# Amendments and Nonconformance Penalties for Model Year 2027 and Later Heavy-Duty Highway Engines and Amendments to Inducement Provisions for SCR-Equipped Diesel Engines: Draft Technical Support Document Nonconformance Penalty Analysis

United States
Environmental Protection
Agency

# Amendments and Nonconformance Penalties for Model Year 2027 and Later Heavy-Duty Highway Engines and Amendments to Inducement Provisions for SCR-Equipped Diesel Engines: Draft Technical Support Document.

## Nonconformance Penalty Analysis

Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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# List of Acronyms

| | |
|---|---|
| CDA | Cylinder Deactivation |
| CI | Compression Ignition |
| CO | Carbon Monoxide |
| $COC_{50}$ | 50th Percentile Cost of Compliance |
| $COC_{90}$ | 90th Percentile Cost of Compliance |
| DEF | Diesel Exhaust Fluid |
| DOC | Diesel Oxidation Catalyst |
| DPF | Diesel Particulate Filter |
| DRIA | Draft Regulatory Impact Analysis |
| EAS | Exhaust Aftertreatment System |
| EGR | Exhaust Gas Recirculation |
| E-heater | Electric Exhaust Heater |
| EPA | Environmental Protection Agency |
| $F_{E\&D}$ | Engineering & Development Factor |
| FTP | Federal Test Procedure |
| GVWR | Gross Vehicle Weight Rating |
| HC | Hydrocarbon |
| HDE | Heavy-Duty Engine |
| HDGE | Heavy-Duty Gasoline Engine |
| HDV | Heavy-Duty Vehicle |
| ICCT | International Council on Clean Transportation |
| LDDT2 | Diesel Fueled Light-Duty trucks with loaded vehicle weight more than 3,750 pounds |
| LDT3 | Light-Duty Truck 3 |
| LHDGE | Light Heavy-Duty Gasoline Engine |
| LLC | Low-Load Cycle |
| MAW | Moving-Average Window |
| $MC_{50}$ | $50^{th}$ Percentile Marginal Cost of Compliance |
| $MC_{90}$ | $90^{th}$ Percentile Marginal Cost of Compliance |
| MY | Model Year |
| NCP | Nonconformance Penalty |
| $NO_X$ | Oxides of Nitrogen |
| PCA | Production Compliance Audit |
| PGM | Platinum Group Metals |
| PM | Particulate Matter |
| RIA | Regulatory Impact Analysis |
| RPE | Retail Price Equivalent |
| SCR | Selective Catalytic Reduction |
| SET | Supplemental Emission Test |
| SI | Spark Ignition |
| TSD | Technical Support Document |

# Chapter 1 Introduction

This Draft Technical Support Document presents analyses and supporting data for the provisions the EPA is using in its proposed nonconformance penalties (NCPs) for model year (MY) 2027 and later certain on-highway heavy-duty diesel engines.

## 1.1 Background on Nonconformance Penalties

Section 206(g) of the Clean Air Act (CAA and the Act), 42 U.S.C. 7525(g), allows the EPA to promulgate regulations permitting manufacturers of heavy-duty engines (HDEs) or heavy-duty vehicles (HDVs) to receive a certificate of conformity for HDEs or HDVs that exceed the applicable emissions standard, provided the manufacturer pays an NCP and that the HDE or HDV emissions do not exceed an appropriate upper limit. Congress adopted CAA section 206(g) in the Clean Air Act Amendments of 1977 as a response to perceived potential for problems with technology-forcing heavy-duty emissions standards. If strict technology-forcing standards were promulgated, then some manufacturers, "technological laggards," might be unable to comply initially and would be forced out of the marketplace. NCPs were intended to remedy this potential problem – any manufacture would have a temporary alternative that would permit them to sell their engines or vehicles by payment of a penalty. At the same time, conforming manufacturers would not suffer an economic disadvantage compared to nonconforming manufacturers, because the NCP would be based, in part, on money saved by the technological laggard. The resulting provisions of the Act require that NCPs account for the degree of emission nonconformity; increase periodically to provide incentive for nonconforming manufacturers to achieve the emission standards; and, most importantly, remove any competitive disadvantage to conforming manufacturers.

CAA section 206(g)(1), which authorizes NCPs, states that they may be offered for heavy-duty engines and vehicles. The Act also states the penalty may vary by pollutant and by class or category of vehicle or engine. HDVs are defined by CAA section 202(b)(3)(C) as vehicles in excess of 6,000 pounds gross vehicle weight rating (GVWR).

CAA section 206(g) authorizes the EPA to require testing of production vehicles or engines to determine the emission level on which the penalty is based. If the emission level of a vehicle or engine exceeds the upper limit of nonconformity (established by the EPA through regulation), the vehicle or engine would not qualify for an NCP under CAA section 206(g) and no certificate of conformity could be issued to the manufacturer. If the emission level is below the upper limit but above the standard, that emission level becomes the "compliance level," which is also the benchmark for warranty and recall liability; the manufacturer who elects to pay the NCP is liable for vehicles or engines in that engine family that exceed the compliance level in-use. The manufacturer does not have in-use warranty or recall liability for emissions levels above the standard but below the compliance level.

Once a regulation promulgated by the Administrator after notice and opportunity for public hearing specifies NCP provisions for a class of engines, any manufacturer may certify engines from that class using NCPs. Manufacturers using NCPs would go through the certification process, submitting data showing that the engine complies with emission standards, except that emissions may be up to the upper limit. Certification would generally be contingent on performing tests in a production compliance audit (PCA) to establish a compliance level, which is used to calculate the penalty for certifying engines with emissions above the applicable standard.

The existing regulatory requirements in 40 CFR 86, subpart L, include five key parameters that are applied in a specific NCP formula to define the per engine penalty amount for a given engine family based upon its compliance level. First, the upper limit (UL) is the emission level above which no engine may be certified. Second, the average cost of compliance ($COC_{50}$) is an estimate of the industry-wide average incremental cost per engine associated with meeting the standard for which an NCP is offered, compared with meeting the upper limit. Third, the 90$^{th}$ percentile cost of compliance ($COC_{90}$) is an estimate of the 90th percentile incremental cost per engine associated with meeting the standard for which an NCP is offered, compared with meeting the associated upper limit. Conceptually, $COC_{50}$ represents costs for a typical or average manufacturer, while $COC_{90}$ represents costs for the manufacturers with the highest compliance costs.[1]

Fourth, $MC_{50}$ is an estimate of the industry-wide average marginal cost of compliance per unit of reduced pollutant associated with the least cost-effective emission control technology installed to meet the new standard. In this proposal, $MC_{50}$ is measured in dollars per mg/hp-hr for heavy-duty engines. Fifth, F is a factor used to derive $MC_{90}$, the 90th percentile marginal cost of compliance based on the average marginal cost (the minimum value of F is 1.1, the maximum value of F is 1.3). $MC_{90}$ defines the slope of the penalty rate curve near the standard and is equal to $MC_{50}$ multiplied by F. Figure 1-1 is an illustrative figure of an NCP penalty curve for oxides of nitrogen ($NO_X$) for MY 2027.

