

# **MOVES Review Work Group 2016–2021**

## **Report to Clean Air Act Advisory Committee**

A draft version of this report was approved by the Mobile Sources Technical Review Subcommittee on October 14, 2021, for submittal to the Clean Air Act Advisory Committee (CAAAC). The CAAAC approved submittal of the report to the Administrator of the U.S. Environmental Protection Agency (EPA) on February 8, 2022. This document is a product of the advisory committee; it does not reflect the views and policies of EPA or represent information disseminated by EPA.

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## 1. Background

The U.S. Environmental Protection Agency’s MOfor Vehicle Emission Simulator (MOVES) is an emission modeling system for estimating air pollution emissions from highway vehicles and nonroad mobile sources. MOVES is used for many purposes; it is used by the U.S. EPA to estimate emission impacts of mobile source regulations and policies, and to generate mobile sector information for national inventories of air pollutants such as the National Emissions Inventory and the National Air Toxics Assessment. In addition, U.S. states and local agencies outside of California use MOVES to develop emission inventories for a variety of regulatory purposes, including the development of state implementation plans (SIPs), transportation conformity determinations, general conformity evaluations, and analyses required under the National Environmental Policy Act (NEPA), among other uses. Academics and interest groups also use MOVES to model the effects of policy choices and various mobile source scenarios. Over time, MOVES has been improved and updated to better characterize the changing mobile sector and to better incorporate new regulations and other new information about vehicle and nonroad engine emissions.<sup>1</sup>

To provide expert feedback and advice on MOVES development, the Mobile Sources Technical Review Subcommittee (MSTRS) has chartered a series of MOVES Review Work Groups. The work group is not designed for policy or advocacy, but rather is a focal point for sharing technical expertise. The first work group was chartered in April 2007 and met through April 2010 to provide feedback on MOVES initial development,<sup>2</sup> culminating with the release of MOVES2010 in December 2009. A second work group met from July 2012 through July 2013 during the development of MOVES2014, released in October 2014. This report summarizes the work of a third work group that met from September 2016 through September 2021 to provide feedback on the development of MOVES3, released in November 2020. Each work group was charged with reviewing information about MOVES development and providing recommendations to the MSTRS. In turn, the MSTRS was to evaluate the work group recommendations and decide how these issues should be reported to the Clean Air Act Advisory Committee (CAAAC),

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<sup>1</sup> [Overview of EPA’s MOfor Vehicle Emission Simulator \(MOVES3\)](#)

<sup>2</sup> [MOVES Review Workgroup Final Report to Mobile Source Technical Review Subcommittee, September 2010](#)

which, under the Federal Advisory Committee Act (FACA), may formally give EPA collective advice. See Appendix A for the 2016 work group charter.

## 2. Work Group Efforts

Members of the work group represented a spectrum of stakeholders, including vehicle and engine manufacturers, fuel producers, state and local emission modelers, academic researchers, environmental advocates, and federal agencies that use MOVES. See Appendix B for the work group membership list. The meetings were open to the public and were well attended by a large group of MOVES stakeholders in addition to the work group members.

Over the course of five years, the current MOVES Review Work Group met 13 times to review and discuss draft information on MOVES algorithms, data inputs and other features. Most presentations were given by the U.S. EPA, but the work group members also shared information (via presentations and discussions) with the work group. Appendix C lists the presentations from each meeting. Presentation slides and summaries of each work group meeting are available on the [MOVES Model Review Work Group web page](#). Work group meetings were characterized by constructive comments and probing questions, with lively discussion with among EPA staff, work group members, and other attendees.

The work group provided status presentations back to the MSTRS in October 2016, May 2017, May 2018, August 2019, and October 2020. In addition, the work group chairs will provide a final presentation in October 2021 that summarizes the information in this report. As part of the May 2017 and May 2018 MSTRS presentations, the work group compiled and shared a set of interim recommendations. These are listed in Appendix D.

After the November 2020 release of MOVES3, the work group chairs solicited feedback on MOVES3. At the September 2021 meeting, work group members and attendees discussed prior recommendations to MSTRS, recommendations sent by email prior to the meeting, and other thoughts on the most important areas for future MOVES development. Work group members were encouraged to email the co-chairs with any follow-up recommendations. The co-chairs then compiled these recommendations into a comprehensive list, grouped by category, and asked members to prioritize by selecting their top five recommendations. The full set of recommendations and the results of the voting are available in Appendix E.

With the completion and release of MOVES3, the work of the current work group has ended. MSTRS may, of course, choose to charter a new iteration of the work group in the future.

## 3. Work Group Recommendations for Future MOVES Work

Based on this selection process described above, the work group shares this list of highest priority recommendations for MOVES development efforts and requests that the MSTRS approve the recommendations and forward to CAAAC for their consideration.

These recommendations are listed in priority order, based on voting by work group members. More details on the voting process are provided in Appendix E.

