WORK ASSIGNMENT 1-08 UNDER
PRIME CONTRACT 68HE0C18C0001

EXTERNAL PEER REVIEW OF TWO DRAFT TECHNICAL REPORTS FOR EPA'S MOTOR VEHICLE EMISSIONS SIMULATOR (MOVES), VERSION: MOVES_CTI_NPRM

FINAL PEER REVIEW REPORT
January 7, 2020

Submitted to:
U.S. Environmental Protection Agency
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1.0 INTRODUCTION

Eastern Research Group, Inc. (ERG), a contractor to the U.S. Environmental Protection Agency (EPA), organized an independent external peer review of two draft technical reports for EPA's *MOtor Vehicle Emissions Simulator* (Version: MOVES_CTI_NPRM), developed by EPA's Office of Transportation & Air Quality (OTAQ). This document briefly describes ERG's peer review process (Section 2.0). Appendix A provides the technical charge to reviewers; Appendix B provides the individual peer reviewer written comment; Appendix C provides peer reviewer resumes; and Appendix D provides signed peer reviewer conflict of interest (COI) statements.

2.0 PEER REVIEW PROCESS

2.1 Reviewer Search and Selection

For this review, ERG identified, screened, and selected reviewers who had no conflict of interest in performing the review and who collectively met the following technical selection criteria provided by EPA:

- Heavy-duty vehicles emissions, including control strategies and technologies
- Heavy-duty vehicle activity
- Vehicle emissions modeling

ERG screened the pool of interested and available candidates against these selection criteria. From the set of candidates who met those criteria, ERG proposed two candidates to EPA on August 28, 2019. Upon EPA confirmation that the proposed candidates met the selection criteria, ERG confirmed the services of the two final reviewers. ERG contracted with and committed the following two experts to perform the review (see Appendix C for resumes):

- Dana M. Lowell, MBA; Senior Vice President and Technical Director, M.J. Bradley & Associates LLC
- Arvind Thiruvengadam, Ph.D.; Assistant Professor, West Virginia University

2.2 Conducting the Review

ERG provided reviewers with instructions for conducting the review, the review documents, the charge to reviewers prepared by EPA (see Appendix A). ERG instructed reviewers that they should maintain the confidentiality of the review documents and not share the review materials or consult with anyone during the review process. ERG scheduled and facilitated a briefing teleconference with reviewers and EPA on November 13, 2019 to provide reviewers with a background on the materials under review and to answer any questions of clarification on the technical charge, materials, or peer review process. After the briefing teleconference reviewers worked individually (i.e., without contact with other reviewers, colleagues, or EPA) to prepare written comments in response to the charge questions over a three-week period (from November 13 to December 3, 2019).

ERG monitored the review and did not receive any additional questions from reviewers. Upon receipt of the written comments from reviewers, ERG confirmed that all reviewers had responded clearly to all charge questions. The reviewers did not provide any additional technical comments outside of the charge questions nor did they provide any editorial or other non-technical comments. ERG then sent the individual comments to EPA to review for any needed clarifications and compiled this report. Comments are presented exactly as submitted, without editing or correction of typographical errors (if any), both as individual comments and within this report.

APPENDIX A

TECHNICAL CHARGE TO REVIEWERS

Technical Charge to External Peer Reviewers

Contract No. 68HE0C18C0001
Work Assignment 1-08
October 2019

External Peer Review of Draft Reports for EPA's MOtor Vehicle Emissions Simulator (MOVES)

Version: MOVES_CTI_NPRM

BACKGROUND

The US Environmental Protection Agency's (EPA's) Office of Transportation & Air Quality (OTAQ) developed a vehicle emission model, MOtor Vehicle Emissions Simulator (MOVES). MOVES estimates emissions from onroad vehicles and nonroad engines; and uses emissions, activity, and vehicle population data to estimate emissions for a broad range of pollutants. The data and algorithms used in MOVES are documented in technical reports. Any significant updates to the data and/or algorithms in MOVES are documented in draft reports and then subjected to an external peer-review.

In 2017, EPA conducted a peer-review of updates made to the development version of MOVES. This included updates to onroad vehicle population and activity, heavy-duty exhaust emission rates, fuel supply defaults, speciation and toxic emissions from onroad vehicles, and particulate matter emissions from light-duty gasoline vehicles. Since this last round of peer-reviews, the Agency has made significant updates to the development version of MOVES, referred to as "MOVES_CTI_NPRM". These updates have been documented in the two draft MOVES reports that are the subject of this external peer review.

