that remaining in liquid phase is collected (note that a fraction of the acetone and toluene will likely be lost to evaporation during mixing). Rinse with solvent volumes that are sufficient to cover all the surfaces exposed to the sample during testing. We recommend three fresh solvent rinses with acetone and two with toluene. We recommend rinse volumes of 60 ml per rinse for all sampling system components except the condenser coil, of which you should use 200 ml per rinse. Keep the acetone rinsate separate from the toluene rinsate to the extent practicable. Rinsate fractions should be stored separately in glass bottles that have been pre-rinsed with acetone, hexane, and toluene (or purchase pre-cleaned bottles).

(3) Use good engineering judgment to determine if you should analyze the aqueous condensate phase for SVOCs. If you determine that analysis is necessary, use toluene to perform a liquid-liquid extraction of the SVOCs from the collected aqueous condensate using a separatory funnel or an equivalent method. Add the toluene from this aqueous extraction to the toluene rinsate fraction described in paragraph (a)(2) of this section.

(4) Reduce rinsate solvent volumes as needed using a Kuderna-Danish concentrator or rotary evaporator and retain these rinse solvents for reuse during sample media extraction for the same test. Be careful to avoid loss of low molecular weight analytes when concentrating with rotary evaporation.

(b) *Sample extraction.* Extract the SVOCs from the sorbent using Soxhlet extraction as described in this paragraph (b). Two 16 hour extractions are necessary to accommodate the Soxhlet extractions of all SVOCs from a single sample. This reduces the possibility of losing low molecular weight SVOCs and promotes water removal. We recommend performing the first extraction with acetone/hexane and the second using toluene (or an equivalent solvent system). You may alternatively use an equivalent method such as an automated solvent extractor.

(1) We recommend equipping the Soxhlet extractor with a Dean-Stark trap to facilitate removal of residual water from the sampling system rinse. The Soxhlet apparatus must be large enough to allow extraction of the PUF, XAD-2, and filter in a single batch. Include in the extractor setup a glass thimble with a coarse or extra coarse sintered glass bottom. Pre-clean the extractor using proper glass-cleaning procedures. We recommend that the Soxhlet apparatus be cleaned with a (4 to 8) hour Soxhlet extraction with methylene chloride at a cycling rate of three cycles per hour. Discard the solvent used for pre-cleaning (no analysis is necessary).

(2) Load the extractor thimble before placing it in the extractor by first rolling the PM filter around the inner circumference of the thimble, with the sampled side facing in. Push one PUF plug down into the bottom of the thimble, add approximately half of the XAD-2, and then spike the XAD-2 in the thimble with the isotopically labeled extraction standards of known mass. Target the center of the XAD-2 bed for delivering the extraction standard. We recommend using multiple isotopically labeled extraction standards that cover the range of target analytes. This generally means that you should use isotopically labeled standards at least for the lowest and highest molecular weight analytes for each category of compounds (such as PAHs and dioxins). These extraction standards monitor the efficiency of the extraction and are also used to determine analyte concentrations after analysis. Upon completion of spiking, add the remaining XAD-2 to the thimble, insert the remaining PUF

plug, and place the thimble into the extractor. Note that if you are collecting and analyzing for SVOCs in gas and particle phases, perform separate extractions for the filter and XAD-2.

(3) For the initial extraction, combine the concentrated acetone rinses (from the sampling system in paragraph (a) of this section) with enough hexane to bring the solvent volume up to the target level of 700 ml. Assemble the extractor and turn on the heating controls and cooling water. Allow the sample to reflux for 16 hours with the rheostat adjusted to cycle the extraction at a rate of (3.0 ± 0.5) cycles per hour. Drain the water from the Dean-Stark trap as it accumulates by opening the stopcock on the trap. Set aside the water for analysis or discard it. In most cases, any water present will be removed within approximately 2 hours after starting the extraction.

(4) After completing the initial extraction, remove the solvent and concentrate it to (4.0 ± 0.5) ml using a Kuderna-Danish concentrator that includes a condenser such as a three-ball Snyder column with venting dimples and a graduated collection tube. Hold the water bath temperature at $(75 \text{ to } 80)^\circ\text{C}$. Using this concentrator will minimize evaporative loss of analytes with lower molecular weight.

(i) Rinse the round bottom flask of the extractor with $(60 \text{ to } 100)$ ml of hexane and add the rinsate to this concentrated extract.

(ii) Concentrate the mixture to (4 ± 0.5) ml using a Kuderna-Danish concentrator or similar apparatus.

(iii) Repeat the steps in paragraphs (b)(4)(i) and (ii) of this section three times, or as necessary to remove all the residual solvent from the round bottom flask of the extractor, concentrating the final rinsate to (4 ± 0.5) ml.

(5) For the second extraction, combine the toluene rinses (from the sampling system in paragraph (a) of this section) with any additional toluene needed to bring the solvent volume up to the target level of 700 ml. As noted in paragraph (a) of this section, you may need to concentrate the rinsate before adding it to the extraction apparatus if the rinsate solvent volume is too large. Allow the sample to reflux for 16 hours with the rheostat adjusted to cycle the extraction at a rate of (3.0 ± 0.5) cycles per hour. Check the Dean-Stark trap for water during the first 2 hours of the extraction (though little or no water should be present during this stage).

(6) Upon completion of the second extraction, remove the solvent and concentrate it to (4 ± 0.5) ml as described in paragraph (b)(4) of this section. Using hexane from paragraph (b)(4) of this section as the rinse solvent effectively performs a solvent exchange of toluene with hexane.

(7) Combine the concentrated extract from paragraph (b)(4) of this section with the concentrated extract from paragraph (b)(6) of this section. Divide the extract into a number of fractions based on the number of analyses you need to perform. Perform the separate sample clean-up described in paragraph (c) of this section as needed for each fraction.

(c) *Sample clean-up.* This paragraph (c) describes how to perform sample cleaning to remove from the sample extract any solids and any SVOCs that will not be analyzed. This process, known as “sample clean-up”, reduces the potential for interference or co-elution of peaks during analytical analysis. Before performing the sample clean-up, spike the extract with an alternate standard that contains a known mass of isotopically labeled compounds that are identical to the target analytes (except for the labeling). The category of the target analyte compounds (such as PAHs or dioxin) will determine the number of compounds that make up the standard. For example, PAHs require the use of four compounds in the alternate standard to cover the four

basic ring structures of PAHs (2-ring, 3-ring, 4-ring, and 5-ring structures). These alternate standards are used to monitor the efficiency of the clean-up procedure. Before sample clean-up, concentrate the fractionated sample to about 2 ml with a Kuderna-Danish concentrator or rotary evaporator, and then transfer the extract to an 8 ml test tube with hexane rinse. Concentrate it to a volume of about 1 ml using a Kuderna-Danish concentrator. Use good engineering judgment to select an appropriate column chromatographic clean-up option for your target analytes. Note that these clean-up techniques generally remove compounds based on their polarity. The following procedures are examples of clean-up techniques for PAHs and nPAHs.

(1) *PAH clean-up*. The following method is appropriate for clean-up of extracts intended for analysis of PAHs:

- (i) Pack a glass gravity column (250 mm x 10 mm recommended) by inserting a clean glass wool plug into the bottom of the column and add 10 g of activated silica gel in methylene chloride. Tap the column to settle the silica gel and then add a 1 cm layer of anhydrous sodium sulfate. Verify the volume of solvent required to completely elute all the PAHs and adjust the weight of the silica gel accordingly to account for variations among batches of silica gel that may affect the elution volume of the various PAHs.
- (ii) Elute the column with 40 ml of hexane. The rate for all elutions should be about 2 ml/min. You may increase the elution rate by using dry air or nitrogen to maintain the headspace slightly above atmospheric pressure. Discard the eluate just before exposing the sodium sulfate layer to the air or nitrogen and transfer the 1 ml sample extract onto the column using two additional 2 ml rinses of hexane. Just before exposing the sodium sulfate layer to the air or nitrogen, begin elution of the column with 25 ml of hexane followed by 25 ml of 40 volume % methylene chloride in hexane. Collect the entire eluate and concentrate it to about 5 ml using the Kuderna-Danish concentrator or a rotary evaporator. Make sure not to evaporate all the solvent from the extract during the concentration process. Transfer the eluate to a small sample vial using a hexane rinse and concentrate it to 100 μ l using a stream of nitrogen without violently disturbing the solvent. Store the extracts in a refrigerator at or below 4 °C, and away from light.

(2) *nPAH clean up*. The following procedure, adapted from “Determination and Comparison of Nitrated-Polycyclic Aromatic Hydrocarbons Measured in Air and Diesel Particulate Reference Materials” (Bamford, H.A., *et al*, Chemosphere, Vol. 50, Issue 5, pages 575 – 587), is an appropriate method to clean up extracts intended for analysis of nPAHs:

- (i) Condition an aminopropyl solid phase extraction (SPE) cartridge by eluting it with 20 ml of 20 volume % methylene chloride in hexane. Transfer the extract quantitatively to the SPE cartridge with at least two methylene chloride rinses. Elute the extract through the SPE cartridge by using 40 ml of 20 volume % methylene chloride in hexane to minimize potential interference of polar constituents, and then reduce the extract to 0.5 ml in hexane and subject it to normal-phase liquid chromatography using a pre-prepared 9.6 mm x 25 cm semi-preparative Chromegabond® amino/cyano column (5 μ m particle size) to isolate the nPAH fraction. The mobile phase is 20 volume % methylene chloride in hexane at a constant flow rate of 5 ml per minute. Back-flash the column with 60 ml of methylene chloride and then condition it with 200 ml of 20 volume % methylene chloride in hexane before each injection. Collect the effluent and concentrate it to about 2 ml using the Kuderna-Danish concentrator or a rotary evaporator. Transfer it to a minivial using a hexane rinse and concentrate it to 100 μ l using a gentle stream of nitrogen. Store the extracts at or below 4 °C, and away from light.

(ii) [Reserved]

§ 1065.1111 Sample analysis.

This subpart does not specify chromatographic or analytical methods to analyze extracts, because the appropriateness of such methods is highly dependent on the nature of the target analytes. However, we recommend that you spike the extract with an injection standard that contains a known mass of an isotopically labeled compound that is identical to one of the target analytes (except for labeling). This injection standard allows you to monitor the efficiency of the analytical process by verifying the volume of sample injected for analysis.

VANADIUM SUBLIMATION IN SCR CATALYSTS

§ 1065.1113 General provisions related to vanadium sublimation temperatures in SCR catalysts.

Sections 1065.1113 through 1065.1121 specify procedures for determining vanadium emissions from a catalyst based on catalyst temperature. Vanadium can be emitted from the surface of SCR catalysts at temperatures above 550 °C, dependent on the catalyst formulation. These procedures are appropriate for measuring the vanadium sublimation product from a reactor by sampling onto an equivalent mass of alumina and performing analysis by Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES). Follow standard analytic chemistry methods for any aspects of the analysis that are not specified.

(a) The procedure is adapted from “Behavior of Titania-supported Vanadia and Tungsta SCR Catalysts at High Temperatures in Reactant Streams: Tungsten and Vanadium Oxide and Hydroxide Vapor Pressure Reduction by Surficial Stabilization” (Chapman, D.M., Applied Catalysis A: General, 2011, 392, 143-150) with modifications to the acid digestion method from “Measuring the trace elemental composition of size-resolved airborne particles” (Herner, J.D. *et al*, Environmental Science and Technology, 2006, 40, 1925–1933).

(b) Laboratory cleanliness is especially important throughout vanadium testing. Thoroughly clean all sampling system components and glassware before testing to avoid sample contamination.

§ 1065.1115 Reactor design and setup.

Vanadium measurements rely on a reactor that adsorbs sublimation vapors of vanadium onto an alumina capture bed with high surface area.

(a) Configure the reactor with the alumina capture bed downstream of the catalyst in the reactor’s hot zone to adsorb vanadium vapors at high temperature. You may use quartz beads upstream of the catalyst to help stabilize reactor gas temperatures. Select an alumina material and design the reactor to minimize sintering of the alumina. For a 1-inch diameter reactor, use 4 to 5 g of 1/8 inch extrudates or -14/+24 mesh (approximately 0.7 to 1.4 mm) gamma alumina (such as Alfa Aesar, aluminum oxide, gamma, catalyst support, high surface area, bimodal). Position the alumina downstream from either an equivalent amount of -14/+24 mesh catalyst sample or an approximately 1-inch diameter by 1 to 3-inch long catalyst-coated monolith sample cored from the production-intent vanadium catalyst substrate. Separate the alumina from the catalyst with a

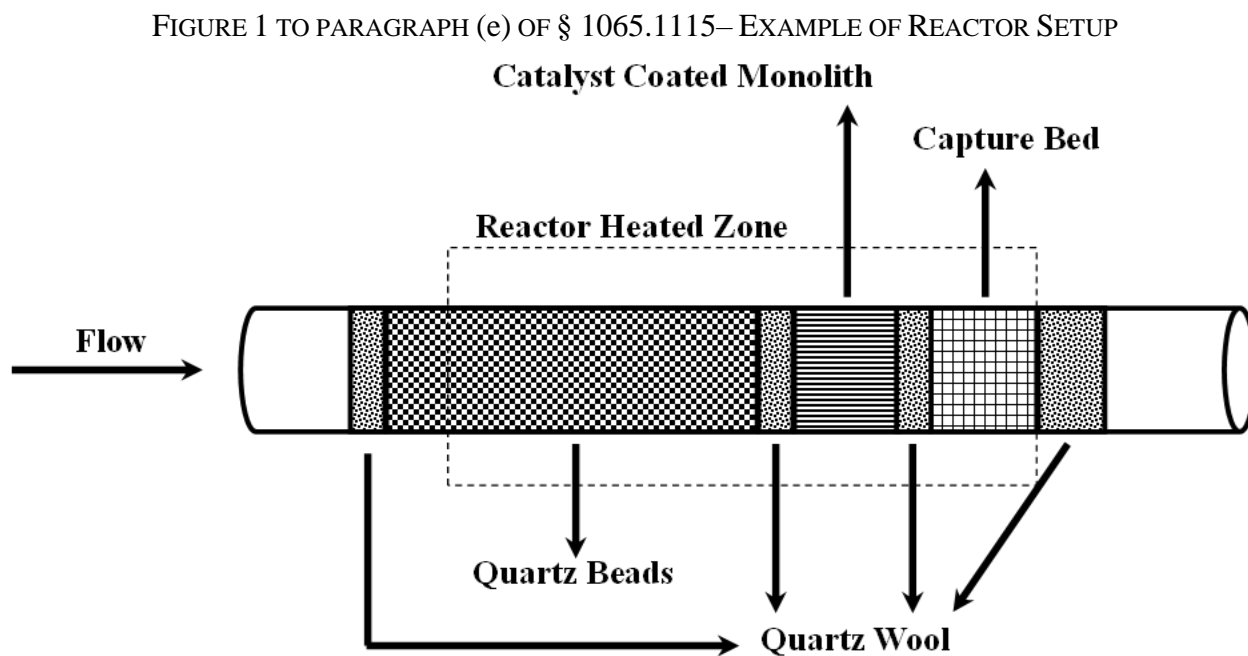
0.2 to 0.4 g plug of quartz wool. Place a short 4 g plug of quartz wool downstream of the alumina to maintain the position of that bed. Use good engineering judgment to adjust as appropriate for reactors of different sizes.