Table 1. Recommendations for MOVES Development

Rank	ID	Recommendation Description
1	D	<p>Improve modeling of energy use and direct emissions from vehicles using <b>alternative fuels and technologies</b>, by compiling emissions, activity, and vehicle characteristics of, for example:</p> <ul style="list-style-type: none"> <li>• battery electric,</li> <li>• hybrid electric,</li> <li>• hydrogen fuel cell,</li> <li>• natural gas, and</li> <li>• propane</li> </ul>
2	B	<p>Update modeling of exhaust emissions from <b>conventional (diesel and gasoline) heavy-duty vehicles</b> in MOVES, such as:</p> <ul style="list-style-type: none"> <li>• <b>Activity</b> – Incorporate latest heavy-duty vehicle project data sets, modify operating modes, and better account for road grade and changes in vehicle mass and road load.</li> <li>• <b>Emissions</b> – Update with latest real-world data, including starts. Account for new regulations, including California’s Advanced Clean Truck program.</li> <li>• <b>Adjustments</b> – Better account for tampering and diesel I/M programs. Better account for biodiesel fuels.</li> <li>• <b>Speciation</b> – Better account for secondary organic aerosol (SOA)-precursors and ultra-fine particles.</li> </ul>
3	A	<p>Update modeling of exhaust emissions from <b>conventional (gasoline and diesel) light-duty vehicles</b> in MOVES, such as:</p> <ul style="list-style-type: none"> <li>• <b>Activity</b> – Make use of large vehicle activity datasets that are becoming increasingly available (e.g., connected and automated vehicle data sets, vehicle telematics) to improve driving cycles, starts activity and other defaults. Better account for road grade and changes in vehicle mass and road load.</li> <li>• <b>Emissions</b> – Collect more data on light-duty starts, including particulate matter and LD diesel. Improve IM and non-IM emission rates for GDI and Tier 3-and-later vehicles. Account for new regulations such as EPA’s August 2021 proposal on new GHG standards for passenger cars and light trucks.</li> <li>• <b>Adjustments</b> – Update air conditioning effects. Account for role of lubricating oil with respect to particle emissions. Update default fuel properties and fuel property effects, including those related to ethanol and aromatics.</li> <li>• <b>Speciation</b> – Better account for secondary organic aerosol (SOA)-precursors and ultra-fine particles.</li> </ul>
4	F	<p>Improve how MOVES <b>works with other models and tools</b> (SMOKE, GREET, VISSIM, AERMOD, etc.), for example:</p> <ul style="list-style-type: none"> <li>• Develop, test, and document best practices.</li> <li>• Provide software tools and application programming interfaces (APIs).</li> <li>• Facilitate Life-Cycle Analysis for electric vehicles and GHGs.</li> <li>• Simplify source types to better align with FHWA vehicle categories.</li> <li>• Allow additional user inputs such as vehicle load or weight.</li> </ul>

Rank	ID	Recommendation Description
5	H	<p>Improve MOVES capabilities for <b>community-scale modeling and equity analysis</b>, for example:</p> <ul style="list-style-type: none"> <li>• Expand on existing project-level guidance to estimate emissions at the community level;</li> <li>• Develop and testing techniques such as Automated License Plate Readers to estimate vehicle mix and activity at the sub-county level;</li> <li>• Develop MOVES-based tools for equity or environmental justice analyses, or to support other EPA tools such as EJSCREEN, COBRA, etc. that require mobile source emissions input.</li> </ul>
6	C	<p>Update modeling of <b>nonroad equipment</b>, such as:</p> <ul style="list-style-type: none"> <li>• Replace with a modern software design that is easy to update.</li> <li>• Update nonroad equipment populations and emissions.</li> <li>• Account for battery-electric equipment and other alternative technologies.</li> <li>• Account for possible altitude effects.</li> </ul>
7	G	<p>Improve MOVES capabilities for <b>project level analyses</b>, for example:</p> <ul style="list-style-type: none"> <li>• Improve linkages with traffic models and dispersion models.</li> <li>• In documentation and/or code, limit modeling of road grades to realistic levels.</li> <li>• Continue improving the MOVES Ramp Tool and create similar tools for acceleration and deceleration links for congested (arterial street) intersections.</li> <li>• Consider adding libraries of vocational duty cycles.</li> <li>• Make vehicle load a user input variable in MOVES.</li> <li>• Add tools to help model project level activity, such as tools to calculate travel fraction by age or model year.</li> <li>• Provide default values for inputs required by regulation (e.g. fuel properties).</li> <li>• Improve interface to facilitate selection of correct pollutants &amp; processes for PM, CO, or air toxics analysis.</li> <li>• Improve interface with AERMOD.</li> </ul>
8	E	<p>Update modeling of <b>brake and tire wear</b> particulate emissions from conventional, electric, and other alternative vehicles—both heavy duty and light-duty. Consider incorporating the calculations of road dust from AP-42 into MOVES.</p>
9	M	<p>Better <b>evaluate MOVES accuracy and applicability</b> through analyses such as:</p> <ul style="list-style-type: none"> <li>• Comparisons to real-world data, including grade and speed effects.</li> <li>• Comparisons with California’s EMFAC model, including results, projections, and policy implications.</li> <li>• With FHWA, create a <a href="#">Transportation Pooled Fund</a> Study that would work with state DOTs and FHWA on assessing uncertainty for the entire project level modeling chain. Involve EPA emission modeling and dispersion modeling staff.</li> </ul>
10	K	<p>Incorporate new options to <b>reduce processing time</b>: e.g., consider pre-calculating look-up tables for cities or regions (e.g., MOVES MATRIX) or converting additional modules to faster languages like Go.</p>