[1] As was done in previous NCP rules, costs include additional manufacturer costs and additional owner costs, but do not consider certification costs because both complying and noncomplying manufacturers must incur certification costs.

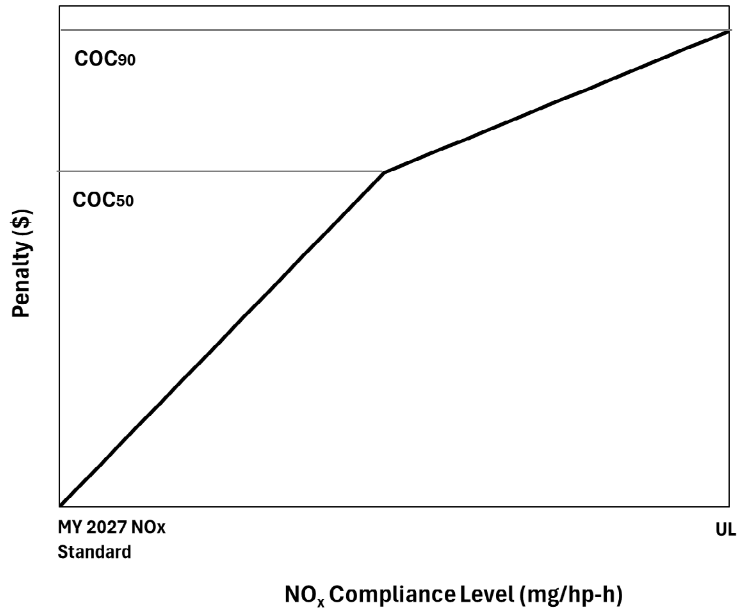


*Figure 1-1 Generic Nonconformance Penalty Versus Compliance Level*

## 1.2 Previous NCP Rulemakings and Regulations

The first NCP rule ("Phase I") was promulgated August 30, 1985 (50 FR 35374). It established regulations for calculating NCPs in 40 CFR Part 86, Subpart L. It also established three basic criteria for determining the eligibility of emission standards for nonconformance penalties in any given model year. First, the emission standard in question is a new emission standard or, if the standard is an existing standard, and becomes more difficult to meet. This can occur in two ways, either by the emission standard itself becoming more stringent, or due to its interaction with another emission standard that has become more stringent.

Second, the EPA must find that substantial work is required to meet the emission standard. The EPA considers "substantial work" to mean the application of technology not previously used in that vehicle or engine class/subclass, or a significant modification of existing technology to bring that vehicle/engine into compliance. The EPA does not consider minor modifications or calibration changes to be classified as substantial work. The EPA considers that substantial work is required if such work is needed to bring emissions from the level of the previous standard to the level of the new or revised standard, even if at the time the NCP rulemaking is taking place, some manufacturers have already completed such work.

Third, the EPA must find that a manufacturer is likely to be noncomplying for technological reasons. Prior NCP rules have considered a technological laggard to be a manufacturer who cannot meet a particular emission standard due to technological (not economic) difficulties and who, in the absence of NCPs, might be forced from the marketplace.

The EPA used the above criteria to determine eligibility for NCPs during Phase II of the NCP rulemaking process (50 FR 53454, December 31, 1985). NCPs were offered for the following

MY 1987 and 1988 standards: the particulate matter (PM) standard for 1987 diesel-fueled light-duty trucks with loaded vehicle weight in excess of 3,750 pounds (LDDT2s), the 1987 gasoline-fueled light HDE (LHDGE) HC and CO emission standards, the 1988 diesel-fueled HDE (HDE) PM standard, and the 1988 HDE $NO_X$ standard. As discussed in the Phase II rule, NCPs were considered, but not offered, for the 1987 HLDT $NO_X$ standard and the 1988 (later, the 1990) gasoline-fueled HDE (HDGE) $NO_X$ standard.

The availability of NCPs for MY 1991 HDE standards was addressed during Phase III of the NCP rulemaking (55 FR 46622, November 5, 1990). NCPs were offered for the following: the 1991 diesel-fueled HDE PM standard for petroleum-fueled urban buses, the 1991 HDE PM standard for petroleum-fueled vehicles other than urban buses, the 1991 petroleum-fueled HDE $NO_X$ standard, and the PM emission standard for MY 1991 and later petroleum-fueled light-duty diesel trucks greater than 3,750 lbs loaded vehicle weight (LDDT2s). As discussed in the Phase III rule, NCPs were also considered, but not offered for the methanol-fueled heavy-duty diesel engine and heavy-duty gasoline engine standards as it was concluded that those standards did not meet the eligibility criteria established in the generic rule. In addition, Phase III of the NCP rulemaking described how NCPs would be integrated into the HDE $NO_X$ and PM averaging program.

The availability of NCPs for HDVs and HDEs subject to the MY 1994 and later emission standards for particulate matter (PM) was addressed by the Phase IV NCP rulemaking (58 FR 68532, December 28, 1993). NCPs were offered for the following: the MY 1994 and later PM standard for diesel-fueled HDE used in urban buses and the MY 1994 and later PM standard for HDEs used in vehicles other than urban buses. NCPs were also considered, but not offered, for the MY 1994 and later methanol-fueled HDE PM standard and the MY 1994 and later cold carbon monoxide (CO) standard for heavy light-duty gasoline fueled trucks.

The availability of NCPs for HDVs and HDEs subject to the MY 1998 and later emission standards for $NO_X$ was addressed by the Phase V NCP rulemaking (61 FR 6949, February 23, 1996). NCPs were offered for the following: the MY 1998 and later $NO_X$ standard for diesel-fueled HDEs, the MY 1996 and later for Light-Duty Truck 3 (LDT3) $NO_X$ standard, and the 1996 and later urban bus PM standard. A concurrent but separate Final Rule (61 FR 6944, February 23, 1996) established NCPs for the 1996 LDT3 PM standard and discussed other standards for which NCPs were considered.

The availability of NCPs for 2004 HDE standards was addressed during the Phase VI NCP rulemaking (67 FR 51464, August 8, 2002). NCPs were offered only for the $NO_X$+NMHC standards. One notable aspect of that rule was that the upper limit for heavy heavy-duty diesel engines was set at a level above the previous standard. This was done because a legal settlement of compliance violations (*i.e.*, a consent decree) allowed certain manufacturers to exceed the otherwise applicable 4.0 g/hp-hr $NO_X$ standard for a brief period. The NCP emissions upper limit for these engines was set at 6.0 g/hp-hr to allow manufacturers to continue producing engines allowed by the consent decree.