(b) Include the quartz wool with the capture bed to measure vanadium content. We recommend analyzing the downstream quartz wool separately from the alumina to see if the alumina fails to capture some residual vanadium.

(c) Configure the reactor such that both the sample and capture beds are in the reactor's hot zone. Design the reactor to maintain similar temperatures in the capture bed and catalyst. Monitor the catalyst and alumina temperatures with Type K thermocouples inserted into a thermocouple well that is in contact with the catalyst sample bed.

(d) If there is a risk that the quartz wool and capture bed are not able to collect all the vanadium, configure the reactor with an additional capture bed and quartz wool plug just outside the hot zone and analyze the additional capture bed and quartz wool separately.

(e) An example of a catalyst-coated monolith and capture bed arrangement in the reactor tube are shown in the following figure:



(f) You may need to account for vanadium-loaded particles contaminating catalyst-coated monoliths as a result of physical abrasion. To do this, determine how much titanium is in the capture bed and compare to an alumina blank. Using these values and available information about the ratio of vanadium to titanium in the catalyst, subtract the mass of vanadium catalyst material associated with the catalyst particles from the total measured vanadium on the capture bed to determine the vanadium recovered due to sublimation.

§ 1065.1117 Reactor aging cycle for determination of vanadium sublimation temperature.

This section describes the conditions and process required to operate the reactor described in § 1065.1115 for collection of the vanadium sublimation samples for determination of vanadium

sublimation temperature. The reactor aging cycle constitutes the process of testing the catalyst sample over all the test conditions described in paragraph (b) of this section.

(a) Set up the reactor to flow gases with a space velocity of at least 35,000/hr with a pressure drop across the catalyst and capture beds less than 35 kPa. Use test gases meeting the following specifications, noting that not all gases will be used at the same time:

(1) 5 vol% O₂, balance N₂.

(2) NO, balance N₂. Use an NO concentration of (200 to 500) ppm.

(3) NH₃, balance N₂. Use an NH₃ concentration of (200 to 500) ppm.

(b) Perform testing as follows:

(1) Add a new catalyst sample and capture bed into the reactor as described in § 1065.1113. Heat the reactor to 550 °C while flowing the oxygen blend specified in paragraph (a)(1) of this section as a pretest gas mixture. Ensure that no H₂O is added to the pretest gas mixture to reduce the risk of sintering and vanadium sublimation.

(2) Start testing at a temperature that is lower than the point at which vanadium starts to sublime. Start testing when the reactor reaches 550 °C unless testing supports a lower starting temperature. Once the reactor reaches the starting temperature and the catalyst has been equilibrated to the reactor temperature, flow NO and NH₃ test gases for 18 hours with a nominal H₂O content of 5 volume percent. If an initial starting temperature of 550 °C results in vanadium sublimation, you may retest using a new catalyst sample and a lower initial starting temperature.

(3) After 18 hours of exposure, flow the pretest oxygen blend as specified in paragraph (b)(1) of this section and allow the reactor to cool down to room temperature.

(4) Analyze the sample as described in § 1065.1121.

(5) Repeat the testing in paragraphs (b)(1) through (4) of this section by raising the reactor temperature in increments of 50 °C up to the temperature at which vanadium sublimation begins.

(6) Once sublimation has been detected, repeat the testing in paragraphs (b)(1) through (4) of this section by decreasing the reactor temperature in increments of 25 °C until the vanadium concentration falls below the sublimation threshold.

(7) Repeat the testing in paragraphs (b)(1) through (6) of this section with a nominal H₂O concentration of 10 volume percent or the maximum water concentration expected at the standard.

(8) You may optionally test in a manner other than testing a single catalyst formulation in series across all test temperatures. For example, you may test additional samples at the same reactor temperature before moving on to the next temperature.

(c) The effective sublimation temperature for the tested catalyst is the lowest reactor temperature determined in paragraph (b) of this section below which vanadium emissions are less than the method detection limit.

§ 1065.1119 Blank testing.

This section describes the process for analyzing blanks. Use blanks to determine the background effects and the potential for contamination from the sampling process.

(a) Take blanks from the same batch of alumina used for the capture bed.

(b) Media blanks are used to determine if there is any contamination in the sample media.

Analyze at least one media blank for each reactor aging cycle or round of testing performed

under § 1065.1117. If your sample media is taken from the same lot, you may analyze media blanks less frequently consistent with good engineering judgment.

(c) Field blanks are used to determine if there is any contamination from environmental exposure of the sample media. Analyze at least one field blank for each reactor aging cycle or round of testing performed under § 1065.1117. Field blanks must be contained in a sealed environment and accompany the reactor sampling system throughout the course of a test, including reactor disassembly, sample packaging, and storage. Use good engineering judgment to determine how frequently to generate field blanks. Keep the field blank sample close to the reactor during testing.

(d) Reactor blanks are used to determine if there is any contamination from the sampling system. Analyze at least one reactor blank for each reactor aging cycle or round of testing performed under § 1065.1117.

(1) Test reactor blanks with the reactor on and operated identically to that of a catalyst test in § 1065.1117 with the exception that when loading the reactor, only the alumina capture bed will be loaded (no catalyst sample is loaded for the reactor blank). We recommend acquiring reactor blanks with the reactor operating at average test temperature you used when acquiring your test samples under § 1065.1117.

(2) You must run at least three reactor blanks if the result from the initial blank analysis is above the detection limit of the method, with additional blank runs based on the uncertainty of the reactor blank measurements, consistent with good engineering judgment.

§ 1065.1121 Vanadium sample dissolution and analysis in alumina capture beds.

This section describes the process for dissolution of vanadium from the vanadium sublimation samples collect in § 1065.1117 and any blanks collected in § 1065.1119 as well as the analysis of the digestates to determine the mass of vanadium emitted and the associated sublimation temperature threshold based on the results of all the samples taken during the reactor aging cycle.

(a) Digest the samples using the following procedure, or an equivalent procedure:

(1) Place the recovered alumina, a portion of the ground quartz tube from the reactor, and the quartz wool in a Teflon pressure vessel with a mixture made from 1.5 mL of 16 N HNO₃, 0.5 mL of 28 N HF, and 0.2 mL of 12 N HCl. Note that the amount of ground quartz tube from the reactor included in the digestion can influence the vanadium concentration of both the volatilized vanadium from the sample and the method detection limit. You must be consistent with the amount ground quartz tube included in the sample analysis for your testing. You must limit the amount of quartz tube to include only portions of the tube that would be likely to encounter volatilized vanadium.

(2) Program a microwave oven to heat the sample to 180 °C over 9 minutes, followed by a 10-minute hold at that temperature, and 1 hour of ventilation/cooling.

(3) After cooling, dilute the digests to 30 mL with high purity 18MΩ water prior to ICP-MS (or ICP-OES) analysis. Note that this digestion technique requires adequate safety measures when working with HF at high temperature and pressure. To avoid “carry-over” contamination, rigorously clean the vessels between samples as described in “Microwave digestion procedures for environmental matrixes” (Lough, G.C. *et al*, *Analyst*. 1998, 123 (7), 103R-133R).

(b) Analyze the digestates for vanadium as follows:

- (1) Perform the analysis using ICP-OES (or ICP-MS) using standard plasma conditions (1350 W forward power) and a desolvating microconcentric nebulizer, which will significantly reduce oxide- and chloride-based interferences.
- (2) We recommend that you digest and analyze a minimum of three solid vanadium NIST Standard Reference Materials in duplicate with every batch of 25 vanadium alumina capture bed samples that you analyze in this section, as described in “Emissions of metals associated with motor vehicle roadways” (Herner, J.D. *et al*, Environmental Science and Technology. 2005, 39, 826–836). This will serve as a quality assurance check to help gauge the relative uncertainties in each measurement, specifically if the measurement errors are normally distributed and independent.
- (3) Use the 3-sigma approach to determine the analytical method detection limits for vanadium and the 10-sigma approach if you determine the reporting limit. This process involves analyzing at least seven replicates of a reactor blank using the analytical method described in paragraphs (a) and (b)(1) of this section, converting the responses into concentration units, and calculating the standard deviation. Determine the detection limit by multiplying the standard deviation by 3 and adding it to the average. Determine the reporting limit by multiplying the standard deviation by 10 and adding it to the average. Determine the following analytical method detection limits:
 - (i) Determine the ICP-MS (or ICP-OES) instrumental detection limit (ng/L) by measuring at least seven blank samples made up of the reagents from paragraph (a) of this section.
 - (ii) Determine the method detection limit ($\mu\text{g}/\text{m}^3$ of flow) by measuring at least seven reactor blank samples taken as described in § 1065.1119(d).
 - (iii) We recommend that your method detection limit determined under paragraph (b)(3)(ii) of this section is at or below $15 \mu\text{g}/\text{m}^3$. You must report your detection limits determined in this paragraph (b)(3) and reporting limits (if determined) with your test results.
- (4) If you account for vanadium-loaded particles contaminating catalyst-coated monoliths as a result of physical abrasion as allowed in § 1065.1115(f), use the 3-sigma approach to determine the analytical method detection limits for titanium and the 10-sigma approach if you determine the reporting limit. This process involves analyzing at least seven replicates of a blank using the analytical method described in paragraphs (a) and (b)(1) of this section, converting the responses into concentration units, and calculating the standard deviation. Determine the detection limit by multiplying the standard deviation by 3 and subtracting it from the average. Determine the reporting limit by multiplying the standard deviation by 10 and subtracting it from the average.
 - (i) Determine the ICP-MS (or ICP-OES) instrumental detection limit (ng/L) by measuring at least seven blank samples made up of the reagents from paragraph (a) of this section.
 - (ii) Determine the method detection limit ($\mu\text{g}/\text{m}^3$ of flow) by measuring at least seven reactor blank samples taken as described in § 1065.1119(d).

SMOKE OPACITY

§ 1065.1123 General provisions for determining exhaust opacity.

The provisions of § 1065.1125 describe system specifications for measuring percent opacity of exhaust for all types of engines. The provisions of § 1065.1127 describe how to use such a system to determine percent opacity of engine exhaust for applications other than locomotives. See 40 CFR 1033.525 for measurement procedures for locomotives.

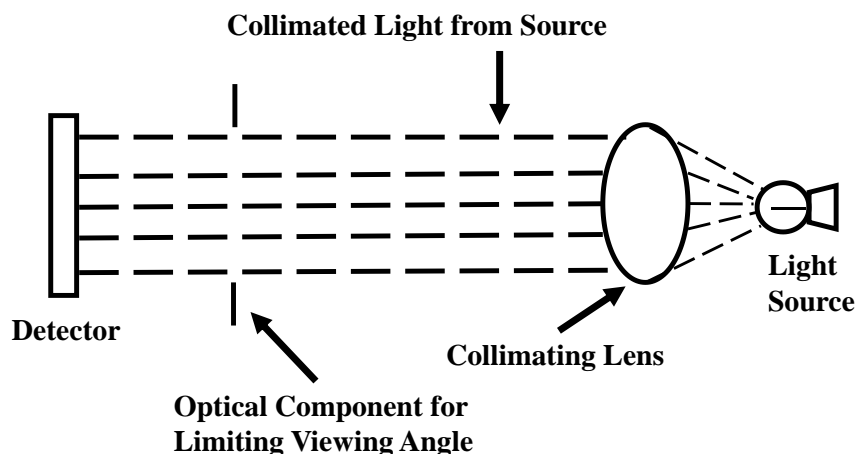
§ 1065.1125 Exhaust opacity measurement system.

Smokemeters measure exhaust opacity using full-flow open-path light extinction with a built-in light beam across the exhaust stack or plume. Prepare and install a smokemeter system as follows:

(a) Except as specified in paragraph (d) of this section, use a smokemeter capable of providing continuous measurement that meets the following specifications:

- (1) Use an incandescent lamp with a color temperature between (2800 and 3250) K or a different light source with a spectral peak between (550 and 570) nm.
- (2) Collimate the light beam to a nominal diameter of 3 centimeters and maximum divergence angle of 6 degrees.
- (3) Include a photocell or photodiode as a detector. The detector must have a maximum spectral response between (550 and 570) nm, with less than 4 percent of that maximum response below 430 nm and above 680 nm. These specifications correspond to visual perception with the human eye.
- (4) Use a collimating tube with an aperture that matches the diameter of the light beam. Restrict the detector to viewing within a 16 degree included angle.
- (5) Optionally use an air curtain across the light source and detector window to minimize deposition of smoke particles, as long as it does not measurably affect the opacity of the sample.
- (6) The diagram in the following figure illustrates the smokemeter configuration:

FIGURE 1 TO PARAGRAPH (a)(6) OF § 1065.1125— SMOKEMETER DIAGRAM.



(b) Smokemeters for locomotive applications must have a full-scale response time of 0.5 seconds or less. Smokemeters for locomotive applications may attenuate signal responses with frequencies higher than 10 Hz with a separate low-pass electronic filter that has the following performance characteristics:

- (1) Three decibel point: 10 Hz.
 - (2) Insertion loss: (0.0 ±0.5) dB.
 - (3) Selectivity: 12 dB down at 40 Hz minimum.
 - (4) Attenuation: 27 dB down at 40 Hz minimum.
- (c) Configure exhaust systems as follows for measuring exhaust opacity:
- (1) For locomotive applications:
 - (i) Optionally add a stack extension to the locomotive muffler.
 - (ii) For in-line measurements, the smokemeter is integral to the stack extension.
 - (iii) For end-of-line measurements, mount the smokemeter directly at the end of the stack extension or muffler.
 - (iv) For all testing, minimize distance from the optical centerline to the muffler outlet; in no case may it be more than 300 cm. The maximum allowable distance of unducted space upstream of the optical centerline is 50 cm, whether the unducted portion is upstream or downstream of the stack extensions.
 - (2) Meet the following specifications for all other applications:
 - (i) For in-line measurements, install the smokemeter in an exhaust pipe segment downstream of all engine components. This will typically be part of a laboratory configuration to route the exhaust to an analyzer. The exhaust pipe diameter must be constant within 3 exhaust pipe diameters before and after the smokemeter's optical centerline. The exhaust pipe diameter may not change by more than a 12-degree half-angle within 6 exhaust pipe diameters upstream of the smokemeter's optical centerline.
 - (ii) For end-of-line measurements with systems that vent exhaust to the ambient, add a stack extension and position the smokemeter such that its optical centerline is (2.5 ±0.625) cm upstream of the stack extension's exit. Configure the exhaust stack and extension such that at least the last 60 cm is a straight pipe with a circular cross section with an approximate inside diameter as specified in the following table:

TABLE 1 TO PARAGRAPH (c)(2)(ii) OF § 1065.1125— APPROXIMATE EXHAUST PIPE DIAMETER BASED ON ENGINE POWER

Maximum rated power	Approximate exhaust pipe diameter (mm)
kW<40	38
40≤kW<75	50
75≤kW<150	76
150≤kW<225	102
225≤kW<375	127
kW≥ 375	152

- (iii) For both in-line and end-of-line measurements, install the smokemeter so its optical centerline is (3 to 10) meters further downstream than the point in the exhaust stream that is farthest downstream considering all the following components: exhaust manifolds, turbocharger outlets, exhaust aftertreatment devices, and junction points for combining exhaust flow from multiple exhaust manifolds.
- (3) Orient the light beam perpendicular to the direction of exhaust flow. Install the smokemeter so it does not influence exhaust flow distribution or the shape of the exhaust plume. Set up the smokemeter's optical path length as follows:
- (i) For locomotive applications, the optical path length must be at least as wide as the exhaust plume.