The MOVES reports document the population and activity data and algorithms used in the MOVES version developed to support an upcoming Notice of Proposed Rulemaking (NPRM) for the Cleaner Trucks Initiative (CTI). EPA refers to this version as MOVES_CTI_NPRM. MOVES_CTI_NPRM is updated from MOVES201X, a draft version which was peer-reviewed in 2017, and from MOVES2014b (the latest public release). MOVES_CTI_NPRM also includes the updates included in the MOVES version used to support the Heavy-duty Greenhouse Gas Phase 2 rulemaking (MOVES HDGHG2 FRM). EPA anticipates that MOVES_CTI_NPRM will serve as the foundation for a future MOVES public release.

PURPOSE

The materials provided should be reviewed for selected methods and underlying assumptions, their consistency with the current science as you understand it, and the clarity and completeness of the presentation. For this review, no independent data analysis is required. Rather, EPA asks that you assess whether the information provided is representative of the state of current understanding, and whether incorporating the information into EPA's MOVES model will result in appropriate predictions and conclusions.

As stated above, many of the updates made in these versions of the reports were peer-reviewed in 2017 as part of the draft MOVES201X technical documentation. You are NOT being charged with a review of the material updated for MOVES201X. Your charge is to review only the specified updated sections listed below for each report.

REVIEW MATERIALS

The peer-review consists of the following two draft documents (provided as email attachments):

1. <u>Exhaust Emission Rates for Heavy-Duty Onroad Vehicles in MOVES_CTI NPRM</u>
The peer review of this document should focus on the following updated sections:

- **Heavy-Duty Diesel Vehicles**
  - NO_x exhaust emission rates for model year (MY) 2010+ based on updated f-scale
    - **Section 2.1.1.4.1** (Hole-filling Missing Operating Modes, subsection "Criteria pollutants and energy rates for MY 2010+)
    - **Appendix G** (Selection of Fixed Mass Factor values for MY 2010+ Heavy-Duty Vehicles)
  - $PM_{2.5}$ running exhaust emission rates based on HDIUT
    - **Section 2.1.2.3 (**Data Analysis for MY 2010+ Rates)
  - HC and CO rates for 2010+ based on updated f-scale
    - **Section 2.1.3.2** (Analysis, subsection "2010 and later base rates)
    - **Section 2.1.3.3** (Sample results, with focus on the 2010 and later emission rates
  - Energy rates for MY 2010-2013 vehicles
    - **Sections 2.1.4.3** (LHD2b3, LHD45, MHD, Urban Bus, and HHD Energy Rates for Model Years 2010-2013)
  - Running, start, extended idle, and APU exhaust emissions from glider trucks
    - **Section 2.5** (Glider Vehicle Emissions)
    - **Appendix H** (Comparing Glider Vehicle and MOVES Model Year 2000 Heavy Heavy-Duty Emission Rates)
- **Heavy-Duty Gasoline Vehicles**
  - HC, CO, NO_x, and $PM_{2.5}$ running exhaust emission rates for MY 2010+
    - **Section 3.1.1.6** (LHD, MHD, and HHD for 2010 and later Model Years)
    - **Section 3.1.2.2** (Model Year 2010 + Particulate Matter Emission Rates)
  - Energy rates for MY 2010-2013 vehicles
    - **Section 3.1.3.3** (Energy Rates for LHD2b3 MY 2010-2013 and LHD45, MHD, and HHD MY 2010-2015)
- **Heavy-Duty Compressed Natural Gas (CNG) Vehicles**
  - HC, CO, NO_x, and $PM_{2.5}$ running exhaust emission rates for MY 2010+
    - **Introduction of Section 4** (everything before 4.1)
    - **Section 4.2.1.3** (MY 2007-2009 and MY 2010+)
    - **Section 4.2.2.3** (MY 2010+)

<u>Sections NOT for peer-review but may provide important background include:</u>

- Section 1.3 (Operating Modes, and introduction of f_{scales})
- Section 2.1.1.1 (Data Sources)
- Section 2.1.1.2 (Calculate STP from 1-Hz data)
- Section 2.1.1.3.2 (Emission Rates for 2010-and-beyond Model Years)

2. <u>Population and Activity of Onroad Vehicles</u>
The peer review of this document should focus on the following updated sections:

- Glider truck populations
  - **Section 5.2.6** (Combination Trucks)

- Heavy-Duty Off-Network Idle
  - **Section 10.3**
- Updated National Default Hotelling Rate
  - **Section 11.2**
- Light-duty Starts by Age
  - **Section 12.1.2**
- Heavy-duty Start Activity
  - **Section 12.2**
- Updated bus and heavy-duty vehicle source mass and fixed mass values
  - **Section 15.1**
- Averaging Methods for Heavy-duty Telematics Data
  - **Appendix J**

Sections NOT for peer-review but may provide important background include:

- Section 1 Introduction
- Section 2 MOVES Vehicle and Activity Classifications
- Section 5.2 Sample Vehicle Population
- Section 10.1 Off-Network Idle Calculation Methodology and Definitions
- Section 11 Hotelling Activity

Although, the peer-review charge is limited to the sections outlined above, EPA has provided the full draft reports to you for context. Comments made on the other sections in the report are outside the scope of the peer-review, and any comments made outside of the charge will be addressed at EPA's discretion.

The reports reference other MOVES draft technical reports. These can be provided to reviewers upon request, but EPA does not anticipate that they will be needed for this work.

CHARGE QUESTIONS

EPA requests specific responses to the following questions:

A. Exhaust Emission Rates for Heavy-Duty Onroad Vehicle

A1. Provide comments on the overall technical merit of each updated section listed above in the REVIEW MATERIALS. For example, do you have recommendation for better or alternate data sources used in this section? Do you have questions, concerns, or suggestions for the methods and procedures described in this section? Are the assumptions in this section (if there are any) appropriate and reasonable? Are the resulting model inputs appropriate and reasonable to the best of your knowledge and experience? If not, please explain why and provide examples and suggestions.

A2. For model year 2010+ HD vehicles, EPA updated the values for the fixed mass factor, f_{scale}, so that the high-power operating modes (OpModes) are populated by the real-world emissions data. Previous to this update, many of the high-power OpModes, such as 29, 30, 39, and 40 would be unpopulated and require to be filled with data from lower-power OpModes using "hole-filling" methods. The selection of new f_{scale} values is described in Appendix G and the previously used hole-filling methods are described in Section 2.1.1.4.1, where EPA also shows a comparison of how the old and new f_{scale} values affect the OpMode rate trends.

- Is EPA's method of selecting new f_{scale} values reasonable? Can you identify any shortcomings or areas for improvement?

A3. EPA did not use the NO_x FEL grouping method (section 2.1.1.3.2) for PM because the PM emission data from HDIUT was sparse (section 2.1.2.3) and use of NO_x FEL groups was causing many OpModes to be unpopulated and under-populated. The PM rates in g/mile are comparable to what is reported by other studies, however, MHD rates are *comparatively* higher.

- Are there other data sets, real-world or lab, that EPA can use for comparison or addition to their existing PM data? Is there a reason why MHD PM rates could be higher?

A4. The HDIUT-based CO emission rates for MY 2010+ HHD vehicles were much higher than MHD and LHD vehicles for the same model years from the same data set. In Section 2.1.3.2, EPA discusses a comment from a previous review about drift in CO emissions and their response to the comment where they say the data does not allow them to confirm or deny a drift.

- Is there a reason for HHD vehicles to have much higher CO compared to MHD and LHD vehicles? What can EPA do to further probe the drift issue? Are there other data sets, for LHD, MHD, and HHD, that EPA can compare against? Are there any studies about the said drift in CO emissions that show emission rates with and without the drift?

A5. For the update to MY 2010+ HD gasoline vehicles THC, NO_x, CO, and CO_2 emission rates, EPA used data from an EPA-run test program that included two engine-certified and one chassis-certified HD gasoline vehicles (Section 3.1.1.6). Due to lack of data, EPA combined data from the three vehicles to update rates for all HD regClasses. Thus, EPA did not use the one chassis-certified vehicle to update emission rates for LHD2b3 (predominantly chassis-certified fleet) and the two engine-certified vehicles to update emission rates for LHD45, MHD, and HHD (entirely engine-certified fleet).

- Do you know of any MY 2010+ HD gasoline 1 hz emissions data sets? Is EPA's current approach more reasonable or should EPA use the one chassis-certified vehicle to represent emission rates for the entire fleet of chassis-certified vehicles (regClass LHD2b3)?