The availability of NCPs for MY 2010 HDE standards was addressed during Phase VII of the NCP rulemaking (77 FR 54384, September 5, 2012). NCPs were offered only for the $NO_X$ standards for Heavy HDE. One notable aspect of that rule was that the upper limit for Heavy HDE was set at a level below the previous standard. This was done because all HDE manufacturers were certifying engines at the family emissions limit (FEL) cap. The upper limit for these engines was set at 0.5 g/hp-hr to allow one manufacturer to continue to produce engines without the use of $NO_X$ credits.

## 1.3 Promulgation of Revised MY 2027 Emission Standards

In the HD 2023 rule, the EPA finalized a program to further reduce air pollution, including pollutants that create ozone and particulate matter, from heavy-duty engines and vehicles across the United States. The final program includes new, more stringent emissions standards that cover a wider range of heavy-duty engine operating conditions compared to today's standards, and it requires these more stringent emissions standards to be met over a longer period of time.

The standards apply to new heavy-duty compression-ignition (CI) and spark-ignition (SI) engines starting with MY 2027. The program is a single-step implementation reflecting the greatest achievable reductions in the MY 2027 timeframe.

The MY 2027 $NO_X$ standards are:

FTP (“Federal test procedure”, a transient, mid/high load test cycle): 35 mg/hp-hr;

SET (“supplemental emission test”, a steady-state, high load test cycle): 35 mg/hp-hr;

LLC (“low load cycle”, a transient, low-load test cycle; CI engines only): 50 mg/hp-hr.

An in-use compliance allowance for $NO_X$ of 15 mg/hp-hr applies to Medium and Heavy HDE for in-use testing (making FTP/SET/LLC 50/50/65 mg/hp-hr, respectively) but does not change the certification standards.

The rule replaced the prior not-to-exceed in-use off-cycle testing and standards approach with a moving-average-window (MAW) framework that evaluates emissions over a broader range of real-world conditions, including low-load and idle, and introduces two “bins” based on average engine power.

The 2023 rule lengthened regulatory useful life periods across heavy-duty classes to increase the amount of operating life the engines are meeting the standards; for the largest heavy-duty engines, useful life mileage increases by about 50% over the MY 2026 and earlier values.

## 1.4 Characterization of the Heavy-Duty Engine and Vehicle Industries

Heavy-duty engines are used in a wide variety of vehicle applications. Smaller engines are used in heavy-duty pickup trucks, vans and other vehicles using those same chassis. At the other extreme, the largest engines are used in cement mixers, garbage trucks, and line-haul tractors. In matching the engines to the vehicles, the minimum requirement is that the engine would be large enough to power a fully-loaded truck up a hill. More typically, especially for the larger trucks, the engine is selected to provide the best fuel consumption. In other cases, especially for light heavy-duty, larger engines are used to provide additional performance.

In applying heavy-duty emission standards, the EPA categorizes heavy-duty vehicles into three service classes: light heavy-duty; medium heavy-duty; and heavy heavy-duty. Light heavy-duty includes heavy-duty pickup trucks and vans. Medium heavy-duty includes delivery trucks and recreational vehicles. Heavy heavy-duty includes buses and line-haul tractors. Table 1-1 lists the gross vehicle weight rating of the vehicles by service class. Engines are classified by the primary vehicle service class for which the engine is intended.

See Chapter 1 of the Draft Regulatory Impact Analysis for this proposed rule for more information on the heavy-duty engine industry.

*Table 1-1 Gross Vehicle Weight Rating of Light, Medium, and Heavy Heavy-Duty Engines and Vehicles*

| **Service Class** | **DOT Weight Classes** | **GVWR (lbs.)** |
|---|---|---|
| Light Heavy | 2b-5 | 8,501 - 19,500 |
| Medium Heavy | 6-7 | 19,501 - 33,000 |
| Heavy Heavy | 8 | 33,001 + |

# Chapter 2 Technologies to Meet the MY 2027 and later Standards

In the 2023 rule the EPA demonstrated the finalized compression-ignition standards could be met through the finalized longer useful life with a combination of technologies – including cylinder deactivation (CDA) or other valvetrain-related air control strategies in combination with dual SCR systems, heated DEF dosing and closed crankcase. The upstream SCR catalyst with heated DEF dosing and CDA provide emissions control under cold start and low-load operation, and the additional SCR catalyst volume improve catalyst washcoat provided additional $NO_X$ control under sustained high load and help to ensure that the emissions control could be achieved through the longer useful life.

Leading up to MY 2027 manufacturers have started to announce the technology packages they will be including on their engines. Some manufacturers have included a similar technology package that EPA used for the feasibility demonstration, while others have developed systems that will use electric exhaust heaters (e-heaters) for increasing exhaust temperature under cold start and low-load operation. Table 2-1 includes a summary of manufacturers' public announcements of their MY 2024 or MY 2027 engines that will have $NO_X$ emissions of 50 mg/hp-hr or lower.

*Table 2-1 Summary of Emissions Control Technology Diesel Engine Manufacturers are Using to Achieve $NO_X$ Emissions of 50 mg/hp-hr or Lower.*

| Manufacturer | Technology | Engine Class | Public Source |
|---|---|---|---|
| Cummins Inc | Single-SCR, e-heater | Medium and Heavy HDE | https://mart.cummins.com/imagelibrary/data/assetfiles/0080207.pdf https://www.cummins.com/engines/on-highway/heavy-duty-truck/2027-x15 |
| Detroit Diesel | Dual-SCR, CDA | Heavy HDE | https://northamerica.daimlertruck.com/news-stories/2026/detroit-introduces-its-2027-heavy-duty-gen-6-engines |
| International | Dual-SCR | Heavy HDE | https://news.international.com/2026-01-07-International-Confirms-EPA-2027-Readiness-with-Proven-S13-Integrated-Powertrain |
| PACCAR | Single-SCR, e-heater | Heavy HDE | https://www.ttnews.com/articles/peterbilt-carb-mx-13-engine |
| Volvo | Dual-SCR, e-heater | Heavy HDE | https://www.volvotrucks.us/news-and-stories/press-releases/2024/july/volvo-trucks-north-america-announces-availability-of-carb-2024-omnibus-compliant-heavy-duty-engine/ |

# Chapter 3 Methodology for Determining Proposed MY 2027 NCPs

This chapter describes our analysis of the costs of compliance. The analysis is based on our projections of engine and vehicle manufacturers' costs and operating costs for vehicle owners.