- (ii) For all other applications, the optical path length must be the same as the diameter of the exhaust flow. For noncircular exhaust configurations, set up the smokemeter such that the light beam's path length is across the longest axis with an optical path length equal to the hydraulic diameter of the exhaust flow.
- (4) The smokemeter must not interfere with the engine's ability to meet the exhaust backpressure requirements in § 1065.130(h).
- (5) For engines with multiple exhaust outlets, measure opacity using one of the following methods:
 - (i) Join the exhaust outlets together to form a single flow path and install the smokemeter (3 to 10) m downstream of the point where the exhaust streams converge or the last exhaust aftertreatment device, whichever is farthest downstream.
 - (ii) Install a smokemeter in each of the exhaust flow paths. Report all measured values. All measured values must comply with standards.
- (6) The smokemeter may use purge air or a different method to prevent carbon or other exhaust deposits on the light source and detector. Such a method used with end-of-line measurements may not cause the smoke plume to change by more than 0.5 cm at the smokemeter. If such a method affects the smokemeter's optical path length, follow the smokemeter manufacturer's instructions to properly account for that effect.
- (d) You may use smokemeters meeting alternative specifications as follows:
 - (1) You may use smokemeters that use other electronic or optical techniques if they employ substantially identical measurement principles and produce substantially equivalent results.
 - (2) You may ask us to approve the use of a smokemeter that relies on partial flow sampling. Follow the instrument manufacturer's installation, calibration, operation, and maintenance procedures if we approve your request. These procedures must include correcting for any change in the path length of the exhaust plume relative to the diameter of the engine's exhaust outlet.

§ 1065.1127 Test procedure for determining percent opacity.

The test procedure described in this section applies for everything other than locomotives. The test consists of a sequence of engine operating points on an engine dynamometer to measure exhaust opacity during specific engine operating modes to represent in-use operation. Measure opacity using the following procedure:

- (a) Use the equipment and procedures specified in this part 1065.
- (b) Calibrate the smokemeter as follows:
 - (1) Calibrate using neutral density filters with approximately 10, 20, and 40 percent opacity. Confirm that the opacity values for each of these reference filters are NIST-traceable within 185 days of testing, or within 370 days of testing if you consistently protect the reference filters from light exposure between tests.
 - (2) Before each test and optionally during engine idle modes, remove the smokemeter from the exhaust stream, if applicable, and calibrate as follows:
 - (i) *Zero*. Adjust the smokemeter to give a zero response when there is no detectable smoke.
 - (ii) *Linearity*. Insert each of the qualified reference filters in the light path perpendicular to the axis of the light beam and adjust the smokemeter to give a result within 1 percentage point of the named value for each reference filter.
- (c) Prepare the engine, dynamometer, and smokemeter for testing as follows:

- (1) Set up the engine to run in a configuration that represents in-use operation.
 - (2) Determine the smokemeter's optical path length to the nearest mm.
 - (3) If the smokemeter uses purge air or another method to prevent deposits on the light source and detector, adjust the system according to the system manufacturer's instructions and activate the system before starting the engine.
 - (4) Program the dynamometer to operate in torque-control mode throughout testing. Determine the dynamometer load needed to meet the cycle requirements in paragraphs (d)(4)(ii) and (iv) of this section.
 - (5) You may program the dynamometer to apply motoring assist with negative flywheel torque, but only during the first 0.5 seconds of the acceleration events in paragraphs (d)(4)(i) and (ii) of this section. Negative flywheel torque may not exceed 13.6 N·m.
- (d) Operate the engine and dynamometer over repeated test runs of the duty cycle illustrated in Figure 1 of this appendix. As noted in the figure, the test run includes an acceleration mode from points A through F in the figure, followed by a lugging mode from points I to J. Detailed specifications for testing apply as follows:
- (1) Continuously record opacity, engine speed, engine torque, and operator demand over the course of the entire test at 10 Hz; however, you may interrupt measurements to recalibrate during each idle mode.
 - (2) Precondition the engine by operating it for 10 minutes at maximum mapped power.
 - (3) Operate the engine for (5.0 to 5.5) minutes at warm idle speed, f_{idle} , with load set to Curb Idle Transmission Torque.
 - (4) Operate the engine and dynamometer as follows during the acceleration mode:
 - (i) *First acceleration event—AB*. Partially increase and hold operator demand to stabilize engine speed briefly at (200 ± 50) r/min above f_{idle} . The start of this acceleration is the start of the test ($t = 0$ s).
 - (ii) *Second acceleration event—CD*. As soon as measured engine speed is within the range specified in paragraph (d)(4)(i) of this section, but not more than 3 seconds after the start of the test, rapidly set and hold operator demand at maximum. Operate the dynamometer using a preselected load to accelerate engine speed to 85 percent of maximum test speed, f_{ntest} , in (5 ± 1.5) seconds. The engine speed throughout the acceleration must be within ± 100 r/min of a target represented by a linear transition between the low and high engine speed targets.
 - (iii) *Transition—DEF*. As soon as measured engine speed reaches 85 percent of f_{ntest} , rapidly set and hold operator demand at minimum and simultaneously apply a load to decelerate to intermediate speed in (0.5 to 3.5) seconds. Use the same load identified for the acceleration event in paragraph (d)(4)(iv) of this section.
 - (iv) *Third acceleration event—FGH*. Rapidly set and hold operator demand at maximum when the engine is within ± 50 r/min of intermediate speed. Operate the dynamometer using a preselected load to accelerate engine speed to at least 95 percent of f_{ntest} in (10 ± 2) seconds.
 - (5) Operate the engine and dynamometer as follows during the lugging mode:
 - (i) *Transition—HI*. When the engine reaches 95 percent of f_{ntest} , keep operator demand at maximum and immediately set dynamometer load to control the engine at maximum mapped power. Continue the transition segment for (50 to 60) seconds. For at least the last 10 seconds of the transition segment, hold engine speed within ± 50 r/min of f_{ntest} and power at or above 95 percent of maximum mapped power. Conclude the transition by

increasing dynamometer load to reduce engine speed as specified in paragraph (d)(4)(iii) of this section, keeping operator demand at maximum.

(ii) *Lugging—IJ*. Apply dynamometer loading as needed to decrease engine speed from 50 r/min below f_{ntest} to intermediate speed in (35 ± 5) seconds. The engine speed must remain within ± 100 r/min of a target represented by a linear transition between the low and high engine speed targets.

(6) Return the dynamometer and engine controls to the idle position described in paragraph (d)(3) of this section within 60 seconds of completing the lugging mode.

(7) Repeat the procedures in paragraphs (d)(3) through (6) of this section as needed to complete three valid test runs. If you fail to meet the specifications during a test run, continue to follow the specified duty cycle before starting the next test run.

(8) Shut down the engine or remove the smokemeter from the exhaust stream to verify zero and linearity. Void the test if the smokemeter reports more than 2 percent opacity for the zero verification, or if the smokemeter's error for any of the linearity checks specified in paragraph (b)(2) of this section is more than 2 percent.

(e) Analyze and validate the test data as follows:

(1) Divide each test run into test segments. Each successive test segment starts when the preceding segment ends. Identify the test segments based on the following criteria:

(i) The idle mode specified in paragraph (d)(3) of this section for the first test run starts immediately after engine preconditioning is complete. The idle mode for later test runs must start within 60 seconds after the end of the previous test run as specified in paragraph (d)(6) of this section. The idle mode ends when operator demand increases for the first acceleration event (Points A and B).

(ii) The first acceleration event in paragraph (d)(4)(i) of this section ends when operator demand is set to maximum for the second acceleration event (Point C).

(iii) The second acceleration event in paragraph (d)(4)(ii) of this section ends when the engine reaches 85 percent of maximum test speed, f_{ntest} , (Point D) and operator demand is set to minimum (Point E).

(iv) The transition period in paragraph (d)(4)(iii) of this section ends when operator demand is set to maximum (Point F).

(v) The third acceleration event in paragraph (d)(4)(iv) of this section ends when engine speed reaches 95 percent of f_{ntest} (Point H).

(vi) The transition period in paragraph (d)(5)(i) of this section ends when engine speed first decreases to a point more than 50 r/min below f_{ntest} (Point I).

(vii) The lugging mode in paragraph (d)(5)(ii) of this section ends when the engine reaches intermediate speed (Point J).

(2) Convert measured instantaneous values to standard opacity values, κ_{std} , based on the appropriate optical path length specified in Table 1 of § 1065.1125 using the following equation:

$$\kappa_{std} = 100 \cdot \left(1 - \left(1 - \frac{\kappa_{meas}}{100} \right)^{\frac{l_{std}}{l_{meas}}} \right)$$

Eq. 1065.1127-1

Where:

κ_{std} = standard instantaneous percent opacity.

κ_{meas} = measured instantaneous percent opacity.

l_{std} = standard optical path length corresponding with engine power, in millimeters.

l_{meas} = the smokemeter's optical path length, in millimeters.

Example for an engine < 40 kW:

$$\kappa_{\text{meas}} = 14.1 \%$$

$$l_{\text{std}} = 38 \text{ mm}$$

$$l_{\text{meas}} = 41 \text{ mm}$$

$$\kappa_{\text{std}} = 100 \cdot \left(1 - \left(1 - \frac{14.1}{100} \right)^{\frac{38}{41}} \right) = 13.1 \%$$

(3) Select opacity results from corrected measurements collected across test segments as follows:

- (i) Divide measurements from acceleration and lugging modes into half-second intervals. Determine average opacity values during each half-second interval.
- (ii) Identify the 15 highest half-second values during the acceleration mode of each test run.
- (iii) Identify the five highest half-second values during the lugging mode of each test run.
- (iv) Identify the three overall highest values from paragraphs (e)(3)(ii) and (iii) of this section for each test run.

(f) Determine percent opacity as follows:

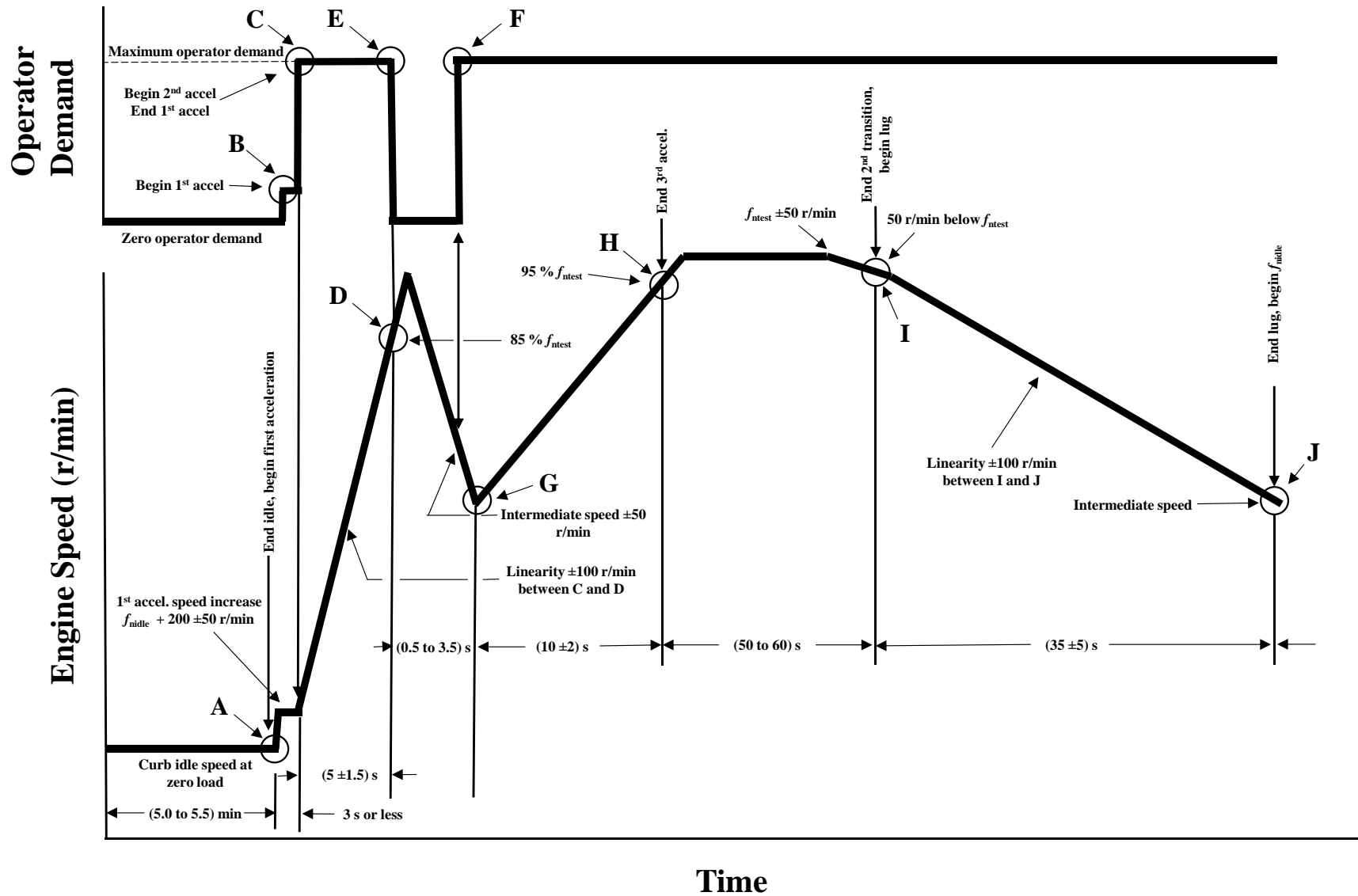
- (1) *Acceleration*. Determine the percent opacity for the acceleration mode by calculating the average of the 45 readings from paragraph (e)(3)(ii) of this section.
- (2) *Lugging*. Determine the percent opacity for the lugging mode by calculating the average of the 15 readings from paragraph (e)(3)(iii) of this section.
- (3) *Peak*. Determine the percent opacity for the peaks in either acceleration or lugging mode by calculating the average of the 9 readings from paragraph (e)(3)(iv) of this section.

(g) Submit the following information in addition to what is required by § 1065.695:

- (1) Exhaust pipe diameter(s).
- (2) Measured maximum exhaust system backpressure over the entire test.
- (3) Most recent date for establishing that each of the reference filters from paragraph (b) of this section are NIST-traceable.
- (4) Measured smokemeter zero and linearity values after testing.
- (5) 10 Hz data from all valid test runs.