Rank	ID	Recommendation Description
11	J	<p>Improve the <b>user interface for inputs and outputs</b>, for example:</p> <ul style="list-style-type: none"> <li>• Consider different graphical user interfaces for different uses.</li> <li>• Provide explicit output of diesel particulate matter.</li> <li>• Provide a “start per vehicle” input as in MOVES2014b.</li> <li>• Allow “custom domain” modeling as in MOVES2014b.</li> <li>• Allow additional user inputs such as vehicle load and weight.</li> <li>• Allow finer day of the week detail (not just weekend day and weekday).</li> <li>• Streamline the export of default data for county databases.</li> <li>• Enable use of the same project and county databases when changing evaluation years in a runspec.</li> <li>• Create a “Scenario Manager” to allow users to better manage modeling multiple runs, compare incremental results, and automate post-processing (e.g. for emission rates).</li> </ul>
12	I	Improve MOVES ability to model emissions from <b>automated and connected vehicles</b> , e.g. through refined operating mode bins or incorporating a true modal emissions model.
13	N	“Write In” recommendations (see Appendix E).
14	L	Improve software <b>installation and update processes</b> . For example, provide test files that users can run to ensure that they have MOVES installed correctly and are generating valid results.

## Appendix A

### MOVES Review Work Group Charter, July 2016

Federal Advisory Committee Act Clean Air Act Advisory Committee  
Mobile Sources Technical Review Subcommittee  
Co-Chairs: Drew Kodjak and Gay MacGregor      Technical Staff Contact: Courtney McCubbin

#### **Mobile Sources Technical Review Subcommittee**

#### **Charter for MOVES Review Work Group**

The MOVES Review Work Group is a work group formed under the Mobile Sources Technical Review Subcommittee (MSTRS). Supplementing EPA's separate peer review efforts, the MOVES Review Work Group is charged to provide input to EPA via the MSTRS and the Clean Air Act Advisory Committee on specific issues regarding the development of the Motor Vehicle Emission Simulator (MOVES). MOVES is an emission modeling system used to estimate air pollution emissions from highway vehicles and nonroad mobile sources.

The MOVES Review Work Group shall serve as an advisory group to the MSTRS on:

1. Evaluating data sources and analysis methods proposed for use in developing **emission rates** to be used in the MOVES model.
2. Evaluating data sources and analysis methods proposed for use in **developing fleet and activity inputs** to be used in the MOVES model.
3. Evaluating data sources and analysis methods proposed for use in developing **emission adjustment factors** to be used in the MOVES model.
4. Evaluating the format of MOVES **input and output structures** and the usefulness of these formats in meeting the needs of modelers developing State Implementation Plans (SIPs) and transportation conformity determinations.

The MOVES Review Work Group shall meet three to four times a year over the next few years, in person and in teleconference.

MOVES Review Work Group members will review draft MOVES reports as they become available and will work collaboratively to provide timely, shared recommendations to the MSTRS which will evaluate them and decide how these issues should be reported to the full Clean Air Act Advisory Committee, which alone may formally give EPA collective advice.

The MOVES Review Work Group shall consist of members who have expertise in modeling emissions from highway and nonroad vehicles and who represent a spectrum of stakeholders, including vehicle and engine manufacturers, fuel producers, state and local emission modelers, academic researchers, environmental advocates, and affected federal agencies.

## Appendix B

### Work Group Members, 2016–2021

To achieve its objectives, the MOVES Review Work Group consists of members who have expertise in modeling emissions from highway and nonroad vehicles.

Over the five years that the work group has been meeting, a few members have retired or moved to other responsibilities. They are noted here as “resigned.” Members who resigned have generally been replaced with a new member representing the same organization.