## 3.1 General Methodology

The costs of compliance for MY 2027 are the primary inputs for determining NCPs. In each of our seven previous NCP rulemakings, the EPA estimated costs using a methodology appropriate for the specific circumstances that applied at the time. In each case the EPA considered key factors such as potential differences in engine calibration, technology hardware, and operating costs, but there have been some NCP calculations where other potential individual cost or cost saving elements have been included or excluded for various specific reasons.

To determine the parameters of the NCP in this proposed rule; $COC_{50}$, $COC_{90}$, $MC_{50}$, and F, the EPA proposes the best approach is to rely on the cost estimates the Agency made in the 2023 rule to meet the MY 2027 $NO_X$ standards. This approach is a reasonable basis for developing NCPs as it relies on peer reviewed cost data that has gone through notice and comment. As was done in other NCP rules the EPA also includes indirect manufacturing costs and operating costs in the proposed NCPs based on the methodologies used in the 2023 Final Rule.

The EPA recognizes there are other technology packages that some firms likely will use to achieve the MY 2027 $NO_X$ standards. Other technology packages may have a different incremental cost impact which could affect the estimated NCPs. One technology path that EPA is aware of is an e-heater system. For this proposal, in addition to the primary methodology for developing the proposed NCPs, the EPA has also developed an estimate of NCPs based on the use of e-heater systems to meet the MY 2027 $NO_X$ standards. The EPA is not basing the proposed NCP parameters on a technology package with an e-heater, as the Agency only has one publicly citable source for a cost estimate for the e-heater systems, which has not gone through a public comment process and it is unclear if that source has been peer reviewed.

## 3.2 Direct Manufacturing Costs

The approach used for the 2023 Final Rule for determining direct manufacturing costs relied on a technology teardown cost study conducted by FEV to estimate the costs for the exhaust aftertreatment system (EAS) components. The EPA also sponsored a study to examine in detail an advanced heavy-duty diesel EAS technology package utilizing a dual-SCR system with heated dosing for the light-off SCR and capable of approximately 90% $NO_X$ reduction relative to post-2010 heavy-duty diesel emission control systems, the Heavy-Duty Vehicles Aftertreatment Systems Cost Assessment (FEV EAS Study)[2]. As with the valvetrain study, this was also

[2] McDonald, J. (2022) Heavy-Duty Vehicle Exhaust Aftertreatment Systems Costs, Calculations, and Updates. *See* attachment Mamidanna, S. 2021. Heavy-Duty Vehicles Aftertreatment Systems Cost Assessment.

conducted by FEV North America, Inc.[2,3] See chapter 3 of the RIA to the 2023 final rule for more information. For this proposal the Platinum Group Metals (PGM) costs shown in Table 3-1 were based on a 2-year average of global prices on the New York Exchange ending December 31, 2025.

*Table 3-1 Two-Year Average of PGM Costs*

| Rule | Platinum ($/troy-oz) | Palladium ($/troy-oz) |
|---|---|---|
| 2023 Final Rule (through 8/31/2022) | $1,030 | $2,331 |
| NCP (through 12/31/2025) | $1,126 | $1,077 |

The cost of CDA for each engine class was estimated based upon a technology tear-down study of heavy-duty diesel valvetrains, the Heavy-Duty Engine Valvetrain Technology Cost Assessment (or "FEV Valvetrain Study").[4] The study was conducted by FEV North America, Inc. under a contract with EPA which underwent an independent peer review.[5] The FEV Valvetrain Study investigated design modifications to a production engine cylinder head from the Cummins X15 engine. These design modifications allowed the addition of individual CDA with an integrated exhaust brake. The objective of the FEV Valvetrain Study was to estimate the incremental cost of CDA hardware.

The cost of the CDA technology package was evaluated relative to a baseline valvetrain technology represented by a MY 2019 Cummins X15 engine. FEV also investigated other valvetrain designs used by diesel HDE to develop fleet average per-cylinder costs for these valvetrain technologies. The baseline and new technology package were required to have similar overall performance with respect to service life and other functional objectives. Table 3-2 shows estimated direct manufacturing costs for application of CDA to diesel HDE based on costs derived from the FEV study.

*Table 3-2 Summary of CDA Direct Manufacturing Costs from Teardown Study*

| EPA HD Engine Class | Medium HDE | Heavy HDE |
|---|---|---|
| CDA Valvetrain Hardware - Tier 1 Supplier Cost to Manufacturer (2024 $): | $184 | $258 |

In the 2023 rule the EPA estimated the initial direct manufacturing cost for manufacturers of closed crankcase systems to be approximately $41 (2002$).[6] To estimate the baseline cost, the EPA multiplied $41 (2002$) by the percentage of engines that already have closed crankcase systems, which resulted in a baseline cost of $13 (2002$). The EPA estimated the percentage of engines that already have closed crankcase systems at 32.5%, based on the certification data. For

[3] McDonald, J. 2022. Heavy-Duty Vehicle Exhaust Aftertreatment Systems Costs, Calculations, and Updates.
[4] McDonald, J. (2022) Heavy-Duty Vehicle Exhaust Aftertreatment Systems Costs, Calculations, and Updates. *See* attachment Mamidanna, S. 2021. Heavy-Duty Engine Valvetrain Technology Cost Assessment. U.S. EPA Contract with FEV North America, Inc., Contract No. 68HERC19D0008, Task Order No. 68HERH20F0041.
[5] McDonald, J. (2022) Heavy-Duty Vehicle Exhaust Aftertreatment Systems Costs, Calculations, and Updates. *See* attachment Eastern Research Group, Inc. 2021. "External Peer Review of Heavy-Duty Engine Valvetrain Technology Cost Assessment". Contract No. 68HE0C18C0001, Work Assignment 2-05. Submitted to the Docket
[6] 69 FR 39126. June 29, 2004.

our cost analysis, the EPA converted these estimates to 2017 dollars, which resulted in $18 (2017$) for the baseline cost and the same cost of $37 (2017$) to implement closed crankcases in the remaining CI engines for the final standards. For input into the estimate of the proposed NCPs, the EPA used the incremental cost of $37 to account for the additional technology needed to comply with the MY 2027 $NO_X$ standards.

As discussed in the NCP proposal preamble section VI and chapter 4 and 5 of this draft TSD, the EPA used electric exhaust heater, 48-V generator, DC-DC converter, and cooling system (e-heater system), to estimate $MC_{50}$, for the proposed and alternate values for the NCPs. To estimate the cost of the e-heater system, the EPA utilized a study conducted by the International Council on Clean Transportation (ICCT) in 2021 to estimate the technology costs to meet the European HD Euro VII $NO_X$ standards.[7] A conversion 1.17 dollars per euro was used to convert the costs in the ICCT study. To determine costs for the 48-V system, ICCT relied on hardware needed for a mild hybrid system which would provide power to other accessories and auxiliaries, and attributed half the DC/DC convertor, starter, motor-generator, and liquid cooling system costs to the e-heater system. For these technologies the EPA also relied on cost reductions due to manufacturer learning projections in the ICCT study. For MY 2027 costs, ICCT estimated that manufacturer learning for the 48V system would result in a 12% reduction (0.88 multiplier) from MY 2021.