(h) The following figure illustrates the dynamometer controls and engine speeds for exhaust opacity testing:

FIGURE 1 TO PARAGRAPH (H) OF § 1065.1127– SCHEMATIC OF SMOKE OPACITY DUTY CYCLE



ACCELERATED AFTERTREATMENT AGING

§ 1065.1131 General provisions related to accelerated aging of compression-ignition aftertreatment for deterioration factor determination.

Sections 1065.1131 through 1065.1145 specify procedures for aging compression-ignition engine aftertreatment systems in an accelerated fashion to produce an aged aftertreatment system for durability demonstration. Determine the target number of hours that represents useful life for an engine family as described in the standard setting part. The method described is a procedure for translating field data that represents a given application into an accelerated aging cycle for that specific application, as well as methods for carrying out aging using that cycle. The procedure is intended to be representative of field aging, includes exposure to elements of both thermal and chemical aging, and is designed to achieve an acceleration of aging that is ten times a dynamometer or field test (1,000 hours of accelerated aging is equivalent to 10,000 hours of standard aging).

(a) Development of an application-specific accelerated aging cycle generally consists of the following steps:

- (1) Gathering and analysis of input field data.
- (2) Determination of key components for aging.
- (3) Determination of a thermal deactivation coefficient for each key component.
- (4) Determination of potential aging modes using clustering analysis.
- (5) Down-selection of final aging modes.
- (6) Incorporation of regeneration modes (if necessary).
- (7) Cycle generation.
- (8) Calculation of thermal deactivation.
- (9) Cycle scaling to reach thermal deactivation.
- (10) Determination of oil exposure rates.
- (11) Determination of sulfur exposure rates.

(b) There are two methods for using field data to develop aging cycles, as described in § 1065.1139(b)(1) and (2). Method selection depends on the type of field data available. Method 1 directly uses field data to generate aging modes, while Method 2 uses field data to weight appropriate regulatory duty cycles that are used for emissions certification.

(c) Carry out accelerated aging on either a modified engine platform or a reactor-based burner platform. The requirements for these platforms are described in § 1065.1141 for engine bench aging and § 1065.1143 for burner-based bench aging.

§ 1065.1133 Application selection, data gathering, and analysis.

This section describes the gathering and analysis of the field generated data that is required for generation of the data cycle. Gather data for the determination of aftertreatment exposure to thermal, lubricating oil, and sulfur related aging factors. You are not required to submit this data as part of your application, but you must make this data available if we request it.

(a) *Field data target selection.* Use good engineering judgment to select one or more target applications for gathering of input field data for the accelerated aging cycle generation that represent a greater than average exposure to potential field aging factors. It should be noted that

the same application may not necessarily represent the worst case for all aging factors. If sufficient data is not available to make this determination with multiple applications, you may select the application that is expected to have the highest sales volume for a given engine family.

(1) *Thermal exposure.* We recommend that you select applications for a given engine family that represent the 90th percentile of exposure to thermal aging. For example, if a given engine family incorporates a periodic infrequent regeneration event that involves exposure to higher temperatures than are observed during normal (non-regeneration) operation, we recommend that you select an application wherein the total duration of the cumulative regeneration events is at the 90th percentile of expected applications for that family. For an engine that does not incorporate a distinct regeneration event, we recommend selecting an application that represents the 90th percentile in terms of the overall average temperature.

(2) *Oil exposure.* Use a combination of field and laboratory measurements to determine an average rate of oil consumption in grams per hour that reaches the exhaust. You may use the average total oil consumption rate of the engine if you are unable to determine what portion of the oil consumed reaches the exhaust aftertreatment.

(3) *Sulfur exposure.* The total sulfur exposure is the sum of fuel- and oil-related sulfur. Oil-related sulfur will be accounted for in the acceleration of oil exposure directly. We recommend that you determine fuel-related sulfur exposure by selecting an application that represents the 90th percentile of fuel consumption. Use good engineering judgment to determine that average rate of fuel consumption for the target application. You may use a combination of field and laboratory measurements to make this determination. Calculate the average rate of fuel-related sulfur exposure in grams per hour from the average rate of fuel consumption assuming a fuel sulfur level of 10 ppm by weight.

(b) *Application data gathering.* Use good engineering judgment to gather data from one or more field vehicles to support the accelerated aging cycle generation. We recommend that you gather data at a recording frequency of 1 Hz. The type of data that you gather will depend on the method you plan to use for cycle generation. Record both the data and the number of engine operating hours which that data represents regardless of method, as this information will be used to scale the cycle calculations. Use good engineering judgment to ensure that the amount of data recorded provides an accurate representation of field operation for the target application. If your application includes a periodic regeneration event, you must record multiple events to ensure that you have accurately captured the variation of those events. We recommend that you record at least 300 hours of field operation, and at least 3 different regeneration events if applicable.

(1) When using Method 1, direct field data use, as described in § 1065.1139(b)(1), record data for exhaust flow rate and at least one representative inlet temperature for each major aftertreatment system catalyst component, such as a diesel oxidation catalyst (DOC), diesel particulate filter (DPF), or selective catalytic reduction (SCR) catalyst. If a given catalyst component has multiple substrates installed directly in sequence, it is sufficient to record only the inlet temperature for the first catalyst substrate in the sequence. It is not necessary to record separate temperatures for substrates that are “zone-coated” with multiple catalyst functions. Record a representative outlet temperature for any major catalyst component that is used to elevate the temperature of downstream components. This could be the inlet of the next major component if that would be representative. We recommend that you record engine fuel rate to assist in the determination of sulfur exposure rates, but you may use other data for this purpose.

(2) When using Method 2, weighting of certification cycles, as described § 1065.1139(b)(2), record data for engine speed and engine load. Record sufficient ECM load parameters to determine a torque value that can be compared directly to engine torque as measured in the

laboratory. You may optionally use ECM fuel rate measurements to determine load, but only if the same measurements can also be performed during laboratory testing on certification test cycles using sensors with comparable response characteristics. For example, you could use ECM fuel consumption rates for both field data and during laboratory tests.

(i) Optionally, as an alternative to the parameters required in this paragraph (b)(2), you may use a system exhaust temperature measurement to represent load. This requires one recorded temperature that represents the aftertreatment system. We recommend that you use a temperature recorded at the outlet of the first major catalyst component. If you choose to use this option, you must use the same temperature sensor for both field and laboratory measurements. Do not compare measurements between on-engine production temperature sensors with laboratory temperature sensors.

(ii) Optionally, as an alternative to the parameters required in this paragraph (b)(2), you may use exhaust flow and temperature measurements recorded in the field to support Method 2 calculations. Only one recorded temperature that represents the aftertreatment system is needed in this case. We recommend that you use a temperature recorded at the outlet of the first major catalyst component. Do not compare measurements between on-engine production temperature sensors with laboratory temperature sensors.

(3) If you have an aftertreatment system which involves periodic regeneration events where the temperature is raised above levels observed during normal operation, you must record data to characterize each such event. Data must be recorded at a frequency of at least 1 Hz, and you must record the exhaust flow rate and inlet temperature of each key catalyst component that will experience elevated temperatures during the regeneration. In addition, record a flag or variable that can be used to determine the beginning and end of a regeneration event. You must record at least three such events to allow determination of the average regeneration profile. If you have multiple types of regeneration events which influence different catalyst components in the system, you must record this data for each type of event separately. Use good engineering judgment to determine the average duration of each type of regeneration event, and the average interval of time between successive regeneration events of that type. You may use the data recorded for this cycle determination, or any other representative data to determine average regeneration duration or regeneration interval. These values may be determined from the analysis used to determine emission adjustments to account for infrequent regeneration of aftertreatment devices in § 1065.680.

§ 1065.1135 Determination of key aftertreatment system components.

Most compression-ignition engine aftertreatment systems contain multiple catalysts, each with their own aging characteristics. However, in the accelerated aging protocol the system will be aged as a whole. Therefore, it is necessary to determine which catalyst components are the key components that will be used for deriving and scaling the aging cycle.

(a) The primary aging catalyst in an aftertreatment system is the catalyst that is directly responsible for the majority of NO_x reduction, such as a urea SCR catalyst in a compression ignition aftertreatment system. This catalyst will be used as the basis for cycle generation. If a system contains multiple SCR catalysts that are separated by other heat generating components that would result in a different rate of heat exposure, then each SCR catalyst must be tracked separately. Use good engineering judgment to determine when there are multiple primary catalyst components. An example of this would be a light-off SCR catalyst placed upstream of a DOC which is used to generate heat for regeneration and is followed by a DPF and a second downstream SCR catalyst. In this case, both the light-off SCR and the downstream SCR would

have very different thermal history, and therefore must be tracked separately. In applications where there is no SCR catalyst in the aftertreatment system, the primary catalyst is the first oxidizing catalyst component in the system which is typically a DOC or catalyzed DPF.

(b) The secondary aging catalyst in an aftertreatment system is the catalyst that is intended to either alter exhaust characteristics or generate elevated temperature upstream of the primary catalyst. An example of a secondary component catalyst would be a DOC placed upstream of an SCR catalyst, with or without a DPF in between.

§ 1065.1137 Determination of thermal reactivity coefficient.

This section describes the method for determining the thermal reactivity coefficient(s) used for thermal heat load calculation in the accelerated aging protocol.

(a) The calculations for thermal degradation are based on the use of an Arrhenius rate law function to model cumulative thermal degradation due to heat exposure. Under this model, the thermal aging rate constant, k , is an exponential function of temperature which takes the form shown in the following equation:

$$k = A \cdot e^{-\frac{E_a}{R \cdot T}}$$

Eq. 1065.1137-1

Where:

A = frequency factor or pre-exponential factor.

E_a = thermal reactivity coefficient ~~in kJ/mol~~.

R = molar gas constant.

T = catalyst temperature ~~in K~~.

(b) The process of determining E_a begins with determining what catalyst characteristic will be tracked as the basis for measuring thermal deactivation. This metric varies for each type of catalyst and may be determined from the experimental data using good engineering judgment. We recommend the following metrics; however, you may also use a different metric based on good engineering judgment:

(1) *Copper-based zeolite SCR*. Total ammonia (NH_3) storage capacity is a key aging metric for copper-zeolite SCR catalysts, and they typically contain multiple types of storage sites. It is typical to model these catalysts using two different storage sites, one of which is more active for NO_x reduction, as this has been shown to be an effective metric for tracking thermal aging. In this case, there are two recommended aging metrics:

(i) is ~~t~~The ratio between the storage capacity of the two sites, with more active site being in the denominator.

(ii) Storage capacity of the more active site.

(2) *Iron-based zeolite SCR*. Total ~~NH_3 ammonia~~ storage capacity is a key aging metric for iron-zeolite SCR catalysts. Using a single storage site is at 250 °C the recommended metric for tracking thermal aging.

(3) *Vanadium SCR*. Brunauer–Emmett–Teller (BET) theory for determination of surface area is a key aging metric for vVanadium-based SCR catalysts. Total NH_3 storage capacity may also be used as a surrogate to probe the surface area. If you use NH_3 storage to probe surface area, using a single storage site do not feature a high level of ammonia storage like zeolites, therefore NO_x reduction efficiency at lower temperatures in the range of 250 °C is the recommended metric for tracking thermal aging. You may also use low temperature NO_x conversion as a metric. If you choose this option, you may be limited in your choice of

temperatures for the experiment described in paragraph (c)(1) of this section due to vanadium volatility. In that case, it is possible that you may need to run a longer experimental duration than the recommended 64 hours to reach reliably measurable changes in NO_x conversion.

(4) Zone-coated zeolite SCR. This type of catalyst is zone coated with both copper- and iron-based zeolite. As noted in paragraphs (b)(1) and (2) of this section, total NH₃ storage capacity is a key aging metric, and each zone must be evaluated separately.

(45) Diesel oxidation catalysts. Conversion rate of NO to NO₂ at 200 °C is ~~†~~ The key aging metric for tracking thermal aging for DOCs which are used to optimize exhaust characteristics for a downstream SCR system is the conversion rate of NO to NO₂. Select a conversion rate temperature less than or equal to 200 °C using good engineering judgement. HC reduction efficiency (as measured using ethylene) at 200 °C is ~~†~~ The key aging metric for DOCs, which are part of a system that does not contain an SCR catalyst for NO_x reduction, is the HC reduction efficiency (as measured using ethylene). Select a conversion rate temperature less than or equal to 200 °C using good engineering judgement. This same guidance applies to an oxidation catalyst coated onto the surface of a DPF, if there is no other DOC in the system.

(c)(1) Use good engineering judgment to select at least three different temperatures to ~~run~~ complete the degradation experiments. We recommend selecting these temperatures to accelerated thermal deactivation such that measurable changes in the aging metric can be observed at multiple time points over the course of no more than ~~50~~ 64 hours. Avoid temperatures that are too high to prevent rapid catalyst failure by a mechanism that does not represent normal aging. An example of temperatures to run the degradation experiment at for a small-pore copper zeolite SCR catalyst is 600 °C, 650 °C, and 725 °C.

(2) For each aging temperature selected, perform testing to assess the aging metric at different times. These time intervals do not need to be evenly spaced and it is typical to ~~run~~ complete these experiments using increasing time intervals (e.g., after 2, 4, 8, 16, and 32 hours). Use good engineering judgment to stop each temperature experiment after sufficient data has been generated to characterize the shape of the deactivation behavior at a given temperature.

(i) For SCR-based NH₃ storage capacity testing, perform a Temperature Programmed Desorption (TPD) following NH₃ saturation of the catalyst (i.e., ramping gas temperature from 200 to 550 °C) to quantify total NH₃ released during the TPD.

(ii) For DOC formulations, conduct an NO Reverse Light Off (RLO) to quantify oxidation conversion efficiency of NO to NO₂ (i.e., ramping gas temperature from 500 to 150 °C).

(d) Generate a fit of the deactivation data generated in paragraph (b) of this section at each temperature ~~using the generalized deactivation equation.:~~

(1) Copper-based zeolite SCR. Process all NH₃ TPD data from each aging condition using an algorithm to fit the NH₃ desorption data.

(i) We recommend that you use the Temkin adsorption model to quantify the NH₃ TPD at each site to determine the desorption peaks of individual storage sites. The adsorption model is adapted from “Adsorption of Nitrogen and the Mechanism of Ammonia Decomposition Over Iron Catalysts” (Brunauer, S. *et al*, Journal of the American Chemical Society, 1942, 64 (4), 751-758) and “On Kinetic Modeling of Change in Active Sites upon Hydrothermal Aging of Cu-SSZ-13” (Daya, R. *et al*, Applied Catalysis B: Environmental, 2020, 263, 118368-118380). It is generalized using the following equation (assuming a two-site model):

$$\frac{d\theta}{dt} = k\theta$$

Eq. 1065.1137-2

Where:

$$k = e^{-E_a(1-\alpha\theta)/RT}$$

E_a = thermal reactivity coefficient of ammonia desorption.

α = Temkin constant.

θ = fraction of adsorption sites currently occupied (initial θ is assumed to be 1).

R = molar gas constant.

T = aging temperature.

(A) Use Eq. 1065.1137-2 to express the NH₃ storage site desorption peaks as follows:

$$Site_1 = N_1 \cdot A_1 \cdot e^{\left[\frac{E_{a,T1}(1-\alpha_1\theta_1)}{R \cdot T}\right]} \cdot \theta_1$$

$$Site_2 = N_2 \cdot A_2 \cdot e^{\left[\frac{E_{a,T2}(1-\alpha_2\theta_2)}{R \cdot T}\right]} \cdot \theta_2$$

Eq. 1065.1137-3

Where:

N_1 = moles of NH₃ desorbed from Site 1.