*Table B-1. MOVES Review Work Group Members and Organizations*

<b>Name</b>	<b>Home Organization</b>	<b>Representing Organization</b>	<b>Sector</b>	<b>Status</b>
Matthew Barth*	University of California, Riverside (CE-CERT)	University of California, Riverside (CE-CERT)	Academia	Co-Chair
Megan Beardsley	EPA Office of Transportation and Air Quality	U.S. EPA	Federal Government	Co-Chair
Giedrius Ambrozaitis	Alliance of Automobile Manufacturers	Alliance of Automobile Manufacturers	Industry	Resigned
Susan Collet	Toyota	Coordinating Research Council (CRC)	Industry	Resigned
Elena Craft*	Environmental Defense Fund (EDF)	Environmental Defense Fund (EDF)	Environmental NGO	
Tim French	Engine Manufacturers Association (EMA)	Engine Manufacturers Association (EMA)	Industry	
Christopher Frey	North Carolina State University	North Carolina State University	Academia	Resigned
Mike Geller	Manufacturers of Emission Controls Association (MECA)	Manufacturers of Emission Controls Association (MECA)	Industry	
Gil Grodzinsky	Georgia Department of Natural Resources	Association of Air Pollution Control Agencies (AAPCA)	State and Local Government	
Michael Hartrick	Alliance for Automotive Innovation	Alliance for Automotive Innovation	Industry	
Cecilia Ho	Federal Highway Administration (FHWA)	Federal Highway Administration (FHWA)	Federal Government	
Britt Holmen	University of Vermont	University of Vermont	Academia	
Jeremy Hunt	Northeast States for Coordinated Air Use Management (NESCAUM)	Northeast States for Coordinated Air Use Management (NESCAUM)	State and Local Government	
Mark Janssen	Lake Michigan Air Directors Consortium (LADCO)	Lake Michigan Air Directors Consortium (LADCO)	State and Local Government	



<b>Name</b>	<b>Home Organization</b>	<b>Representing Organization</b>	<b>Sector</b>	<b>Status</b>
Chris Kite	Texas Commission on Environmental Quality	Association of Air Pollution Control Agencies (AAPCA)	State and Local Government	Resigned
Jim Kliesch*	Honda	Honda	Industry	Resigned
David Lax	American Petroleum Institute (API)	American Petroleum Institute (API)	Industry	
Sam Pournazeri	California Air Resources Board (CARB)	California Air Resources Board (CARB)	State and Local Government	
Lubna Shoaib	East-West Gateway Council of Governments	Association of Metropolitan Planning Organizations (AMPO)	State and Local Government	
Jenny Sigelko	Volkswagen of America, Inc.	Coordinating Research Council (CRC)	Industry	
Matthew Thornton	National Renewable Energy Laboratory (NREL)	National Renewable Energy Laboratory (NREL)	Federal Government	
Steven Vander Griend	ICM Inc.	Energy Future Coalition/Urban Air Initiative	Industry	
Chris Voigt	Virginia Department of Transportation	Amer. Assoc. of State Highway and Transportation Officials (AASHTO)	State and Local Government	
Jesse Way	Northeast States for Coordinated Air Use Management (NESCAUM)	Northeast States for Coordinated Air Use Management (NESCAUM)	State and Local Government	Resigned
Dale Wells	Colorado Department of Public Health and Environment	National Association of Clean Air Agencies (NACAA)	State and Local Government	
Wei Zhang	Idaho Department of Environmental Quality	National Association of Clean Air Agencies (NACAA)	State and Local Government	

\*Member of MSTRS

## Appendix C

### Work Group Meeting Dates and Topics

Presentation slides and summaries of each work group meeting are available on the [MOVES Model Review Work Group web page](#). All presentations were by EPA staff unless noted otherwise.

#### **September 2016:**

- Work Group Introduction
- MOVES2014 Overview and Plans for the Future
- Options for Simplifying MOVES Onroad Source Types and Ramps
- MOVES-NONROAD Model Plans and Data Updates
- Heavy-Duty Greenhouse Gas Phase 2 in MOVES

#### **December 2016:**

- Update to Running Exhaust Criteria Pollutant Emission Rates for Model Year 2010+ Heavy-Duty Diesel Vehicles
- Updated Emission Rates for Extended Idle and Auxiliary Power Units
- MOVES Onroad Population and Activity Update
- Updating Hotelling Hours in MOVES

#### **March 2017:**

- Vehicle Idle Activity in MOVES
- Model Evaluation
- Light-Duty Particulate Matter Emission Rates Update

#### **June 2017:**

- Revising Start/Soak Emissions for LDGV and HDV
- Heavy Duty CNG category
- Telematics: valuable for many aspects of MOVES
- Updated Speciation Profiles
- Updated Total Organic Gases

#### **September 2017:**

- Updated NONROAD population rates
- Updated LD Emission Rate Comparison
- MOVES Future Fuel Supply Updates

#### **December 2017:**

- Update for Tier-4 Nonroad Diesel Engines
- Draft Tool to Model Ramps in Project Scale
- Updates to MOVES HD Source Masses using VTRIS
- Updates to HDV Fixed Mass Factor and Diesel PM rates
- *Coordinating Research Council 2017 and 2018 MOVES related projects* – **Susan Collet, Toyota, CRC AIC Co-Chair; Scott Mason, Phillips 66, CRC EC Co-Chair**

**March 2018:**

- *Ethanol's Emission Effects in MOVES2014 – Steven VanderGriend, Urban Air Initiative*
- *Growth Energy Ethanol and Aromatics Testing Program – Tom Darlington, Air Improvement Resource, Inc.*
- *Implications of Emerging Trends and Needs for MOVES – Prof. Christopher Frey, North Carolina State University*

**June 2018:**

- MOVES2014b Plans and Comparisons
- Heavy-Duty Vehicle Activity in MOVES: Idle, Starts, Soaks and Hotelling
- Update: Revising Start/Soak Relationships for Light-Duty Gaseous Emissions
- *Utilizing MOVES for Evaluating Shared, Electric, Connected and Automated Vehicles – Prof. Matthew Barth, University of California, Riverside*