A6. The data set (described in Section 3.1.1.6) used to update the THC, NO_x, CO, and CO_2 rates for MY 2010+ HD gasoline vehicles did not have 1 hz PM emissions data. EPA decided to use the MY 2010+ HD diesel data from the HDIUT program to update the gasoline PM rates (Section 3.1.2.2) because the cycle average rates based on real-world diesel vehicle data compare well with the lab filter-based PM measurements from the gasoline vehicles. EPA used the diesel age effects to calculate rates for age 4+ vehicles. EPA used gasoline specific EC and nonEC split.

- Do you know any HD gasoline 1 hz PM emission rate data sets that could be used? Are there any shortcomings with this current approach?

A7. EPA added glider vehicles as a new source type. In Appendix H, EPA compares the emission rates from two glider vehicles tested at US EPA labs with MOVES base emission rates for various model year HD diesel vehicles. EPA selected MY 2000 HD diesel vehicles to be representative of current glider fleet.

- Do you know of additional glider vehicle data sets? Is this current method and resulting emission rates for glider vehicles reasonable?

A8. EPA updated MY 2010+ CNG vehicle emission rates based on data from 11 vehicles from two CNG engine families in the HDIUT data set (see Sections 4.2.1.3 and 4.2.2.3). The zero-mile (age 0) rates are the same for all model years starting 2010.

- Are there other MY 2010+ HD CNG emissions data sets that EPA can consult or incorporate?
- Have CNG vehicle emission rates, for one or more pollutants, changed significantly in recent model year engines and thus, EPA should consider splitting the model year groups as, for example, 2010-2013 and 2014+?

EPA applied the age-based deterioration derived from HD gasoline vehicles to the HD CNG vehicles due to lack of CNG specific deterioration effects and because both vehicle types use stoichiometric combustion with three-way catalyst.

- Is this a reasonable assumption? Do you know of any data sets that can be used to derive CNG specific age-based deterioration ratios?

B. Population and Activity

B1. Provide comments on the overall technical merit of each updated section listed above in the REVIEW MATERIALS. For example, do you have recommendation for better or alternate data sources used in this section? Do you have questions, concerns, or suggestions for the methods and procedures described in this section? Are the assumptions in this section (if there is any) appropriate and reasonable? Are the resulting model inputs appropriate and reasonable to the best of your knowledge and experience? If not, please explain why and provide examples and suggestions.

B2 With the updated start tables and algorithms (Section 12), EPA now has the ability to model the number of starts by vehicle age. For both light-duty (Section 12.1.2) and heavy-duty (Section 12.2.3), EPA adjusted the starts per day based on the mileage accumulation rates such that the starts/mile is constant as the vehicle ages.

- Is this a defensible approach? Are there other datasets or methods you would recommend using to estimate starts as a function of vehicle age?

B3. EPA has also added the ability to model the starts operating mode distribution by vehicle age. As mentioned at the end of Section 12.1.4, MOVES_CTI_NPRM has the capability to model different soak distributions by vehicle age, but EPA is currently using the same soak distribution across all vehicle ages. In general, as vehicles age, it is expected that would be less vehicle starts on average and a soak distribution to shift towards longer soak times. Access to a large data set covering a wider range of ages would help EPA better quantify this.

- Is using a single soak distribution across ages a defensible approach? As described in Section 12.2.1 the Fleet DNA dataset for heavy-duty vehicles is more limited, especially at older vehicle ages. Are there other datasets or methods you would recommend using to estimate soak distributions as a function of vehicle age?

B4. As presented in Section 12.2.2, the starts per day between different vocations within single-unit short-haul trucks have substantial variation. As mentioned, EPA is treating their sample as being representative of the national fleet, because they have not been able to estimate national populations of different vocations represented by the FleetDNA data.

- Are there any other datasets or methods you would recommend using to improve these estimates?

B5. Because glider vehicles have such high emissions, EPA's estimate of their population by model year (Section 5.2.6) is particularly important.

- Do you have any suggestions for improving these estimates and projections?

B6. The average time that combination long-haul trucks spend hotelling, and the fraction of that time spent in extended idle mode both have important implications for emission inventories.

- In addition to the work described here, what data sources or approaches could be used to improve these activity estimates in MOVES?

B7. As discussed in Appendix J, EPA evaluated different methods to summarize the heavy-duty telematics data for use in MOVES. EPA chose Method 3 – "Normalized Sum over Sum", as the method to calculate the idle fraction, start fraction, and soak fractions. In this method, the average fractions are weighted most heavily by the vehicles with the most daily average activity.