A_1 = pre-exponential factor associated with Site 1.

$E_{a,T1}$ = thermal reactivity coefficient of ammonia desorption for Site 1.

N_2 = moles of NH₃ desorbed from Site 2.

A_2 = pre-exponential factor associated with Site 2.

$E_{a,T2}$ = thermal reactivity coefficient of ammonia desorption for Site 2.

(B) Optimize $E_{a,T1}$, α_1 , A_1 , $E_{a,T2}$, α_2 , and A_2 to fit each NH₃ TPD peak to give the best fit. The moles of NH₃ (N_1 and N_2) may vary for each individual TPD data set.

(ii) Use one of the following modeling approaches to derive the thermal reactivity coefficient, $E_{a,D}$. We recommend that you use both models to fit the data and check that the resulting $E_{a,D}$ values for the two methods are within 3% of each other.

(A) *General Power Law Expression (GPLe)*. Generate a fit of the deactivation data from paragraph (d)(1)(i) of this section for each aging temperature using the following expression:

$$-\frac{d\Omega}{dt} = k_D \cdot (\Omega - \Omega_{eq})^m$$

Eq. 1065.1137-4

Where:

k_D = the thermal aging rate constant.

$$k_D = A \cdot e^{-\frac{E_{a,D}}{R \cdot T}}$$

Eq. 1065.1137-5

A = pre-exponential factor.

$E_{a,D}$ = thermal reactivity coefficient.

R = molar gas constant.

T = aging temperature.

$\Omega = N_2/N_1$ or $= N_2$ (normalizing Ω to the degreened Ω value for each new catalyst component prior to aging is recommended (i.e., $\Omega = 1$ at $t = 0$ for each aging temperature).

Ω_{eq} = aging metric at equilibrium (set = 0 unless there is a known activity minimum).

m = model order (assumed to be 2 for copper-based zeolite SCR).

(1) Solve Eq. 1065.1137-4 for Ω to yield the following expression:

$$\Omega = \left[A \cdot e^{-\frac{E_{a,D}}{R \cdot T} \cdot t} + \Omega_0 \right]^{-1}$$

Eq. 1065.1137-6

Where:

$\Omega_0 = 1$ (assumes that N_2/N_1 or $= N_2$ values were normalized to the degreened value for each aging temperature).

A = pre-exponential factor.

$E_{a,D}$ = thermal reactivity coefficient.

R = molar gas constant.

T = aging temperature.

t = aging time.

(2) Use a global fitting approach to solve for $E_{a,D}$ and A_D by applying a generalized reduced gradient (GRG) nonlinear minimization algorithm, or equivalent. For the global fitting approach, optimize the model by minimizing the Global Sum of Square Errors (SSE_{Global}) between the experimental Ω and model Ω while only allowing $E_{a,D}$ and A_D to vary. Global SSE is defined as the summed total SSE for all aging temperatures evaluated.

$$SSE_{Global} = \sum_{i=0}^n SSE_{Ti}$$

Eq. 1065.1137-7

Where:

n = total number of aging temperatures.

i = an indexing variable that represents one aging temperature.

SSE_T = sum of square errors (SSE) for a single aging temperature, T , (see Eq. 1065.1137-8).

$$SSE_T = \sum_{i=0}^n (\Omega_{Exp i} - \Omega_{model i})^2$$

Eq. 1065.1137-8

Where:

n = total number of aging intervals for a single aging temperature.

i = an indexing variable that represents one aging interval for a single aging temperature.

Ω_{Exp} = experimentally derived aging metric for aging temperature, T .

Ω_{model} = aging metric calculated from Eq. 1065.1137-6 for aging temperature, T .

(B) Arrhenius approach. In the Arrhenius approach, the deactivation rate constant, k_D , of the aging metric, Ω , is calculated at each aging temperature.

(1) Generate a fit of the deactivation data in paragraph (d)(1)(i) of this section at each aging temperature using the following linear expression:

$$\frac{1}{\Omega} = k_D \cdot t + 1$$

Eq. 1065.1137-9

Where:

$\Omega = N_2/N_1$ or $= N_2$ (Ω is to be normalized to the degreened Ω value for each new catalyst component prior to aging, i.e. $\Omega = 1$ at $t = 0$ for each aging temperature).

$$k_D = A \cdot e^{-\frac{E_{a,D}}{R \cdot T}} \quad \text{(Eq. 1065.1137-5)}$$

A = pre-exponential factor.

$E_{a,D}$ = thermal reactivity coefficient.

R = molar gas constant.

T = aging temperature.

(2) Generate a plot of $1/\Omega$ versus t for each aging temperature evaluated in paragraph (c)(1) in this section. The slope of each line is equal to the thermal aging rate, k_D , at a given aging temperature. Using the data pairs of aging temperature and thermal aging rate constant, k_D , determine the thermal reactivity coefficient, E_a , by performing a regression analysis of the natural log of k_D versus the inverse of temperature, T , in Kelvin. Determine $E_{a,D}$ from the slope of the resulting regression line, $m_{\text{deactivation}}$, using the following equation:

$$E_{a,D} = -m_{\text{deactivation}} \cdot R$$

Eq. 1065.1137-10

Where:

$m_{\text{deactivation}}$ = the slope of the regression line of $\ln(k_D)$ versus $1/T$.

R = molar gas constant.

(2) Iron-based zeolite or vanadium SCR. Process all NH_3 TPD data from each aging condition using a GPLE to fit the NH_3 desorption data (or BET surface area data for vanadium SCR). Note that this expression is different from the one used in paragraph (d)(1)(ii)(A) of this section because the model order m is allowed to vary. This general expression takes the following form:

$$-\frac{d\Omega}{dt} = k_D \cdot (\Omega - \Omega_{\text{eq}})^m$$

Eq. 1065.1137-11

Where:

Ω = total NH_3 (or BET surface area) normalized to the degreened value for each new catalyst component prior to aging (i.e. $\Omega = 1$ at $t = 0$ for each aging temperature).

$$k_D = A \cdot e^{-\frac{E_{a,D}}{R \cdot T}} \quad \text{(Eq. 1065.1137-5)}$$

A = pre-exponential factor.

E_{a,D} = thermal reactivity coefficient.

R = molar gas constant.

T = aging temperature.

t = time.

Ω_{eq} = aging metric at equilibrium (set to 0 unless there is a known activity minimum).

m = model order.

(i) Solve Eq. 1065.1137-10 for Ω to yield the following expression:

$$\Omega = \left[(m - 1) \cdot A \cdot e^{-\frac{E_{a,D}}{R \cdot T}} \cdot t + (\Omega_0)^{1-m} \right]^{1/1-m}$$

Eq. 1065.1137-12

Where:

Ω₀ = 1 (assumes total NH₃ storage, or BET surface area, was normalized to the degreened value for each aging temperature).

A = pre-exponential factor.

E_{a,D} = thermal reactivity coefficient.

R = molar gas constant.

T = aging temperature.

t = aging time.

m = model order (to be varied from 1 to 8 using whole numbers).

(ii) Global fitting is to be used to solve for E_{a,D} and A_D by applying a GRG nonlinear minimization algorithm, as described in paragraph (d)(1)(ii)(A) of this section. Minimize the SSE_{Global} for each model order, m, while only allowing E_{a,D} and A_D to vary. The optimal solution is determined by selecting the model order, m, that yields the lowest global fit SSE. If you have a range of model order solutions where the SSE_{Global} does not vary substantially, use good engineering judgement to choose the lowest m for this range.

(3) Zone-coated zeolite SCR. Derive the thermal reactivity coefficient, E_{a,D}, for each zone of the SCR, based on the guidance provided in paragraphs (d)(1) and (2) of this section. The zone that yields the lowest E_{a,D} shall be used for calculating the target cumulative thermal load, as outlined in § 1065.1139.

(4) Diesel oxidation catalyst. (i) The catalyst monolith is modeled as a plug flow reactor with first order reaction rate:

$$-v \frac{dX}{dV} = k_D \cdot (1 - X)$$

Eq. 1065.1137-13

Where:

v = velocity.

X = conversion (NO to NO₂) in %/100.

V = volume of reactor.

$$k_D = A_D \cdot e^{-\frac{E_{a,D}}{R \cdot T}}$$

Eq. 1065.1137-14

A_D = pre-exponential factor.

$E_{a,D}$ = thermal reactivity coefficient.

R = molar gas constant.

T = aging temperature.

(ii) For a diesel oxidation catalyst, the preexponential term A_D is proportional to the number of active sites and is the desired aging metric. Solving Eq. 1065.1137-13 for k_D , substituting it for k_D in Eq. 1065.1137-5, and then solving for A_D yields Eq. 1065.1137-15:

$$A_D = \frac{-SV * \ln(1 - X \%)}{e^{-E_{a,D}/RT}}$$

Eq. 1065.1137-15

Where:

SV = space velocity used during RLO testing.

X = conversion (NO to NO₂).

$E_{a,D}$ = thermal reactivity coefficient.

T = temperature where X was measured.

R = molar gas constant.

(iii) Process all NO to NO₂ oxidation RLO data for each aging condition by determining the average oxidation conversion efficiency, X , at the temperature determined in paragraph (b)(5) of this section. We recommend maintaining the target oxidation conversion temperature to ± 5 °C. For each aging condition (aging temperature, T and aging time, t), calculate the aging metric, Ω , by normalizing A_D to the degreened A_D value for each new catalyst component prior to aging (i.e., $\Omega = 1$ at $t = 0$ for each aging temperature).

(A) Use the GPLF to fit the NO to NO₂ conversion data, X , at each aging temperature. The GPLF takes the following form:

$$-\frac{d\Omega}{dt} = k_D \cdot (\Omega - \Omega_{eq})^m$$

Eq. 1065.1137-16

Where:

Ω = aging metric for diesel oxidation catalysts.

$$k_D = A_D \cdot e^{-\frac{E_{a,D}}{R \cdot T}} \text{ (Eq. 1065.1137-14)}$$

R = molar gas constant.

T = aging temperature.

t = aging time.

Ω_{eq} = aging metric at equilibrium (set to 0 unless there is a known activity minimum).

m = model order.

(B) Solve Eq. 1065.1137-12 for Ω to yield the following expression:

$$\Omega = \left[(m - 1) \cdot A \cdot e^{-\frac{E_{a,D}}{R \cdot T}} * t + (\Omega_{eq})^{1-m} \right]^{1/1-m}$$

Eq. 1065.1137-17

Where:

$\Omega_{eq} = 1$ (assumes the oxidation efficiency, X , was normalized to the degreened value for each aging temperature).

$A =$ pre-exponential factor.

$E_{a,D} =$ thermal reactivity coefficient.

$R =$ molar gas constant.

$T =$ aging temperature.

$t =$ aging time.

$m =$ model order (to be varied from 1 to 8 using whole numbers)

(iv) Use global fitting to solve for $E_{a,D}$ and A by applying a GRG nonlinear minimization algorithm, as described in paragraph (d)(1)(ii)(A) of this section. Minimize the SSE_{Global} for each model order, m , while only allowing $E_{a,D}$ and A to vary. The optimal solution is determined by selecting the model order, m , that yields the lowest global fit SSE. If you have a range of model order solutions where the SSE_{Global} does not vary substantially, use good engineering judgement to choose the lowest m for this range.

Eq. 1065.1137-2

Where:

$\Omega =$ aging metric.

$k =$ thermal aging rate constant for a given temperature.

$\Omega_{EQ} =$ aging metric at equilibrium (set to 0 unless there is a known activity minimum).

$m =$ model order (the model order should be set at the lowest value that best fits the data at all temperatures, minimum = 1).

(e) Using the data pairs of temperature and thermal aging rate constant, k , from paragraph (e)(2) of this section, determine the thermal reactivity coefficient, E_a , by performing a regression analysis of the natural log of k versus the inverse of temperature, T , in Kelvin. Determine E_a from the slope of the resulting line using the following equation:

$$E_a = -\frac{m}{R}$$

Eq. 1065.1137-3

Where:

$m =$ the slope of the regression line of $\ln(k)$ versus $1/T$.

$R =$ molar gas constant.

§ 1065.1139 Aging cycle generation.

Generation of the accelerated aging cycle for a given application involves analysis of the field data to determine a set of aging modes that will represent that field operation. There are two methods of cycle generation, each of which is described separately below. Method 1 involves the direct application of field data and is used when the recorded data includes sufficient exhaust flow and temperature data to allow for determination of aging conditions directly from the field data set and must be available for all of the key components. Method 2 is meant to be used when insufficient flow and temperature data is available from the field data. In Method 2, the field data is used to weight a set of modes derived from the laboratory certification cycles for a given application. These weighted modes are then combined with laboratory recorded flow and

temperatures on the certification cycles to derive aging modes. There are two different cases to consider for aging cycle generation, depending on whether or not a given aftertreatment system incorporates the use of a periodic regeneration event. For the purposes of this section, a “regeneration” is any event where the operating temperature of some part of the aftertreatment system is raised beyond levels that are observed during normal (non-regeneration) operation. The analysis of regeneration data is considered separately from normal operating data.

(a) *Cycle generation process overview.* The process of cycle generation begins with the determination of the number of bench aging hours. The input into this calculation is the number of real or field hours that represent the useful life for the target application. This could be given as a number of hours or miles, and for miles, the manufacturer must use field data and good engineering judgment to translate this to an equivalent number of operating hours for the target application. The target for the accelerated aging protocol is a 10-time acceleration of the aging process, therefore the total number of aging hours is always set at useful life hours divided by 10. For example, if an on-highway heavy duty engine has a full useful life of 750,000 miles and this is determined to be represented by 24,150 field hours, the target duration for the DAAAC protocol for this application would be 2,415 bench-aging hours. The 2,415 hours will then be divided among different operating modes that will be arranged to result in repetitive temperature cycling over that period. For systems that incorporate periodic regeneration, the total duration will be split between regeneration and normal (non-regeneration) operation. The analysis of normal operation data is given in paragraph (b) of this section. The analysis of regeneration data is given in paragraph (c) of this section.

(b) *Analysis of normal (non-regeneration) operating data.* This analysis develops a reduced set of aging modes that represent normal operation. As noted earlier, there are two methods for conducting this analysis, based on the data available.

(1) *Method 1 – Direct clustering.* Use Method 1 when sufficient exhaust flow and temperature data are available directly from the field data. The data requirements for Method 1 are described in § 1065.1133(b)(1). The method involves three steps: clustering analysis, mode consolidation, and cycle building.