**April 2019:**

- Updates to EPA's Motor Vehicle Emission Simulator
- Updates to "High-Power" Emission Rates and Start Deterioration for Light-Duty Vehicles
- Updates to MOVES Heavy-Duty Running Exhaust Rates: Diesel Gasoline and Natural Gas
- Modeling of Gliders in MOVES

**October 2019:**

- *Project Level Analyses – Christopher Voigt, Virginia DOT; Vice-Chair, AASHTO Air Quality, Climate Change and Energy Subcommittee*
- *Enhancing MOVES for Connected and Automated Vehicle Analysis – Prof. Matthew Barth, University of California, Riverside*
- *Integrating Models at Multiple Scales for Transportation Energy and Emissions Assessment – Prof. Randall Guenther, Georgia Institute of Technology.*

**October 2020:**

- Planned Updates to Light-Duty Gaseous Emission Rates and Base Fuels in MOVES3
- Updates to Energy and CO2 Rates for Light-Duty Vehicles with SAFE Rule
- Crankcase Emissions for MY2007+ Heavy-Duty Diesel Trucks
- MOVES Plans & Status
- Planned Updates to Default Fuel Supply for MOVES3

**December 2020:**

- MOVES3 Introduction and Overview

**September 2021**

- MOVES3 Fuel Consumption Evaluation
- MOVES Review Work Group Recommendations to MSTRS Process Outline

## Appendix D

### Previous Recommendations to MSTRS

Tables D-1 and D-2 below summarize the MRWG recommendations to MSTRS from [May 2017](#) and [May 2018](#). The year in parentheses indicates the year of the recommendation to MSTRS.

Table D-1 for short-term recommendations also explains how the recommendations were addressed in EPA’s release of the [MOVES3 model](#) in November 2020. For more information on MOVES3 updates, see the MOVES technical reports.<sup>3</sup>

*Table D-1. Short-Term Recommendations and Status*

Recommendation	Status
Update MOVES-NONROAD portion of the model with better data and better documentation. (2017) Use the best data available to estimate nonroad equipment populations and technologies. (2018)	<a href="#">MOVES2014b</a> (August 2018) improved emission estimates for nonroad mobile sources updating nonroad engine population growth indices; nonroad Tier 4 engine populations and rates and speciation; and sulfur levels of nonroad diesel fuels. These updates were carried into MOVES3. EPA is continuing to collect and analyze nonroad data for future model updates.
Simplify Ramps in MOVES (2017)	MOVES3 removed “ramps” as a separate road type. Ramp driving activity is now incorporated in rural and urban freeway driving. Ramps can still be modeled separately at Project Scale.
Update MOVES Onroad Population and Activity (2017)	MOVES3 updated historic and projected VMT based on 2019 Highway Statistics and Annual Energy Outlook (AEO). Updated vehicle age distributions. Updated default speed distributions.
Update Hotelling Hours in MOVES (2017)	MOVES3 updated HD hotelling assumptions (extended idling for diesel long-haul combination trucks at truck stops) based on new information.
Update Running Exhaust Criteria Pollutant Emission Rates for Model Year 2010+ Heavy-Duty Diesel Vehicles (2017)	MOVES3 updated the heavy-duty (HD) diesel running emission rates based on manufacturer-run in-use testing data from hundreds of HD trucks
Update Emission Rates for Extended Idle and Auxiliary Power Units (2017)	MOVES3 updated HD diesel emission rates for extended idling and auxiliary power units.
Update Light-Duty Particulate Matter Emission Rates (2017)	MOVES3 included new data from GDI (Gasoline Direct Injection) vehicles, and updated PM temperature adjustments

<sup>3</sup> <https://www.epa.gov/moves/moves-onroad-technical-reports> and <https://www.epa.gov/moves/nonroad-technical-reports>