*Table 3-3 Cost of E-heater and Supporting Hardware*

| **Components** | **Cost (2021 Euros)** | **Cost (2021$)** | **Cost (2021$) with learning and 50% adjustment** |
|---|---|---|---|
| Resistive coil (heater) | €210 | $246 | $216 |
| DC/DC convertor | €2,100 | $2,457 | $1,081 |
| Starter | | | |
| Motor-generator | | | |
| Liquid cooling system | | | |

## 3.3 Indirect Manufacturing Costs

The indirect costs presented here are all the costs estimated to be incurred by manufacturers of new heavy-duty engines and vehicles associated with producing the unit of output that are not direct costs. Indirect costs include costs related to production (such as research and development (R&D)), corporate operations (such as salaries, pensions, and health care costs for corporate staff), or selling (such as transportation, dealer support, and marketing). Indirect costs are generally recovered by allocating a share of the costs to each unit of good sold. Although it is possible to account for direct costs allocated to each unit of goods sold, it is more challenging to account for indirect costs allocated to a unit of goods sold. To ensure that NCP analysis captures the changes in indirect costs, markup factors, which relate total indirect costs to total direct costs, have been developed and used by the EPA and other stakeholders. These markup factors are often referred to as retail price equivalent (RPE) multipliers. RPE multipliers provide, at an aggregate level, the relative shares of revenues, where:

[7] Ragon, P., Rodriquez, F., 2021. Estimated cost of diesel emissions control technology to meet future Euro VII standards, https://theicct.org/wp-content/uploads/2021/06/tech-cost-euro-vii-210428.pdf

Revenue = Direct Costs + Indirect Costs

so that:

Revenue/Direct Costs = 1 + Indirect Costs/Direct Costs = RPE

and,

Indirect Costs = Direct Costs x (RPE - 1).

For this proposed rule we relied on the RPE for the HD truck industry show in Table 3-4, which are the same RPE factors used in the 2023 Final Rule.[8] The markup factors are based on financial filings with the Securities and Exchange Commission for several engine and engine/truck manufacturers in the heavy-duty industry as detailed in a study done by RTI International for EPA.[9]

*Table 3-4 Retail Price Equivalent Factors in the Heavy-Duty Industry*

| **Cost Contributor** | **HD Truck Industry** |
|---|---|
| Direct manufacturing cost | 1.00 |
| Warranty | 0.03 |
| R&D | 0.05 |
| Other (admin, retirement, health, etc.) | 0.29 |
| Profit (cost of capital) | 0.05 |
| RPE | 1.42 |

## 3.4 Operating of Costs

The EPA estimates the only impact on operating costs expected to be incurred by users of new MY 2027 and later heavy-duty vehicles, compared MY 2026 engines, is increased diesel exhaust fluid (DEF) consumption by diesel vehicles due to increased DEF dose rates to enable compliance with more stringent $NO_X$ standards. To estimate the baseline case (MY 2026) DEF consumption in heavy-duty vehicles with diesel engines, this analysis uses the relationship of DEF dose rate relative to the reduction in $NO_X$ over the SCR catalyst shown below,[10,11]

$$NOx\ reduction = -73.679y + 0.0149$$

where *y* is equal to the DEF dose rate. This relationship was developed considering FTP emissions. By estimating the FTP $NO_X$ reduction across the SCR catalyst, the DEF dose rate can be calculated. $NO_X$ reduction is estimated from the difference between estimated engine-out and

[8] See chapter 7 of the regulatory impacts analysis to the 2023 Final Rule. Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards, Regulatory Impact Analysis. December 2022. EPA-420-R-22-035.

[9] Heavy Duty Truck Retail Price Equivalent and Indirect Cost Multipliers, Draft Report, RTI International, RTI Project Number 021 1577.003.002, July 2010.

[10] The relationship between DEF dose rate and $NO_x$ reduction across the SCR catalyst is based on methodology presented in the Technical Support Document to the 2012 Non-conformance Penalty rule (the NCP Technical Support Document, or NCP TSD).

[11] U.S. Environmental Protection Agency. "Nonconformance Penalties for On-highway Heavy-duty Diesel Engines: Technical Support Document," EPA-420-R-12-014, Figure 3-1 at page 37.

FTP tailpipe $NO_X$ emissions; these variables along with the calculated DEF dose rate for the baseline case are shown in Table 3-5.

*Table 3-5 Diesel Exhaust Fluid Consumption Rates for Diesel Vehicles in the Baseline Case*

| | **Value** |
|---|---|
| **Engine-out $NO_X$** (FTP g/hp-hr) | 4.0 |
| **Tailpipe $NO_X$** (FTP mg/hp-hr) | 200 |
| **DEF Dose Rate** (% of fuel consumed) | 5.18% |

The EPA developed a new approach in the 2023 Final Rule to estimate DEF consumption impacts for MY 2027 engines, which are subject to changes to not only the new FTP emission standards but also the new SET and LLC standards along with new off-cycle standards. For this analysis, the EPA scaled DEF consumption with $NO_X$ reductions. To do this, the EPA considered the molar mass of $NO_X$, the molar mass of urea, the molar ratio of NO to $NO_2$, the mass concentration of urea in DEF and the density of DEF to estimate the theoretical gallons of DEF consumed per ton of $NO_X$ reduced at 442 gallons/ton. The theoretical DEF dosing rates were then compared to the data collected by Southwest Research Institute from the CARB Stage 3 test program for the hot-start FTP, the SET and the LLC (see Chapter 3 of the RIA for the 2023 Final Rule). The data from this testing showed that the $NO_X$ specific DEF dosing was 536, 478, and 568 gallons/ton for the hot FTP, SET and LLC, respectively. Since this data incorporates over dosing that occurs for part of the cycle, and $NO_2$/NO ratio being greater than 1 for parts of the cycle, the EPA adjusted the theoretical 442 gallons/ton $NO_X$ to the average of the hot FTP, SET and LLC, which is 527 gallons/ton. These values are shown in Table 3-6.

*Table 3-6 Derivation of DEF Consumption per Ton of $NO_X$ Reduced*

| | **Value** |
|---|---|
| Molar mass of $NO_X$ (g/mol) | 46.0055 |
| Molar mass of urea (g/mol) | 60.07 |
| Molar ratio of NO to $NO_2$ | 1 |
| Mass concentration of urea in DEF | 0.325 |
| Density of DEF (g/mL) | 1.09 |
| Theoretical gallons DEF/ton $NO_X$ reduced | 442 |
| Proposed gallons DEF/ton $NO_X$ reduced | 527 |

The final calculation of DEF consumption for each engine class is determined by multiplying the gallons of diesel fuel consumed by 5.18%, to account for the baseline DEF consumption and add to that amount 527 gallons of DEF for each ton of $NO_X$ reduced from the baseline. Both the gallons of diesel fuel consumed and the tons of $NO_X$ reduced are taken directly from the year-over-year MOVES results from the 2023 final.