(i) The primary method for determining modes from a field data set involves the use of k-means clustering. K-means clustering is a method where a series of observations is partitioned into set of clusters of “similar” data points, where every observation is a member of a cluster with the nearest mean, which is referred to as the centroid of that cluster. The number of clusters is a parameter of the analysis, and the k-means algorithm generally seeks an optimal number of clusters to minimize the least-squares distance of all points to their respective centroids. There are a number of different commercially available software programs to perform k-means clustering, as well as freely available algorithm codes. K-means clustering can arrive at many different solutions, and we are providing the following guidance to help select the optimal solution for use in accelerated aging cycle generation. The process involves analyzing the data multiple time using an increasing number of clusters for each analysis. Use at least 5 clusters, and we recommend developing solutions for the range between 5 and 8 clusters, although you may use more if desired. Each cluster is a potential aging mode with a temperature and flow rate defined by the centroid. More clusters result in more aging modes, although this number may be reduced later via model consolidation.

(ii) The cubic clustering criteria (CCC) is a metric calculated for each solution having a different number of clusters. The computation of CCC is complex and described in more detail in the following reference. The CCC computation is normally available as one of the metrics in commercially available software packages that can be used for k-means

clustering. The optimal solution is typically the one with the number of clusters corresponding to the highest CCC.

(iii) Check each solution, starting with the one with the highest CCC to determine if it satisfies the following requirements:

(A) No more than one cluster contains fewer than 3 % of the data points.

(B) The temperature ratio between the centroid with the maximum temperature and the centroid with the minimum temperature is at least 1.6 for clusters containing more than 3% of the data points.

(C) If that solution does not satisfy these requirements move to the solution with the next highest CCC.

(iv) The process described in paragraph (c)(1)(iii) of this section generally works well for most data sets, but if you have difficulty with the CCC metric in a particular data set, use good engineering judgment to leverage additional criteria to help the down-selection process. Examples of alternate clustering metrics include a Davies-Bouldin Index (optimizing on the minimum value) or a Calinski-Harabasz Index (optimize on the maximum value).

(v) The initial candidate mode conditions are temperature and flow rate combinations that are the centroids for each cluster from the analysis in paragraph (c)(1)(iii) of this section. As part of the analysis, you must also determine the 10th percentile and 90th percentile temperatures for each cluster. These additional values may be needed later for the cycle heat load tuning process described in § 1065.1143.

(vi) The mode weight factor for a given cluster is the fraction data points contained within that cluster.

(2) *Method 2 – Cluster-based weighting of certification cycle modes.* Use Method 2 if there is insufficient exhaust flow and temperature data from the field at the time the cycle is being developed. The data requirements for Method 2 are described in § 1065.1133(b)(2). You also need laboratory data recorded in the form of 1 Hz data sets for the regulatory duty cycles you are certifying to for your application as described in the standard setting part. Include exhaust flow rate and the inlet temperature for each key catalyst component in the laboratory data sets, as described in paragraph (e) of this section. The laboratory data sets must also include parameters that match the field data as described in § 1065.1133(b)(2), which will be used to facilitate the clustering analysis.

(i) Perform k-means clustering as described in § 1065.1133(b)(1) but using data sets containing the two parameters recorded in the field data sets. For example, you might use speed and torque, as recorded both in the field and the laboratory for Method 2 clustering.

(ii) Determine the fraction of points from each of the regulatory laboratory duty-cycles that are within each cluster, in addition to the overall fraction of points from the entire data set.

(iii) For each cycle, calculate a square sum error, *SSE*, as follows:

$$SSE = \sum_{i=1}^N (Cycle_{probi} - RefData_{probi})^2$$

Eq. 1065.1139-1

Where:

i = an indexing variable that represents one cluster.

N = total number of clusters.

$Cycle_{prob}$ = the fraction of points in a given cluster, i , for the regulatory duty-cycle of interest.

$RefData_{prob}$ = the fraction of points in a given cluster, i , for the full data set.

(iv) For each cycle, calculate a dissimilarity index as follows:

$$Dissimilarity = \sqrt{\frac{SSE}{N}}$$

Eq. 1065.1139-2

Where:

SSE = sum square error from Eq. 1065.1139-2.

N = total number of clusters.

(v) If you have more than one regulatory duty cycle, weight the regulatory cycles.

(A) Determine the weighting factors for a given regulatory cycle, w_i , by solving a system of equations:

$$w_i = \frac{1}{1 + \sum_{j \neq i} \frac{d_j}{d_i}}$$

Eq. 1065.1139-3

Where:

d_i = dissimilarity for a given regulatory cycle, i .

d_j = dissimilarity for a given regulatory cycle, j .

(B) For example, for three duty cycles, calculate w_1 as follows:

$$w_1 = \frac{1}{1 + \frac{d_1}{d_2} + \frac{d_1}{d_3}}$$

Eq. 1065.1139-4

(C) Calculate subsequent w_i values after calculating w_1 as follows:

$$w_i = w_1 \cdot \frac{d_1}{d_i}$$

Eq. 1065.1139-5

(D) Calculate the sum of the weighting factors to verify that they are equal to one.

$$w_1 + \dots + w_n = 1$$

Eq. 1065.1139-6

Where:

n = number of regulatory cycles for the application.

(vi) For each regulatory cycle determine the average exhaust flow and the average inlet temperature for each key catalyst. Determine the 25th and 90th percentile inlet temperatures for the primary catalyst and the respective associated exhaust flow rate for each data point.

(vii) Use the cycle weights from paragraph (b)(2)(v) of this section and the mode conditions from paragraph (b)(2)(vi) of this section to generate a set of candidate aging modes by multiplying the cycle weight factor, w_{cycle} by 0.25 for the 25th percentile temperature mode, 0.65 for the 50th percentile temperature mode, and by 0.10 for the 90th percentile temperature mode. This will generate a weighted set of mode numbers three times the number of regulatory cycles for the target application. Each mode will have a target temperature and exhaust flow rate.

(viii) If you have only one regulatory cycle for your application, use the cycle modes and weighting factors as they are given in the standard setting part.

(3) *Determination of mode total durations.* The output for either method will be a set of mode exhaust conditions, with an associated weighting factor for each mode. Multiply the mode weight factors by the total number of normal operating (non-regenerating) hours, to get a target mode duration for each mode. This will be used in the heat load calculations.

(c) *Mode consolidation.* Sometimes the clustering analysis process will generate multiple modes that are very similar to each other in temperature, such that although they are distinct modes they will not have a significantly different impact on aftertreatment aging. To reduce the complexity of the aging cycle, you may consolidate modes that are similar into a single mode as described below.

(1) Consolidate any two or more modes which have a target temperature within 10 °C into a single mode. If you choose to do this, the target temperature of the single consolidated mode is the temperature associated with the highest weight factor mode before consolidation. If the modes being consolidated all have weighting factors within 0.05 of each other, use the highest temperature among the modes.

(2) Use the highest exhaust flow target among the modes being combined as the target exhaust flow for new consolidate mode.

(3) Use the combined sum of the weighting factors for all modes being consolidate as the weighting factor for the new consolidated mode. Similarly, the total duration of the new consolidated mode is the sum of the durations of the modes being consolidated.

(d) *Analysis of regeneration data.* Regeneration data is treated separately from the normal operating mode data. Generally, the target for accelerated aging cycle operation is to run all of the regenerations that would be expected over the course of useful life. If multiple types of regeneration are conducted on different system components, each type of regeneration must be analyzed separately using the steps in this paragraph (d). The data requirements for input into this process are described in § 1065.1133(b)(3). The process described below is meant to determine a representative regeneration profile that will be used during aging. You may also ask us to allow the use of other engineering data or analysis to determine a representative regeneration profile.

(1) The total number of regenerations that will be run during the accelerated aging process will be the same as the total number of regenerations over useful life. Calculate this number by dividing the total number of useful life hours by the interval between regenerations as determined in § 1065.1133(b)(3).

(2) Use the 1 Hz regeneration data to determine an appropriate regeneration profile. The recorded regeneration event begins when the engine indicates it has started regeneration using the recorded regeneration indicator and ends when the aftertreatment has returned back to the normal operating temperature after the flag indicates the regeneration is complete.

(3) For each recorded regeneration, calculate the cumulative deactivation, D_t , using the equations in paragraph (e) of this section.

(4) If you have a large number of recorded regenerations in your data set, select a regeneration event with a cumulative deactivation representing the 75th percentile of the distribution of heat loads in your recorded data set. If you have a smaller number of recorded regenerations, such that you cannot clearly identify the real distribution, select the recorded regeneration with the highest recorded cumulative deactivation.

(5) This regeneration event will be used as the regeneration profile for that type of event during aging. The profile should include the entire event, include the temperature ramp and cool-down period.

(6) The regeneration must be conducted in the same manner as it is run in the field. For instance, if the regeneration temperature is generated from an exothermic reaction by injecting fuel in front of a DOC, this methodology should also be used during bench aging.

(7) If part of the system is at a lower temperature during regeneration because it is upstream of the temperature generating component, the set the target temperature for the aftertreatment system inlet to be equivalent to the system inlet temperature used during the highest duration non-regeneration mode, or 350 °C, whichever is lower.

(e) *Heat load calculation and tuning for systems that have regeneration events.* Perform this procedure after the preliminary cycles are completed for both normal and regeneration operation. The target cumulative deactivation is determined from the input field data, and then a similar calculation is performed for the preliminary aging cycle. If the cumulative deactivation for the preliminary cycle does not match cumulative deactivation from the field data, then the cycle is tuned over a series of steps until the target is matched.

(1) The deactivation for a given catalyst is calculated for each time step as follows:

$$D_i = e^{\left(\frac{E_a}{R} \cdot \left(\frac{1}{T_{std}} - \frac{1}{T+273.15}\right)\right)}$$

Eq. 1065.1139-7

Where:

D_i = incremental deactivation for time step i .

E_a = thermal reactivity coefficient for the catalyst as determined in § 1065.1137.

R = molar gas constant in kJ/mol·K.

T_{std} = standard temperature = 293.15 K.

T = catalyst temperature in K.

(2) Calculate the cumulative deactivation, D_t , for a given catalyst over a series of time steps, N , using the following equation:

$$D_t = \sum_{i=0}^N D_i$$

Eq. 1065.1139-8

Where:

i = an indexing variable that represents one time step.

N = total number of cumulative deactivation time steps in the data set.

D_i = incremental deactivation for each time step.

(3) Calculate the cumulative deactivation, D_t , for the input field data set. The time step for the calculations should be 1 second for 1-Hz input data.

- (i) First calculate D_t for the non-regeneration portion of the field data set. For Method 2 use the 1-Hz data from the regulatory cycles as the field data set.
 - (ii) Divide the calculate field D_t by the number of hours represented in the field data set.
 - (iii) Multiply the hourly D_t by the number of hours required to reach full useful life. This is the target $D_{t,field-normi}$.
 - (iv) Multiply the total number of regenerations for full useful life by the cumulative deactivation D_t for the target regeneration profile determined in paragraph (d)(4) of this section. This is the target $D_{t,field-regen}$.
 - (v) The total target cumulative deactivation for the field data, $D_{t,field}$, is the sum of $D_{t,field-normi}$ and $D_{t,field-regen}$.
- (4) Calculate the cumulative deactivation for the candidate aging cycle generated under paragraphs (c) and (d) of this section as follows:
- (i) Using the modes and mode durations for normal operation generated in paragraph (c) of this section, calculate the cumulative deactivation, $D_{t,cycle-norm}$, using the method given in paragraph (e)(2) of this section.
 - (ii) The total cumulative deactivation for the candidate aging cycle, D_t , is the sum of $D_{t,cycle-norm}$ and $D_{t,field-regen}$.
- (5) If $D_{t,cycle}$ is within $\pm 1\%$ of $D_{t,field}$, the candidate cycle is deemed representative and may be used for aging.
- (6) If $D_{t,cycle}$ is not within $\pm 1\%$ of $D_{t,field}$, the candidate cycle must be adjusted to meet this criterion using the following steps. It should be noted that if the $D_{t,cycle}$ is outside of the criteria it will usually be lower than the $D_{t,field}$.
- (i) Increase the duration of the stable portion of the regeneration profile, which is defined as the portion of the regeneration profile where the temperature has completed ramping and is being controlled to a stationary target temperature. Note that this will increase the number of hours of regeneration time. You must compensate for this by decreasing the total number of normal operation (non-regeneration) hours in the cycle. Recalculate the duration of all the normal operation modes. You may not increase the duration of the stable portion of the regeneration profile by more than a factor of 2. If you reach this limit and you still do not meet the criteria in paragraph (e)(5) of this section, proceed to the next step.
 - (ii) Increase the target temperature of the stable portion of the regeneration profile by the amount necessary to reach the target criteria. You may not increase this temperature higher than the temperature observed in the regeneration profile with the highest D_t observed in the field. If you reach this limit and you still do not meet the criteria in paragraph (e)(5) of this section, proceed to the next step.
 - (iii) Increase the target temperature of the highest temperature normal operation mode. You may not increase this temperature above the 90th percentile determined in paragraph (b)(1)(v) of this section for Method 1, or above the maximum temperature for the regulatory cycle from which the mode was derived for Method 2. If you reach this limit and you still do not meet the criteria in paragraph (e)(5) of this section, you may repeat this step using the next highest temperature mode, until you reach the target, or all modes have been adjusted.
 - (iv) If you are unable to reach the target deactivation by following paragraphs (e)(6)(i) through (iii) of this section, use good engineering judgment to increase the number of regenerations to meet the criteria in paragraph (e)(5) of this section. Note that this will increase the total regeneration hours, therefore you must decrease the number of normal operation hours and re-calculate mode durations for the normal operation modes.

(v) If you are not able to achieve the target $D_{t,field}$ using the steps in paragraphs (e)(6)(i) thru (iv) of this section without exceeding catalyst temperature limits, use good engineering judgement to reduce the acceleration factor from 10 to a lower number. If you reduce the acceleration factor you must re-calculate the number of hours determine in paragraph (a) of this section and re-run the process in this paragraph (e). Note that if you reduce the acceleration factor you must use the same lower acceleration factor in the chemical exposure calculations in paragraph (h) of this section, instead of 10.

(f) *Heat load calculation and tuning for systems that do not have regeneration events.* Follow the steps described for systems with regeneration events to calculate $D_{t,field}$ and $D_{t,cycle}$, omitting the steps related to regeneration events. The $D_{t,cycle}$ will be well below the $D_{t,field}$. Follow the steps given below to adjust the cycle until you meet the criteria in paragraph (e)(5) of this section.

(1) Increase the temperature of the highest temperature mode. Use good engineering judgment to ensure that this temperature does not exceed the limits of the catalyst in a way that might cause rapid deactivation or failure via a mechanism that is not considered normal degradation.

(2) Increase the duration of the highest temperature mode and decrease the duration of the other modes in proportion. You may not increase the duration highest temperature mode by more than a factor of 2.

(3) If you are not able to achieve the target $D_{t,field}$ using the steps in paragraphs (f)(1) and (2) of this section without exceeding catalyst temperature limits, use good engineering judgement to reduce the acceleration factor from 10 to a lower number. If you reduce the acceleration factor you must re-calculate the number of hours determine in paragraph (a) of this section and re-run the process in this paragraph (f). Note that if you reduce the acceleration factor you must use the same lower acceleration factor in the chemical exposure calculations in paragraph (h) of this section, instead of 10.

(g) *Final aging cycle assembly.* The final step of aging cycle development is the assembly of the actual cycle based on the mode data from either paragraph (e) of this section for systems with infrequent regeneration, or paragraph (f) of this section for systems that do not incorporate infrequent regeneration. This cycle will repeat a number of times until the total target aging duration has been reached.