Recommendation	Status
Incorporate Heavy-Duty Greenhouse Gas Phase 2 in MOVES (2017)	MOVES3 incorporated the effects of the HD GHG Phase 2 rule.
Incorporate additional data on LD & HD starts, including GDI PM and LD diesel (CARB data, etc.) (2018)	<p>MOVES3 includes a number of updates for start emissions:</p> <ul style="list-style-type: none"> <li>• updated particulate matter (PM) rates for starts based on data gasoline direct injection (GDI) vehicles.</li> <li>• updated heavy-duty (HD) diesel start rates for hydrocarbon (THC), carbon monoxide (CO), oxides of nitrogen (NOx) and PM.</li> <li>• because there are relatively few light-duty (LD) diesel vehicles, MOVES3 did not update LD diesel start rates based on data from LD diesel vehicles; instead these rates were set equal to the rates for LD gasoline vehicles.</li> <li>• included updates to start activity based on instrumented vehicle data, and updates to start emission adjustments based on time parked before the start (“soak” time).</li> </ul>
Add more options for CNG vehicles. (2018)	MOVES3 allows modeling of CNG fuel for most HD source types: school buses, transit buses, other buses, refuse trucks, short-haul single-unit trucks, long-haul single-unit trucks, and short-haul combination trucks.
Maximize use of emerging telematics data wherever possible. (2018)	MOVES3 used LD and HD telematics data to estimate activity for vehicle speed distributions, start activity, and idle time.
Reconsider how to handle Fixed Mass Factors for different model year groups. (Having different values for different MY groups is confusing.) (2018)	In MOVES3, the Fixed Mass Factors (fscale) used in the MOVES calculation of Scaled Tractive Power (STP) for HD vehicles were updated for model years (MY) 2010-and-later. Updates to MOVES3 now allow different fscale values to be used for individual regulatory classes, as in the MOVES3 emission rate update for HD vehicles for MY 2010-and-later. Updating emission rates for HD vehicles for pre-MY 2010 vehicles would require re-analysis of the emission rates for these model years. This has been listed as a potential project for future MOVES updates.
Use certification data to decide how to model pre-MY2010 particulate matter from HD vehicles (to address concern about using MY 2010+ data for pre-MY2010 emission rates). (2018)	EPA certification data was used to develop PM emission rates for HD diesel MY2006-2009. PM emission rates for earlier HD diesel vehicles are based on data from the CRC E-55/59 research program

Table D-2. Long-Term Recommendations

Long-Term Recommendations
<b>Improve MOVES Current Capabilities with Updated Data &amp; Analysis</b>
<p>Update modeling of Heavy-Duty Diesel vehicles in MOVES:</p> <ul style="list-style-type: none"> <li>Activity – incorporate latest heavy-duty vehicle project data sets, modify operating modes, and add road grade (2017, 2018)</li> </ul> <p>Emissions – update with latest real-world data, including tampering, malfunction, and mal-maintenance (2017,2018)</p>
<p>Invest in a robust data collection program to gather information on how vehicles are actually used in-use and associated emissions and emission control technology. (2017,2018)</p> <ul style="list-style-type: none"> <li>Collect more data on light-duty &amp; heavy-duty starts, including particulate matter and LD diesel. (2018)</li> <li>Improve IM and non-IM rates (2018)</li> </ul> <p>Make use of huge vehicle activity datasets that are becoming available (connected vehicle data, telematics) to improve driving cycles, starts activity and other defaults (2017, 2018)</p>
<p>More detailed handling of air conditioning usage. (2017)</p> <p>Update modeling of air conditioning impacts (2018)</p>
<p>Improved handling of road dust and brake and tire wear. (2017)</p> <p>Improve modeling of brake and tire wear (2018)</p>
<p>Update MOVES default fuel parameters and fuel effects, including ethanol effects in Tier 3 and GDI vehicles (2018)</p>
<p>Evaluate MOVES estimates with comparisons to real-world data. (2017) (2018)</p>
<b>Expand MOVES Capabilities by Collecting New Data and Adding New Features</b>
<p>Improved handling of alternative fuels and technology (ethanol, natural gas, electric vehicles, hybrid electric vehicle), for both tailpipe and evaporative emissions. (2017)</p> <p>Improve modeling of alternative fuels and technology (ethanol, biodiesel, natural gas, electric vehicles, hybrid electric vehicles, gas direct injection, flex fuels), for both tailpipe and evaporative emissions. (2018)</p>
<p>Better account for secondary organic aerosol (SOA)-precursors and ultra-fine particles (2018)</p>
<p>Account for role of lubricating oil with respect to particle emissions (2018)</p>
<p>Allow additional user inputs such as vehicle load or weight (2018)</p>
<p>Improve MOVES capabilities for project level analyses:</p> <ul style="list-style-type: none"> <li>Consider incorporating a true modal emissions model (2017 &amp; 2018)</li> <li>Improve linkages with traffic models (2017 &amp; 2018)</li> <li>Limit modeling of road grades to realistic levels (2017 &amp; 2018)</li> <li>Continue improving the MOVES Ramp Tool, and create similar tools for acceleration and deceleration links for congested (arterial street) intersections (2018)</li> <li>Consider adding libraries of vocational duty cycles (2018)</li> <li>Make vehicle load a user input variable in MOVES (2018)</li> <li>Add tools to help model project level activity, such as tools to calculate travel fraction by model year (2018)</li> </ul>

<b>Long-Term Recommendations</b>	
<b>Make MOVES Easier to Use</b>	
Simplify MOVES Onroad Source Types: e.g., combine some source types, converge with FHWA vehicle types. (2017, 2018)	
Provide explicit output of diesel particulate matter (2018)	
Consider different interfaces for different uses (multiple graphical user interfaces). (2017, 2018)	
Create a “Scenario Manager” to allow users to better manage modeling multiple runs, compare incremental results, and automate post-processing. (2017, 2018)	
Establish better methods of interfacing MOVES to other models (SMOKE, etc.) (2018)	
Incorporate new options for improving processing time: e.g., consider pre-calculating look-up tables for cities or regions. (2017, 2018))	
Provide documentation on how MOVES can be used for Life-Cycle Emissions Analysis (2017, 2018)	
Improve software installation and update processes, including providing test files that users can run to ensure that they have MOVES installed correctly and are generating valid results (2017, 2018)	

## Appendix E

### Recommendation Prioritization

#### MOVES Review Work Group 2016–2021

Table E-1 of this appendix lists the recommendation options compiled from the work group discussions. The list was emailed to members on September 23, 2021. Each member was asked to rank their top five recommendations. The “Sum of Votes” shown in Figure E-1 is computed from the preferences expressed by the 19 of 20 current work group members who responded, with a score of five given to each member’s highest priority ranking and a score of one to the lowest.