The gallons of DEF consumed are then multiplied by the estimated price of DEF per gallon. This analysis uses the DEF prices presented in this NCP Draft Technical Support Document with growth beyond 2042 projected at the same 1.3 percent rate as noted in the 2012 NCP TSD. Note that the DEF prices presented in Table 3-7 update the 2012 NCP TSD's 2011 prices to 2024 dollars.

*Table 3-7 Diesel Exhaust Fluid Price per Gallon (2024 dollars)*

| Calendar Year | DEF Price/Gallon |
|---|---|
| 2027 | 4.05 |
| 2028 | 4.11 |
| 2029 | 4.15 |
| 2030 | 4.20 |
| 2031 | 4.26 |
| 2032 | 4.31 |
| 2033 | 4.38 |
| 2034 | 4.44 |
| 2035 | 4.49 |
| 2036 | 4.54 |
| 2037 | 4.60 |
| 2038 | 4.67 |
| 2039 | 4.72 |
| 2040 | 4.79 |
| 2041 | 4.85 |
| 2042 | 4.91 |
| 2043 | 4.98 |
| 2044 | 5.04 |
| 2045 | 5.11 |

The total incremental lifetime DEF costs for Medium and Heavy HDE are shown in Table 3-7. The values were determined by vehicle population weighting each of the MOVES source types in Table 7-32 of the RIA of the 2023 Final Rule. The EPA used a 7% discount rate for the future costs, as was done in the 2012 NCP Phase VII rule.[12]

*Table 3-8 MY2027 Lifetime DEF Costs for Medium and Heavy HDE Associated with 2023 Final Rule $NO_X$ Standards, 2024 dollars, 7% Discount Rate*

| | Medium HDE | Heavy HDE |
|---|---|---|
| 2023 Final Rule Baseline | $4,474 | $16,559 |
| 2023 Final Rule Baseline + Final Program | $4,907 | $18,601 |
| Increased Cost of the 2023 Final Rule | $433 | $2,041 |

[12] U.S. Environmental Protection Agency. Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards Regulatory Impact Analysis. EPA-420-R-22-035. December 2022

# Chapter 4 EPA Analysis of Costs for Medium Heavy-Duty Engines

## 4.1 Basis of EPA Cost Estimates

For engines that do not meet the MY 2027 and later standards, the EPA selected a baseline engine technology package using the same core emission controls that are used on MY 2026 and earlier HDE to meet the MY 2026 $NO_X$ and PM limits; exhaust gas recirculation (EGR), optimized turbocharging, optimized fuel injection, a diesel oxidation catalyst (DOC), a diesel particulate filter (DPF), and a liquid-urea-based selective catalytic reduction (SCR) system with a single urea doser.

For estimates of the 50$^{th}$ and 90$^{th}$ percentile costs of compliance for NCPs in this proposal, the EPA assumes a technology package that includes an engine equipped with cylinder deactivation (CDA), dual-SCR aftertreatment configuration, closed crankcase, and heated diesel exhaust fluid (DEF) dosing systems, consistent with the technology package used in the EPA's feasibility demonstration and cost projections for the 2023 rule. The cost estimates used to develop the Medium HDE NCPs relied on the methods and data described in Chapter 3.

In addition to the primary methodology for developing the proposed NCPs, the EPA has also developed an alternate estimate of NCPs based on the use of an aftertreatment electric-heater (e-heater) system, which the EPA is requesting comment on. With this alternate technology package, the e-heater system replaces the CDA hardware and the close-coupled (CC) SCR catalysts, CC DEF doser, and CC mixer. The e-heater technology package also requires a power generation source (a 48-volt generator), along with supporting technology (a DC-DC converter and a cooling system).

## 4.2 Proposed NCP Compliance Costs: $COC_{50}$

As discussed in Chapter 4.1, for the 50$^{th}$ percentile cost of compliance for this proposal the EPA relied on the same DOC, DPF, and SCR catalyst volumes used in the 2023 Final Rule for the MY 2027 system, which sizes the aftertreatment based on sales-weighted average engine displacement. For Medium HDE, the sales-weighted average engine displacement is 7.54 L. For the proposed NCP the estimated CDA costs of $184 per engine shown in Table 3-2 of Chapter 3.2 was used.

*Table 4-1: 50th Percentile Incremental Direct Manufacturing Costs for Medium HDE Aftertreatment Technology (dual-SCR and single-SCR systems with an e-heater)*

| | | MY 2027 Dual-SCR aftertreatment | MY 2027 Single-SCR aftertreatment (part of e-heater system) |
|---|---|---|---|
| 01 | DOC | -$51 | -$51 |
| 02 | DPF | $16 | $16 |
| 03 | LO-SCR | $185 | not applicable |
| 4 | SCR | $288 | $288 |
| 05 | Mixer | $152 | $20 |
| 06 | Sensors & Wiring Harness | $416 | $33 |
| 07 | Dosing Subsystem | $374 | $2 |
| 08 | DEF Tank Subsystem | $72 | $72 |
| 09 | Structural Hardware & Assembly | $606 | $606 |
| Total Cost | | $2,058 | $985 |

For the alternate estimate of NCPs that relies on an emissions control system utilizing e-heaters, the EPA used the costs in Table 3-3 converted to 2024$. For this system the EPA assumed that two e-heaters would be used with the DC/DC converter, starter, motor-generator, and liquid cooling system. The total direct manufacturing costs of the e-heater system in 2024$ is $1,720.

For both the primary and alternate estimate of NCPs the assumption is that closed crankcase technology would be used with an incremental cost of $46 in 2024$.

To estimate the incremental lifetime DEF consumption, the EPA relied on the 2023 Final Rule's analysis that estimated lifetime DEF consumption for each MOVES vehicle source type and regulatory class. For this analysis the EPA created a single cost for each MOVES regulatory class (which corresponds with primary intended service class in 40 CFR 1036.140) by using a population-weighted average of each MOVES vehicle source type. Lifetime costs were determined using a 7% discount rate, which the EPA believes best matches how the heavy-duty industry considers future costs. The lifetime DEF costs for Medium HDE were estimated to be $433 in 2024$.

Table 4-2 includes the direct manufacturing costs, indirect manufacturing costs, and operating costs that were used to calculate the $COC_{50}$ for the proposed and the alternate NCPs. The EPA proposes the MHDE $COC_{50}$ be set at a value of $3,683. The EPA also requests comment on the alternate technology path (e-heater system) $COC_{50}$ value of $4,341.