(1) *Cycle assembly with infrequent regenerations.* For systems that use infrequent regenerations, the number of cycle repeats is equal to the number of regeneration events that happen over full useful life. ~~The infrequent regenerations are placed at the end of the cycle.~~ The total cycle duration of the aging cycle is calculated as the total aging duration in hours divided by the number of infrequent regeneration events. In the case of systems with multiple types of infrequent regenerations, use the regeneration with the lowest frequency to calculate the cycle duration.

(i) If you have multiple types of infrequent regenerations, arrange the more frequent regenerations such that they are spaced evenly throughout the cycle.

(ii) Determine the length of the normal (non-regeneration) part of the cycle by subtracting the regeneration duration, including any regeneration extension determined as part of cycle tuning from paragraph (e) of this section, from the total cycle duration. If you have multiple types of regeneration, then the combined total duration of regeneration events performed in the cycle must be subtracted from the total. For example, if you have one type of regeneration that is performed for 30 minutes every 30 cycle hours, and a second type that is performed for 30 minutes every 10 cycle hours (such that 3 of these secondary events will happen during each cycle), then you would subtract a total of 2 hours of regeneration time from the total cycle duration considering all 4 of these events.

(iii) Divide the duration of the normal part of the cycle into modes based on the final weighting factors determined in paragraph (c) of this section following any mode consolidation.

(iv) Place the mode with the lowest temperature first, then move to the highest temperature mode, followed by the next lowest temperature mode, and then the next highest mode, continuing in this alternating pattern until all modes are included.

(v) Transition between normal modes within (60 to 300) seconds. The transition period is considered complete when you are within ± 5 °C of the target temperature for the primary key component. Transitions may follow any pattern of flow and temperature to reach this target within the required 300 seconds.

(vi) For normal modes longer than 30 minutes, you may count the transition time as time in mode. Account for the transition time for modes shorter than 30 minutes by shortening the duration of the longest mode by an equivalent amount of time.

(vii) If the shortest normal operating mode is longer than 60 minutes, you must divide the normal cycle into shorter sub-cycles with the same pattern in paragraph (g)(1)(iii) of this section, but with shorter durations, so that the pattern repeats two or more times. You must divide the cycle into sub-cycles until the duration of the shortest mode in each sub-cycle is no longer than 30 minutes. No mode may have a duration shorter than 15 minutes, not including transition time.

(viii) If a regeneration event is scheduled to occur during a normal mode, shift the start of regeneration to the end of the nearest normal mode.

(2) *Cycle assembly without infrequent regenerations.* For systems that do not use infrequent regenerations, the cycle will be arranged to achieve as much thermal cycling as possible using the following steps.

(i) Assign a duration of 15 minutes to the mode with the lowest weight factor. Calculate the duration of the remaining modes in proportion to the final weight factors after mode durations have been adjusted during heat load tuning in paragraph (f) of this section.

(ii) Place the mode with the lowest temperature first, then move to the highest temperature mode, followed by the next lowest temperature mode, and then the next highest mode, continuing in this alternating pattern until all modes are included.

(iii) Transition between normal modes within (60 to 300) seconds. The transition period is considered complete when you are within ± 5 °C of the target temperature for the primary key component. Transitions may follow any pattern of flow and temperature to reach this target within the required 300 seconds.

(iv) For normal modes longer than 30 minutes, you may count the transition time as time in mode. Account for the transition time for modes shorter than 30 minutes by shortening the duration of the longest mode by an equivalent amount of time.

(v) This cycle will be repeated the number of times necessary to reach the target aging duration.

(h) [Chemical exposure targets. Determine targets for accelerated oil and fuel sulfur exposure as follows:](#)

[\(1\) Determination of accelerated oil-Oil exposure targets.](#) The target oil exposure rate during accelerated aging is 10 times the field average oil consumption rate determined in § 1065.1133(a)(2). You must achieve this target exposure rate on a cycle average basis during aging. Use good engineering judgment to determine the oil exposure rates for individual operating modes that will achieve this cycle average target. For engine-based aging stands you will likely have different oil consumption rates for different modes depending on the speed and load conditions you set. For burner-based aging stands, you may

find that you have to limit oil exposure rates at low exhaust flow or low temperature modes to ensure good atomization of injected oil. On a cycle average basis, the portion of oil exposure from the volatile introduction pathway (i.e., oil doped in the burner or engine fuel) must be between (10 to 30) % of the total. The remainder of oil exposure must be introduced through bulk pathway.

(12) *Determination of accelerated fuel-Fuel sulfur exposure targets.* The target sulfur exposure rate for fuel-related sulfur is determined by utilizing the field mean fuel rate data for the engine determined in § 1065.1133(a)(3). Calculate the total sulfur exposure mass using this mean fuel rate, the total number of non-accelerated hours to reach full useful life, and a fuel sulfur level of 10 ppmw.

(i) For an engine-based aging stand, if you perform accelerated sulfur exposure by additizing engine fuel to a higher sulfur level, determine the accelerated aging target additized fuel sulfur mass fraction, w_s , as follows:

$$w_{S,\text{target}} = \frac{\bar{m}_{\text{fuel,field}}}{\bar{m}_{\text{fuel,cycle}}} \cdot m_{S\text{fuel,ref}} \cdot S_{\text{acc,rate}}$$

Eq. 1065.1139-9

Where:

$\bar{m}_{\text{fuel,field}}$ = field mean fuel flow rate.

$\bar{m}_{\text{fuel,cycle}}$ = accelerated aging cycle mean fuel flow rate.

$m_{S\text{fuel,ref}}$ = reference mass of sulfur per mass of fuel = 0.00001 kg/kg.

$S_{\text{acc,rate}}$ = sulfur acceleration rate = 10.

Example:

$\bar{m}_{\text{fuel,field}} = 54.3$ kg/hr

$\bar{m}_{\text{fuel,cycle}} = 34.1$ kg/hr

$m_{S\text{fuel,ref}} = 0.00001$ kg/kg.

$S_{\text{acc,rate}} = 10$

$$w_{S,\text{target}} = \frac{54.3}{34.1} \cdot 0.00001 \cdot 10$$

$w_{S,\text{target}} = 0.000159$

(ii) If you use gaseous SO₂ to perform accelerated sulfur exposure, such as on a burner-based stand, calculate the target SO₂ concentration to be introduced, $x_{\text{SO}_2,\text{target}}$, as follows:

$$x_{\text{SO}_2,\text{target}} = \frac{\bar{m}_{\text{fuel,field}}}{\bar{m}_{\text{exhaust,cycle}}} \cdot \left(\frac{x_{S\text{fuel,ref}} \cdot S_{\text{acc,rate}} \cdot M_{\text{exh}}}{M_S} \right)$$

Eq. 1065.1139-10

Where:

$\bar{m}_{\text{fuel,field}}$ = field mean fuel flow rate.

$\bar{m}_{\text{exhaust,cycle}}$ = mean exhaust flow rate during the burner aging cycle.

$x_{S\text{fuel,ref}}$ = reference mol fraction of sulfur in fuel = 10 μmol/mol.

$S_{\text{acc,rate}}$ = sulfur acceleration rate = 10.

M_{exh} = molar mass of exhaust = molar mass of air.

M_S = molar mass of sulfur.

Example:

$$\dot{m}_{\text{fuel,field}} = 54.3 \text{ kg/hr}$$

$$\dot{m}_{\text{exhaust,cycle}} = 1000.8 \text{ kg/hr}$$

$$x_{\text{Sfuel,ref}} = 10 \text{ } \mu\text{mol/mol}$$

$$S_{\text{acc.rate}} = 10$$

$$M_{\text{exh}} = 28.96559 \text{ g/mol}$$

$$M_{\text{S}} = 32.065 \text{ g/mol}$$

$$x_{\text{SO}_2,\text{target}} = \frac{54.3}{1000.8} \cdot \left(\frac{10 \cdot 10 \cdot 28.96559}{32.065} \right)$$

$$x_{\text{SO}_2,\text{target}} = 4.90 \text{ } \mu\text{mol/mol}$$

(iii) You may choose to turn off gaseous sulfur injection during infrequent regeneration modes, but if you do you must increase the target SO₂ concentration by the ratio of total aging time to total normal (non-regeneration) aging time.

(2) [Reserved]

§ 1065.1141 Facility requirements for engine-based aging stands.

An engine-based accelerated aging platform is built around the use of a compression-ignition engine for generation of heat and flow. You are not required to use the same engine as the target application that is being aged. You may use any compression-ignition engine as a bench aging engine, and the engine may be modified as needed to support meeting the aging procedure requirements. You may use the same bench aging engine for deterioration factor determination from multiple engine families. The engine must be capable of reaching the combination of temperature, flow, NO_x, and oil consumption targets required. We recommend using an engine platform larger than the target application for a given aftertreatment system to provide more flexibility to achieve the target conditions and oil consumption rates. You may modify the bench aging engine controls in any manner necessary to help reach aging conditions. You may bypass some of the bench aging engine exhaust around the aftertreatment system being aged to reach targets, but you must account for this in all calculations and monitoring to ensure that the correct amount of oil and sulfur are reaching the aftertreatment system. If you bypass some of the engine exhaust around the aftertreatment system, you must directly measure exhaust flow rate through the aftertreatment system. You may dilute bench aging engine exhaust prior to introduction to the aftertreatment system, but you must account for this in all calculations and monitoring to ensure that the correct engine conditions and the correct amount of oil and sulfur are reaching the aftertreatment system. Your engine-based aging stand must incorporate the following capabilities:

(a) Use good engineering judgment to incorporate a means of controlling temperature independent of the engine. An example of such a temperature control would be an air-to-air heat exchanger. The temperature control system must be designed to prevent condensation in the exhaust upstream of the aftertreatment system. This independent temperature control is necessary to provide the flexibility required to reach temperature, flow, oil consumption targets, and NO_x targets.

(b) Use good engineering judgment to modify the engine to increase oil consumption rates to levels required for accelerated aging. These increased oil consumption levels must be sufficient to reach the bulk pathway exposure targets determined in § 1065.1139(h). A combination of engine modifications and careful operating mode selection will be used to reach the final bulk pathway oil exposure target on a cycle average. You must modify the engine in a fashion that

will increase oil consumption in a manner such that the oil consumption is still generally representative of oil passing the piston rings into the cylinder. Use good engineering judgment to break in the modified engine to stabilize oil consumption rates. We recommend the following methods of modification (in order of preference):

(1) Install the ~~top-second~~ compression rings inverted (upside down) on ~~all-one or more of~~ the cylinders of the bench aging engine. This is most effective on rings that feature a sloped design to promote oil control when normally installed.

(2) If the approach in paragraph (b)(1) of this section is insufficient to reach the targets, modify the oil control rings in one or more cylinders to reduce the spring tension on the oil control ring. It should be noted that this is likely to be an iterative process until the correct modification has been determined.

(3) If the approach in paragraph (b)(1) of this section is insufficient to reach the targets, modify the oil control rings in one or more cylinders to create small notches or gaps (usually no more than 2 per cylinder) in the top portion of the oil control rings that contact the cylinder liner (care must be taken to avoid compromising the structural integrity of the ring itself).

(c) We recommend that the engine-aging stand include a constant volume oil system with a sufficiently large oil reservoir to avoid oil “top-offs” between oil change intervals.

(d) If the engine-aging stand will be used for aging of systems that perform infrequent regenerations, the aging stand must incorporate a means of increasing temperature representative of the target application. For example, if the target application increases temperature for regeneration by introducing fuel into the exhaust upstream of an oxidation catalyst, the aging stand must incorporate a similar method of introducing fuel into the exhaust.

(e) If the engine-aging stand will be used for aging systems that incorporate SCR-based NO_x reduction, the aging stand must incorporate a representative means of introducing DEF at the appropriate location(s).

(f) Use good engineering judgment to incorporate a means of monitoring oil consumption on ~~at least~~ a periodic basis. You may use a periodic drain and weigh approach to quantify oil consumption. We recommend that you incorporate a method of continuous oil consumption monitoring, but you must validate that method with periodic draining and weighing of the engine oil. You must validate that the aging stand reaches oil consumption targets prior to the start of aging. You must verify oil consumption during aging prior to each emission testing point, and at each oil change interval. Validate or verify oil consumption over a running period of at least 72 hours to obtain a valid measurement. If you do not include the constant volume oil system recommended in paragraph (c) of this section, you must account for all oil additions.

(g) Use good engineering judgment to establish an oil change interval that allows you to maintain relatively stable oil consumption rates over the aging process. Note that this interval may be shorter than the normal recommended interval for the engine due to the modifications that have been made.

(h) If the engine-aging stand will be used for aging of systems that incorporate a diesel particulate filter (DPF), we recommend you perform secondary tracking of oil exposure by using clean (soot free) DPF weights to track ash loading and compare this mass of ash to the amount predicted using the measured oil consumption mass and the oil ash concentration. The mass of ash found by DPF weight should fall within (55 to 70) % of the of mass predicted from oil consumption measurements.

(i) Incorporate a means of introducing lubricating oil into the engine fuel to enable the volatile pathway of oil exposure. You must introduce sufficient oil to reach the volatile pathway oil

exposure targets determined in paragraph (h) of this section. You must measure the rate of volatile pathway oil introduction on a continuous basis.

(j) If you perform sulfur acceleration by increasing the sulfur level of the engine fuel, you must meet the target sulfur level within ± 5 ppmw. Verify the sulfur level of the fuel prior to starting aging, or whenever a new batch of aging fuel is acquired.

(k) If you use gaseous SO₂ for sulfur acceleration, you must incorporate a means to introduce the gaseous SO₂ upstream of the aftertreatment system. Use good engineering judgment to ensure that gaseous SO₂ is well mixed prior to entering the aftertreatment system. You must monitor the rate of gaseous SO₂ introduction on a continuous basis.

§ 1065.1143 Requirements for burner-based aging stands.

A burner-based aging platform is built using a fuel-fired burner as the primary heat generation mechanism. The burner must utilize diesel fuel and it must produce a lean exhaust gas mixture. You must configure the burner system to be capable of controlling temperature, exhaust flow rate, NO_x, oxygen, and water to produce a representative exhaust mixture that meets the accelerated aging cycle targets for the aftertreatment system to be aged. You may bypass some of the bench aging exhaust around the aftertreatment system being aged to reach targets, but you must account for this in all calculations and monitoring to ensure that the correct amount of oil and sulfur are reaching the aftertreatment system. The burner system must incorporate the following capabilities:

(a) Directly measure the exhaust flow through the aftertreatment system being aged.

(b) Ensure transient response of the system is sufficient to meet the cycle transition time targets for all parameters.

(c) Incorporate a means of oxygen and water control such that the burner system is able to generate oxygen and water levels representative of compression-ignition engine exhaust.