*Figure E-1. Work Group Votes on Recommendation Options*

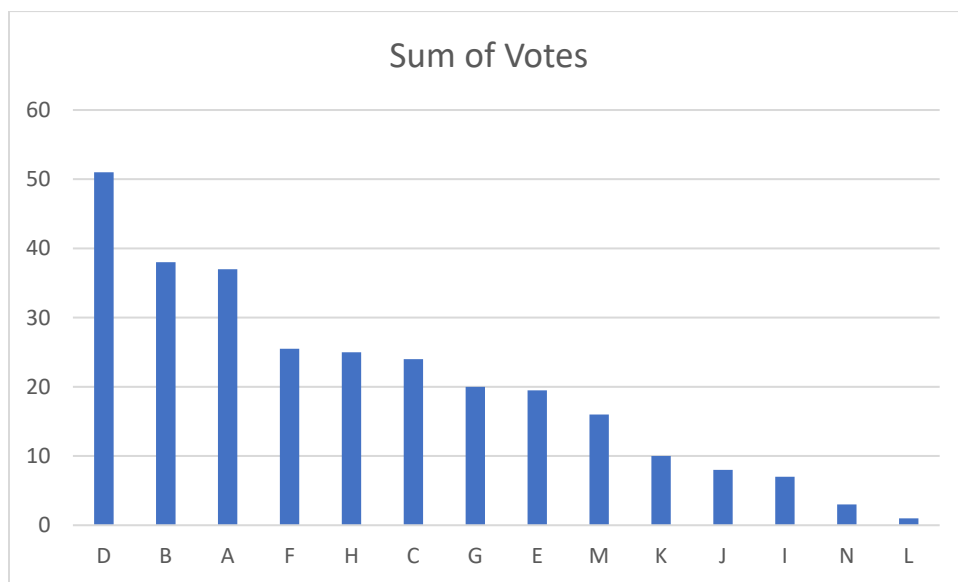




Table E-1. Recommended Options and Work Group Votes

ID	Description	Sum of Votes
A	<p>Update modeling of exhaust emissions from <b>conventional (gasoline and diesel) light-duty vehicles</b> in MOVES, such as:</p> <ul style="list-style-type: none"> <li>• <b>Activity</b>—Make use of large vehicle activity datasets that are becoming increasingly available (e.g., connected and automated vehicle data sets, vehicle telematics) to improve driving cycles, starts activity and other defaults. Better account for road grade and changes in vehicle mass and road load.</li> <li>• <b>Emissions</b>—Collect more data on light-duty starts, including particulate matter and LD diesel. Improve IM and non-IM emission rates for GDI and Tier 3-and-later vehicles. Account for new regulations such as EPA’s August 2021 proposal on new GHG standards for passenger cars and light trucks.</li> <li>• <b>Adjustments</b>—Update air conditioning effects. Account for role of lubricating oil with respect to particle emissions. Update default fuel properties and fuel property effects, including those related to ethanol and aromatics.</li> <li>• <b>Speciation</b>—Better account for secondary organic aerosol (SOA)-precursors and ultra-fine particles.</li> </ul>	37
B	<p>Update modeling of exhaust emissions from <b>conventional (diesel and gasoline) heavy-duty vehicles</b> in MOVES, such as:</p> <ul style="list-style-type: none"> <li>• <b>Activity</b> – Incorporate latest heavy-duty vehicle project data sets, modify operating modes, and better account for road grade and changes in vehicle mass and road load.</li> <li>• <b>Emissions</b> – Update with latest real-world data, including starts. Account for new regulations, including California’s Advanced Clean Truck program.</li> <li>• <b>Adjustments</b> – Better account for tampering and diesel I/M programs. Better account for biodiesel fuels.</li> <li>• <b>Speciation</b> – Better account for secondary organic aerosol (SOA)-precursors and ultra-fine particles.</li> </ul>	38
C	<p>Update modeling of <b>nonroad equipment</b>, such as:</p> <ul style="list-style-type: none"> <li>• Replace with a modern software design that is easy to update.</li> <li>• Update nonroad equipment populations and emissions.</li> <li>• Account for battery-electric equipment and other alternative technologies.</li> <li>• Account for possible altitude effects.</li> </ul>	24