*Table 4-2 Medium HDE $COC_{50}$ Costs for the Proposed and the Alternate NCPs*

| | Proposed | Alternate |
|---|---|---|
| Direct manufacturing costs | $2,289 | $2,752 |
| Warranty | $69 | $83 |
| R&D | $114 | $138 |
| Other (admin, retirement, health, etc.) | $664 | $798 |
| Profit (cost of capital) | $114 | $138 |
| DEF operating costs | $433 | $433 |
| **Total costs - $COC_{50}$** | **$3,683** | **$4,341** |

## 4.3 Proposed NCP Compliance Costs: $COC_{90}$

For the $90^{th}$ percentile cost of compliance the EPA used the same configuration as used for the $50^{th}$ percentile system, with the addition of an increase in the catalyst substrate volumes, PGM loading, canning size, and washcoat to account for the larger aftertreatment volume needed for the largest displacement Medium HDEs. These values were determined using the relationships built into the FEV analysis. For the $COC_{90}$ the EPA used an engine displacement of 10 L, which is the largest displacement Medium HDE EPA is aware of. For the proposed NCP the cost of CDA from Chapter 3.2, was used. Table 4-3 shows the estimated incremental DMC for the aftertreatment system for the $90^{th}$ percentile cost of compliance for both the dual-SCR aftertreatment system and for the alternate compliance approach single-SCR aftertreatment used in the e-heater system.

*Table 4-3 90th percentile incremental direct manufacturing costs for Medium HDE dual-SCR and Single-SCR Systems for the Alternate NCP*

| | | MY 2027 Dual-SCR aftertreatment | MY 2027 Single-SCR aftertreatment |
|---|---|---|---|
| 01 | DOC | $33 | $33 |
| 02 | DPF | $128 | $128 |
| 03 | LO-SCR | $246 | not applicable |
| 04 | SCR | $487 | $487 |
| 05 | Mixer | $152 | $20 |
| 06 | Sensors & Wiring Harness | $416 | $33 |
| 07 | Dosing Subsystem | $374 | $2 |
| 08 | DEF Tank Subsystem | $72 | $72 |
| 09 | Structural Hardware & Assembly | $606 | $606 |
| **Total Cost** | | **$2,513** | **$1,380** |

*Table 4-4 Medium HDE $COC_{90}$ Costs for the Proposed and the Alternate NCPs*

| | Proposed | Alternate |
|---|---|---|
| Direct manufacturing costs | $2,744 | $3,147 |
| Warranty | $82 | $94 |
| R&D | $137 | $157 |
| Other (admin, retirement, health, etc.) | $796 | $913 |
| Profit (cost of capital) | $137 | $157 |
| DEF operating costs | $433 | $433 |
| Total costs - $COC_{90}$ | $4,330 | $4,902 |

## 4.4 Proposed $MC_{50}$ and F

$MC_{50}$ is the marginal cost of compliance for the average vehicle, expressed in terms of dollars per mg/hp-hr of $NO_X$ emission controlled. $MC_{50}$ should represent the difference in total compliance costs for an engine that has emissions equal to the standard and an engine that has emissions slightly above the standard. To estimate $MC_{50}$, the EPA assumed use of a less cost-effective emission control technology to reduce $NO_X$ emissions from 65 mg/hp-hr to 35 mg/hp-hr. Reducing emissions by the last 30 mg/hp-hr requires technology that can raise the exhaust temperatures under low-load and cold-start operation. For the 2023 Final Rule this level of emissions reduction was achieved by a combination of equipping the engine with cylinder deactivation and raising the engine idle speed. An alternative technology would be to install an electric exhaust heater with a 48 V generator (e-heater). Since the incremental cost for an e-heater is greater (*i.e.*, less cost-effective) than the costs of CDA and engine calibration, we used the cost of the e-heater system to determine $MC_{50}$.[13] In addition to basing $MC_{50}$ on the

[13] See Chapter 3 of this DTSD.

incremental direct and indirect manufacturing costs, we have also estimated the incremental increase in DEF needed to reduce $NO_X$ from 65 mg/hp-hr to 35 mg/hp-hr as shown in Table 4-5.

*Table 4-5 50th Percentile Marginal Cost of Compliance*

| | |
|---|---|
| Direct manufacturing costs | $1,475 |
| Indirect costs | $619 |
| DEF operating costs | $79 |
| Total costs | $2,173 |
| $MC_{50}$ | $72/(mg/hp-hr) |

The F factor is defined in 40 CFR 86.1113-87(a)(4) and in the proposed new 40 CFR 1071.60(a) as the ratio of $MC_{90}$ to $MC_{50}$. To estimate the F factor, the EPA proposes to use the ratio of $COC_{90}$ over $COC_{50}$, which reasonably approximates the increase in the $MC_{90}$ over $MC_{50}$ since the Agency expects the marginal cost of compliance to scale with the absolute cost of compliance.[14] With this approach the F factor for Medium HDE is 1.176.

## 4.5 Refund for Engineering and Development Costs

Section 86.1113-87(h) of the existing regulations specifies provisions under which a manufacturer that pays NCPs can recover some of the amount it has paid, provided it certifies a conforming replacement for the engines which used the NCPs. The maximum amount that can be recovered is limited to 90 percent of the penalty which the EPA determines to be related to engineering and development. Thus, it is necessary for the EPA to establish in each NCP rule a factor, $F_{E\&D}$, for each engine service class for which an NCP is made available which defines the fraction of the NCP which is related to engineering and development. As discussed in Chapter 4.3, we determined that $137 of the NCP $COC_{90}$ value is related to engineering and development. Thus, the $F_{E\&D}$ value is equal to $137 divided by the $COC_{90}$ value of $4,330, or 0.032.

[14] In the 2012 rule we took a similar approach by determining F by dividing $MC_{90}$ by $MC_{50}$. In the 2012 rule both $MC_{90}$ and $MC_{50}$ were determined by dividing $COC_{90}$ and $COC_{50}$ by 0.3 g/hp-hr, so F is also equal to $COC_{90}$ divided by $COC_{50}$.

# Chapter 5 EPA Analysis of Costs for Heavy Heavy-Duty Engines

## 5.1 Basis of EPA Cost Estimates

For Heavy HDE engines the EPA relied on the same methodology used for Medium HDE as described in Chapter 4.

## 5.2 Proposed NCP Compliance Costs: $COC_{50}$

As discussed above, for the 50th percentile cost of compliance the EPA relied on the same DOC, DPF, and SCR catalyst volumes used in the 2023 Final Rule for the MY 2027 system, which sizes the aftertreatment based on sales-weighted average engine displacement. For Heavy HDE, the sales-weighted average engine displacement is 13.23 L. For the proposed NCP the $258/engine cost of CDA from Chapter 3.2 was used.