(d) Incorporate a means of oil introduction for the bulk pathway. You must implement a method that introduces lubricating oil in a region of the burner that does not result in complete combustion of the oil, but at the same time is hot enough to oxidize oil and oil additives in a manner similar to what occurs when oil enters the cylinder of an engine past the piston rings. Care must be taken to ensure the oil is properly atomized and mixed into the post-combustion burner gases before they have cooled to normal exhaust temperatures, to insure proper digestion and oxidation of the oil constituents. You must measure the bulk pathway oil injection rate on a continuous basis. You must validate that this method produces representative oil products using the secondary method in § 1065.1141(h) regardless of whether you will use the burner-based aging stand to age systems which include a DPF. Use good engineering judgment to select a DPF for the initial validation of the system. Perform this validation when the burner-based aging stand is first commissioned or if any system modifications are made that affect the oil consumption introduction method. We also recommend that you examine ash distribution on the validation DPF in comparison to a representative engine aged DPF.

(e) Incorporate a means of introducing lubricating oil into the burner fuel to enable the volatile pathway of oil exposure. You must introduce sufficient oil to reach the volatile pathway oil exposure targets determined in § 1065.1139(h). You must measure the rate of volatile pathway oil introduction on a continuous basis.

(f) If the burner-based aging stand will be used for aging of systems that perform infrequent regenerations, the aging stand must incorporate a means of increasing temperature representative of the target application. For example, if the target application increases temperature for

regeneration by introducing fuel into the exhaust upstream of an oxidation catalyst, the aging stand must incorporate a similar method of introducing fuel into the exhaust.

(g) If the burner-based aging stand will be used for aging of systems that incorporate SCR-based NO_x reduction, the aging stand must incorporate a representative means of introducing DEF at the appropriate location(s).

(h) If the burner-based aging stand will be used for aging of systems that incorporate a diesel particulate filter (DPF), we recommend you perform secondary tracking of oil exposure by using clean (soot free) DPF weights to track ash loading and compare this mass of ash to the amount predicted using the measured oil consumption mass and the oil ash concentration. The mass of ash found by DPF weight should fall within (55 to 70) % of the of mass predicted from oil consumption measurements.

(i) You must incorporate a means to introduce the gaseous SO₂ upstream of the aftertreatment system. Use good engineering judgment to ensure that gaseous SO₂ is well mixed prior to entering the aftertreatment system. You must monitor the rate of gaseous SO₂ introduction on a continuous basis.

§ 1065.1145 Execution of accelerated aging, cycle tracking, and cycle validation criteria.

The aging cycle generally consists first of practice runs to validate and tune the final cycle, followed by the actual running of the repeat cycles needed to accumulate field equivalent hours to reach full useful life. During the course of the aging run, various aging parameters are tracked to allow verification of proper cycle execution, as well as to allow for correction of the aging parameters to stay within the target limits.

(a) *Preliminary cycle validation runs.* Prior to the start of aging, conduct a number of practice runs to tune the cycle parameters. It is recommended that initial practice runs be conducted without the aftertreatment installed, but with the backpressure of the aftertreatment simulated to help ensure that the tuned cycle is representative. For final cycle tuning, including regenerations, it is recommended to use a duplicate or spare aftertreatment system of similar design to the target system, to avoid damage or excessive initial aging during the tuning. However, it is permissible to conduct final tuning using the target system being aged, but you must limit the total duration to no more than 100 field equivalent hours (10 hours of accelerated aging), including both thermal and chemical components. The process followed for these initial runs will vary depending on whether you are using an engine-based platform or a burner-based platform.

(1) *Engine-based platform.* (i) *Initial cycle development.* It will be necessary to determine a set of engine modes that will generate the required combinations of temperature, exhaust flow, oil consumption, and NO_x to meet the target aging requirements. The development of these modes will be an iterative process using the engine and independent temperature control features of the aging stand. This process assumes that you have already implemented the oil consumption increase modifications, and that these have already been stabilized and validated to reach the necessary levels of bulk oil exposure. In general, we recommend the use of higher engine speeds and loads to generate the desired oil consumption, leveraging the temperature controls as needed to lower temperature to the targets. Several iterations will likely be needed to reach all targets. Note that during transitions you may utilize any combination of conditions necessary to help primary component catalysts reach the target temperature and flow conditions within no more than 5 minutes. For example, you may use a higher exhaust flow rate and lower temperature to rapidly cool the aftertreatment system to the next temperature. NO_x targets do not need to be met during transitions. It is permissible to deviate from engine-out NO_x

emission targets if needed to reach the temperature, exhaust flow, and oil consumption targets. We recommend that you maintain a NO_x level that is at the target level or higher, but you may lower NO_x by up to 25 %, if necessary, on some modes. Note that validation of oil consumption requires at least 72 hours of operation. Tune the parameters for infrequent regeneration towards then end of this initial development process (such as hydrocarbon injection schedules and temperature ramp rates).

(ii) *Final cycle validation.* Once the cycle is tuned, conduct a final run using the target aftertreatment system to verify conditions and log temperatures for heat load calculation. Using the recorded cycle data, calculate D_t for all primary component catalysts to ensure that you are matching the desired $D_{t,\text{cycle}}$ targets. If you are not within ± 3 % of the target $D_{t,\text{cycle}}$, adjust the cycle accordingly. Calculate D_t for any secondary catalyst components to verify that they are within ± 3 % of either the target D_t or the target aging metric. Note that the accelerated aging methodology assumes that the relationship between the temperature of the primary and secondary catalyst components will be the same as the field observations. If this relationship deviates in the lab by having more or less heat transfer through the system, it may be necessary to modify that relationship on the aging stand. You may need to take measures such as adding or removing insulation or utilize external cooling fans to help these parameters match more closely.

(2) *Burner-based platform.* (i) *Cycle development.* The burner-based platform will be able to meet the exhaust flow, temperature, NO_x , and oil consumption targets directly without the need for additional cycle development. This process assumes that you have already implemented and validated your oil consumption exposure methods to reach the necessary levels of bulk oil exposure. In addition, you must meet the oxygen and water targets during aging modes within ± 2 % for oxygen and ± 2 % for water. Note that during transitions you may utilize any combination of conditions necessary to help primary component catalysts reach the target temperature and flow conditions within no more than 5 minutes. For example, you may use a higher exhaust flow rate and lower temperature to rapidly cool the aftertreatment system to the next temperature. NO_x , oxygen, and water targets do not need to be met during transitions.

(ii) *Final cycle validation.* Once the cycle is tuned, conduct a final run using the target aftertreatment system to verify conditions and log temperatures for heat load calculation. Using the recorded cycle data, calculate D_t for all primary components catalysts to ensure that you are matching the desired $D_{t,\text{cycle}}$ targets. If you are not within ± 3 % of the target $D_{t,\text{cycle}}$, adjust the cycle accordingly. Calculate D_t for any secondary catalyst components to check that they are within ± 3 % of either the target D_t or the target aging metric. Note that the accelerated aging methodology assumes that the relationship between the temperature of the primary and secondary catalyst components will be the same as that observed in the field. If this relationship deviates in the lab by having more or less heat transfer through the system, it may be necessary to modify that relationship on the aging stand. You may need to take measures such as adding or removing insulation or utilize external cooling fans to help these parameters match more closely.

(b) *Aftertreatment break in.* Break in the emission-data engine and aftertreatment prior to the initial zero-hour test by running both on an engine dynamometer as described in subpart E of this part. Use good engineering judgment to develop a representative cycle that represents the field data. You may use the same data used for accelerated aging cycle development or other data. If your system utilizes infrequent regeneration, include at least one complete regeneration event, but we recommend that you include at least two such events to stabilize emissions performance. Your break in process must include at least 125 hours of engine operation with the aftertreatment

system. You may ask to use a longer break in duration based on good engineering judgment, to ensure that emission performance is stabilized prior to the zero-hour testing.

(c) *Initial emission testing.* Prior to the start of accelerated aging conduct the initial zero-hour emission test and any required engine dynamometer aging following the requirements of the standard setting part for your engine. Dynamometer aging hours count toward the total aging hours.

(d) *Accelerated aging.* Following zero-hour emission testing and any engine dynamometer aging, perform accelerated aging using the cycle validated in either paragraph (a)(1) or (2) of this section. Repeat the cycle the number of times required to reach full useful life equivalent aging. Interrupt the aging cycle as needed to conduct any scheduled intermediate emission tests, clean the DPF of accumulated ash, and for any facility-related reasons. We recommended you interrupt aging at the end of a given aging cycle, following the completion of any scheduled infrequent regeneration event. [If an aging cycle is paused for any reason, we recommended that you resume the aging cycle at the same point in the cycle where it stopped to ensure consistent thermal and chemical exposure of the aftertreatment system.](#)

(e) *QA tracking and validation.* During aging, track a number of aging parameters to ensure that fall within the required limits. Correct aging parameters as need to remain within the required control limits.

(1) *Thermal load tracking.* For each primary catalyst component, generate a target line which describes the relationship between aging hours on the cycle and cumulative deactivation, D_t . Generate control limit lines that are ± 3 % of the target line. You must remain within these control limits over the course of aging. Adjust aging parameters as needed to remain within these limits for the primary catalyst components. For each secondary catalyst component, generate both a target D_t line and a line describing the target behavior of the aging metric directly. You must remain within either ± 10 % of either the D_t line or ± 3 % of the aging metric target line for any secondary catalyst component. Adjust aging parameters as needed to remain within these limits noting that you must remain within limits for the primary components. Adjusting the secondary catalyst aging may require altering heat transfer through the system to make it more representative of the field aging.

(2) *Oil consumption tracking.* Generate a target oil consumption line for both the bulk and volatile pathway which describes the relationship between oil exposure and aging hours on the cycle. For the engine-based stand the control limits are ± 10 % for total oil consumption, noting that the volatile pathway must not exceed 30 % of the total. For the burner-based stand, the controls limits are ± 5 % for both pathways, which are tracked separately.

(i) *Changing engine oil.* For an engine-based platform, periodically change engine oil to maintain stable oil consumption rates and maintain the health of the aging engine.

Interrupt aging as needed to perform oil changes. Perform a drain-and-weigh measurement. [Following an oil change you must run at least 4 hours with the exhaust bypassing the aftertreatment system to stabilize the new oil.](#) If you see a sudden change in oil consumption it may be necessary to stop aging and either change oil or correct an issue with the accelerated oil consumption. If the aging engine requires repairs to correct an oil consumption issue in the middle of aging, you must re-validate the oil consumption rate for 72 hours before you continue aging. The engine exhaust should be left bypassing the aftertreatment system until the repaired engine has been validated.

(ii) *Secondary oil consumption validation.* If your aftertreatment includes a diesel particulate filter, we recommend that you perform secondary validation of oil consumption by using clean (soot free) DPF weights to track ash loading and compare this mass of ash to the amount predicted using the measured oil consumption mass and

the oil ash concentration. The mass of ash found by DPF weight should fall within a range of (55 to 70) % of the of mass predicted from oil consumption measurements. Perform this validation at the end of aging, at any intermediate emission test points, and at any point where you need to clean the DPF of accumulated ash in according with recommended maintenance.

(iii) *Sulfur tracking*. Generate a fuel sulfur exposure line describing the relationship between aging hours and cumulative target sulfur exposure mass. The control limits for sulfur exposure are ± 3 %. Log actual fuel consumption and the measured fuel sulfur level of the current batch of fuel (if you are doping fuel to accelerate sulfur exposure) for engine stand aging. Use these measurements to ensure that sulfur exposure remains within the control limits. Adjust sulfur doping levels in the fuel from batch to batch as needed to stay within limits. If you use gaseous SO₂ for sulfur acceleration, monitor the mass flow rate of the gaseous sulfur. Use these measurements to calculate total sulfur mass exposure, and correct SO₂ gas flow rates as needed to stay within the control limits.

(f) *Emission testing at intermediate and final test points*. Conduct emission testing at the end of aging and at any intermediate emission test points as described in the standard setting part. Following installation of the aged aftertreatment system on the emission-data engine at intermediate or final test points, prior to the start of emission testing, use good engineering judgment to operate the engine and aftertreatment system for a number of hours to stabilize emission controls and to allow any adaptive controls to update. Declare the number of stabilization hours prior to the start of the accelerated aging program.

PART 86—CONTROL OF EMISSIONS FROM NEW AND IN-USE HIGHWAY VEHICLES AND ENGINES

1. The authority citation for part 86 continues to read as follows:

Authority: 42 U.S.C. 7401-7671q.

2. Amend § 86.1819-14 by revising paragraph (d)(2)(i) and adding paragraph (d)(2)(iv) to read as follows:

§ 86.1819-14 Greenhouse gas emission standards for heavy-duty vehicles.

* * * * *

(d) * * *

(2) * * *

(i) Except as specified in paragraph (d)(2)(iv) of this section, credits you generate under this section may be used only to offset credit deficits under this section. You may bank credits for use in a future model year in which your average CO₂ level exceeds the standard. You may trade credits to another manufacturer according to § 86.1865-12(k)(8). Before you bank or trade credits, you must apply any available credits to offset a deficit if the deadline to offset that credit deficit has not yet passed.

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(iv) Credits generated under this section may be used to demonstrate to compliance with the CO₂ emission standards for vehicles certified under 40 CFR part 1037 as described in 40 CFR 1037.150(z).

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PART 1039— CONTROL OF EMISSIONS FROM NEW AND IN-USE NONROAD COMPRESSION-IGNITION ENGINES

115. The authority citation for part 1039 continues to read as follows:

Authority: 42 U.S.C. 7401-7671q.

116. Amend § 1039.705 by revising paragraph (b) to read as follows:

§ 1039.705 How do I generate and calculate emission credits?

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(b) For each participating family, calculate positive or negative emission credits relative to the otherwise applicable emission standard. Calculate positive emission credits for a family that has an FEL below the standard. Calculate negative emission credits for a family that has an FEL above the standard. Sum your positive and negative credits for the model year before rounding.

Round the sum of emission credits to the nearest kilogram (kg), using consistent units throughout the following equation:

$$\text{Emission credits (kg)} = (\text{Std} - \text{FEL}) \times (\text{Volume}) \times (\text{AvgPR}) \times (\text{UL}) \times (10^{-3})$$

Where:

Std = the emission standard, in grams per kilowatt-hour, that applies under subpart B of this part for engines not participating in the ABT program of this subpart (the “otherwise applicable standard”).

FEL = the family emission limit for the engine family, in grams per kilowatt-hour.

Volume = the number of engines eligible to participate in the averaging, banking, and trading program within the given engine family during the model year, as described in paragraph (c) of this section.

AvgPR = the average value of maximum engine power values for the engine configurations within an engine family, calculated on a sales-weighted basis, in kilowatts.

UL = the useful life for the given engine family, in hours.

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PART 1054— CONTROL OF EMISSIONS FROM NEW, SMALL NONROAD SPARK-IGNITION ENGINES AND EQUIPMENT

117. The authority citation for part 1054 continues to read as follows:

Authority: 42 U.S.C. 7401-7671q.

118. Amend § 1054.501 by revising paragraph (b)(7) to read as follows:

§ 1054.501 How do I run a valid emission test?

* * * * *

(b) * * *

(7) Determine your test fuel's ~~the~~ carbon mass fraction ~~of fuel~~, w_c , using a calculation based on ~~measured~~ fuel properties as described in 40 CFR 1065.655(d)(1); however, you must measure fuel properties for α and β rather than using the default values specified in ~~You may not use the default values specified in~~ 40 CFR 1065.655(e)(d)(2).

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