ID	Description	Sum of Votes
D	<p>Improve modeling of energy use and direct emissions from vehicles using <b>alternative fuels and technologies</b>, by compiling emissions, activity, and vehicle characteristics of, for example:</p> <ul style="list-style-type: none"> <li>• battery electric,</li> <li>• hybrid electric,</li> <li>• hydrogen fuel cell,</li> <li>• natural gas, and</li> <li>• propane</li> </ul>	51
E	<p>Update modeling of <b>brake and tire wear</b> particulate emissions from conventional, electric, and other alternative vehicles—both heavy duty and light-duty. Consider incorporating the calculations of road dust from AP-42 into MOVES.</p>	19.5
F	<p>Improve how MOVES <b>works with other models and tools</b> (SMOKE, GREET, VISSIM, AERMOD, etc.), for example:</p> <ul style="list-style-type: none"> <li>• Develop, test, and document best practices.</li> <li>• Provide software tools and application programming interfaces (APIs).</li> <li>• Facilitate Life-Cycle Analysis for electric vehicles and GHGs.</li> <li>• Simplify source types to better align with FHWA vehicle categories.</li> <li>• Allow additional user inputs such as vehicle load or weight.</li> </ul>	25.5
G	<p>Improve MOVES capabilities for <b>project level analyses</b>, for example:</p> <ul style="list-style-type: none"> <li>• Improve linkages with traffic models and dispersion models.</li> <li>• In documentation and/or code, limit modeling of road grades to realistic levels.</li> <li>• Continue improving the MOVES Ramp Tool and create similar tools for acceleration and deceleration links for congested (arterial street) intersections.</li> <li>• Consider adding libraries of vocational duty cycles.</li> <li>• Make vehicle load a user input variable in MOVES.</li> <li>• Add tools to help model project level activity, such as tools to calculate travel fraction by age or model year.</li> <li>• Provide default values for inputs required by regulation (e.g. fuel properties).</li> <li>• Improve interface to facilitate selection of correct pollutants &amp; processes for PM, CO or air toxics analysis.</li> <li>• Improve interface with AERMOD.</li> </ul>	20

ID	Description	Sum of Votes
H	<p>Improve MOVES capabilities for <b>community-scale modeling and equity analysis</b>, for example:</p> <ul style="list-style-type: none"> <li>• Expand on existing project-level guidance to estimate emissions at the community level;</li> <li>• Develop and testing techniques such as Automated License Plate Readers to estimate vehicle mix and activity at the sub-county level;</li> <li>• Develop MOVES-based tools for equity or environmental justice analyses, or to support other EPA tools such as EJSCREEN, COBRA, etc. that require mobile source emissions input.</li> </ul>	25
I	<p>Improve MOVES ability to model emissions from <b>automated and connected vehicles</b>, e.g. through refined operating mode bins or incorporating a true modal emissions model.</p>	7
J	<p>Improve the <b>user interface for inputs and outputs</b>, for example:</p> <ul style="list-style-type: none"> <li>• Consider different graphical user interfaces for different uses.</li> <li>• Provide explicit output of diesel particulate matter.</li> <li>• Provide a “start per vehicle” input as in MOVES2014b.</li> <li>• Allow “custom domain” modeling as in MOVES2014b.</li> <li>• Allow additional user inputs such as vehicle load and weight.</li> <li>• Allow finer day of the week detail (not just weekend day and weekday).</li> <li>• Streamline the export of default data for county databases.</li> <li>• Enable use of the same project and county databases when changing evaluation years in a runspec.</li> <li>• Create a “Scenario Manager” to allow users to better manage modeling multiple runs, compare incremental results, and automate post-processing (e.g. for emission rates).</li> </ul>	8
K	<p>Incorporate new options to <b>reduce processing time</b>: e.g., consider pre-calculating look-up tables for cities or regions (e.g., MOVES MATRIX) or converting additional modules to faster languages like Go.</p>	10
L	<p>Improve software <b>installation and update processes</b>. For example, provide test files that users can run to ensure that they have MOVES installed correctly and are generating valid results.</p>	1
M	<p>Better <b>evaluate MOVES accuracy and applicability</b> through analyses such as:</p> <ul style="list-style-type: none"> <li>• Comparisons to real-world data, including grade and speed effects.</li> <li>• Comparisons with California’s EMFAC model, including results, projections, and policy implications.</li> <li>• With FHWA, create a <a href="#">Transportation Pooled Fund Study</a> that would work with state DOTs and FHWA on assessing uncertainty for the entire project level modeling chain. Involve EPA emission modeling and dispersion modeling staff.</li> </ul>	16
N	<p>You may “write in” a recommendation if your recommendation is not listed above.</p>	3

**“Write In” recommendations**

We offered members the opportunity to “Write In” a recommendation if they felt the options listed on the ballot did not capture their highest priorities.

Steven Vander Griend wrote in:

*Mobile Sources* Technical Review Subcommittee (MSTRS) comprises of approximately 30 technical experts drawn from a wide range of stakeholder organizations. The MOVES Model Review Work Group also list multiple outside members but past meetings clearly show EPA controls the direction and decisions of this group. More transparency is needed in future work groups.

Chris Voigt wrote in:

Work with US DOT and state DOTs on development of tool for specifying links for intersections for project-level modeling.