*Table 5-1 50th Percentile Incremental Direct Manufacturing Costs for Medium HDE Dual-SCR and Single-SCR Systems for the Alternate NCP*

| | | MY 2027 Dual-SCR aftertreatment | MY 2027 Single-SCR aftertreatment (part of e-heater system) |
|---|---|---|---|
| 01 | DOC | -$131 | -$131 |
| 02 | DPF | $43 | $43 |
| 03 | LO-SCR | $564 | not applicable |
| 4 | SCR | $457 | $457 |
| 05 | Mixer | $152 | $5 |
| 06 | Sensors & Wiring Harness | $416 | $33 |
| 07 | Dosing Subsystem | $374 | $2 |
| 08 | DEF Tank Subsystem | $80 | $80 |
| 09 | Structural Hardware & Assembly | $670 | $670 |
| **Total Cost** | | $2,626 | $1,159 |

*Table 5-2 Heavy HDE $COC_{50}$ Costs for the Proposed and the Alternate NCPs*

| | Proposed | Alternate |
|---|---|---|
| Direct manufacturing costs | $2,930 | $2,925 |
| Warranty | $88 | $88 |
| R&D | $147 | $146 |
| Other (admin, retirement, health, etc.) | $850 | $848 |
| Profit (cost of capital) | $147 | $146 |
| DEF operating costs | $2,041 | $2,041 |
| **Total costs - $COC_{50}$** | **$6,202** | **$6,195** |

## 5.3 Proposed NCP Compliance Costs: $COC_{90}$

For the 90th percentile cost of compliance the EPA used the same configuration as used for the 50th percentile system, with the addition of an increase in the catalyst substrate volumes, PGM loading, canning size, and washcoat to account for the larger aftertreatment volume needed for the largest displacement Heavy HDEs. These values were determined using the relationships built into the FEV analysis. For the $COC_{90}$ the EPA used an engine displacement of 14.9 L, which is the largest Heavy HDE EPA is aware of. For the proposed NCP the cost of CDA from Chapter 3.2, was used.

Table 5-3 shows the estimated incremental DMC for the aftertreatment system for the 90th percentile cost of compliance for both the dual-SCR aftertreatment system and for the alternative compliance approach single-SCR aftertreatment used in the e-heater system.

*Table 5-3 90th Percentile Incremental Direct Manufacturing Costs for Heavy HDE dual-SCR and single-SCR System for the Alternate NCP.*

| | | Dual-SCR aftertreatment | Single-SCR aftertreatment |
|---|---|---|---|
| 01 | DOC | -$48 | -$48 |
| 02 | DPF | $160 | $160 |
| 03 | LO-SCR | $635 | $0 |
| 04 | SCR | $593 | $593 |
| 05 | Mixer | $152 | $5 |
| 06 | Sensors & Wiring Harness | $416 | $33 |
| 07 | Dosing Subsystem | $374 | $2 |
| 08 | DEF Tank Subsystem | $80 | $80 |
| 09 | Structural Hardware & Assembly | $670 | $670 |
| Total Cost | | $3,034 | $1,495 |

*Table 5-4 Heavy HDE $COC_{90}$ Costs for the Proposed and the Alternate NCPs*

| | Proposed | Alternate |
|---|---|---|
| Direct manufacturing costs | $3,338 | $3,520 |
| Warranty | $100 | $106 |
| R&D | $167 | $176 |
| Other (admin, retirement, health, etc.) | $968 | $1,021 |
| Profit (cost of capital) | $167 | $176 |
| DEF operating costs | $2,041 | $2,041 |
| Total costs | $6,781 | $7,040 |

## 5.4 Proposed $MC_{50}$ and F

$MC_{50}$ is the marginal cost of compliance for the average vehicle, expressed in terms of dollars per mg/hp-hr of $NO_X$ emission controlled. $MC_{50}$ should represent the difference in total compliance costs for an engine that has emissions equal to the standard and an engine that has emissions slightly above the standard. To estimate $MC_{50}$, the EPA assumed use of a less cost-effective emission control technology to reduce $NO_X$ emissions from 65 mg/hp-hr to 35 mg/hp-hr. Reducing emissions by the last 30 mg/hp-hr requires technology that can raise the exhaust temperatures under low-load and cold-start operation. For the 2023 Final Rule this level of emissions reduction was achieved by a combination of equipping the engine with cylinder deactivation and raising the engine idle speed. An alternative technology would be to install an e-heater system. Since the incremental cost for an e-heater is greater (*i.e.*, less cost-effective) than the costs of CDA and engine calibration, we used the cost of the e-heater system to determine $MC_{50}$. In addition to basing $MC_{50}$ on the incremental direct and indirect manufacturing costs, the EPA has also estimated the incremental increase in DEF needed to reduce $NO_X$ from 65 mg/hp-hr to 35 mg/hp-hr as shown in Table 5-5

*Table 5-5 50$^{th}$ Percentile Marginal Cost of Compliance*

| | |
|---|---|
| Direct manufacturing costs | $1,475 |
| Warranty | $619 |
| DEF operating costs | $371 |
| Total costs | $2,465 |
| $MC_{50}$ | $82/(mg/hp-hr) |

The F factor is defined in existing 40 CFR 86.1113-87(a)(4) and in the proposed new 40 CFR 1071.60(a) as the ratio of $MC_{90}$ to $MC_{50}$. To estimate the F factor for Heavy HDEs, the EPA proposes using the ratio of $COC_{90}$ over $COC_{50}$, which reasonably approximates the increase in the $MC_{90}$ over $MC_{50}$ since the Agency expects the marginal cost of compliance to scale with the absolute cost of compliance. With this approach the F factor for Heavy HDE is 1.093. Consistent with the existing and new proposed definitions that limit F to values between 1.1 and 1.3, the EPA proposes to round the F factor for Heavy HDE up from 1.093 to 1.1.

## 5.5 Refund for Engineering and Development Costs

Section 86.1113-87(h) of the existing regulations specifies provisions under which a manufacturer that pays NCPs can recover some of the amount it has paid, provided it certifies a conforming replacement for the engines which used the NCPs. The maximum amount that can be recovered is limited to 90 percent of the portion of the penalty which the EPA determines to be related to engineering and development. Thus, it is necessary for the EPA to establish in each NCP rule a factor for each service class ($F_{E\&D}$) which defines the fractions of the NCP which are related to engineering and development. As discussed in Chapter 4.3, the EPA determined that $167 of the NCP $COC_{90}$ value is related to engineering and development. Thus, the $F_{E\&D}$ value for Heavy HDE is equal to $167 divided by the $COC_{90}$ value of $6,781, or 0.025.