- Do you agree with EPA using this approach to summarize the telematics data? Would you also recommend this approach as EPA incorporates additional datasets (e.g., CE-CERT study).

B8. As presented in Figure 12-7, there is substantial variation in the starts per day within the single-unit short-haul sourcetype among different vocations. Thus, the average activity inputs calculated by sourcetype (starts per day, idle fractions), can be very sensitive to the sample of vehicles instrumented. In Appendix J, EPA presents Method 4 –"Vocation and Activity Weighted fraction" as a method to weight the averages to be representative of the national population of vocational vehicles. This method would help control for this variability, by weighting the vehicles from each vocation, to their representative contribution in the national fleet. However, EPA discusses two challenges in being able to implement this approach in Appendix J. 1) Lack of national population data for truck vocations by clearly defined vocations. 2) Insufficient telematics data to represent all important truck vocations.

- Do you have any recommendations of datasets or methods that could be used to address these challenges?

C. Additional Comments (if any)

- Please provide any additional technical comments you would like to make regarding the review documents.
- Please provide any non-technical comments in a separate file (e.g., editorial, organization, formatting, and other minor issues).

APPENDIX B

INDIVIDUAL REVIEWER COMMENTS

COMMENTS RECEIVED FROM
MR. DANA LOWELL

A. Exhaust Emission Rates for Heavy-Duty Onroad Vehicle

A1. Provide comments on the overall technical merit of each updated section listed above in the REVIEW MATERIALS. For example, do you have recommendation for better or alternate data sources used in this section? Do you have questions, concerns, or suggestions for the methods and procedures described in this section? Are the assumptions in this section (if there are any) appropriate and reasonable? Are the resulting model inputs appropriate and reasonable to the best of your knowledge and experience? If not, please explain why and provide examples and suggestions.

Section 2.1.1.4.1

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Appendix G

Table G-1 would be more understandable if data in columns 8-13 was presented as percentage of total cycle time rather than seconds.

Section 2.1.2.3

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 2.1.3.2

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 2.1.3.3

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Sections 2.1.4.3

To calculate energy rates for MY2010 – 2013, why did EPA not analyze only a subset of the available HDUIT data to include only the MY2010-2013 vehicles, instead of using the entire data set, in which 10% of vehicles were MY2014-2015?

Section 2.5

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Appendix H

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 3.1.1.6

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 3.1.2.2

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 3.1.3.3

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Introduction of Section 4

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 4.2.1.3

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 4.2.2.3

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

A2. For model year 2010+ HD vehicles, EPA updated the values for the fixed mass factor, f_{scale}, so that the high-power operating modes (OpModes) are populated by the real-world emissions data. Previous to this update, many of the high-power OpModes, such as 29, 30, 39, and 40 would be unpopulated and require to be filled with data from lower-power OpModes using "hole-filling" methods. The selection of new f_{scale} values is described in Appendix G and the previously used hole-filling methods are described in Section 2.1.1.4.1, where EPA also shows a comparison of how the old and new f_{scale} values affect the OpMode rate trends.

- **Is EPA's method of selecting new f_{scale} values reasonable? Can you identify any shortcomings or areas for improvement?**

In general, the process used to choose f_{scales} seems reasonable. In particular, the final results are well supported by the resulting CO_2 emission rates. My only comment is that the logic behind the preferred time distribution of data among OP modes was not explained – is there data to support that the distribution resulting from the chosen f_{scales} is representative of real-world experience?

A3. EPA did not use the NO_x FEL grouping method (section 2.1.1.3.2) for PM because the PM emission data from HDIUT was sparse (section 2.1.2.3) and use of NO_x FEL groups was causing many OpModes to be unpopulated and under-populated. The PM rates in g/mile are comparable to what is reported by other studies, however, MHD rates are *comparatively* higher.

- **Are there other data sets, real-world or lab, that EPA can use for comparison or addition to their existing PM data? Is there a reason why MHD PM rates could be higher?**

I do not know of any other PM data sets that could be used to supplement this analysis.

The only possible explanation for higher MHD PM rates I can think of is the potential for higher rates of forced emissions system regen, due to differences in duty cycle for MHD versus the other classes (slower speed urban stop and go cycle). However, if this were the explanation one would expect it to be true for urban bus as well.

A4. The HDIUT-based CO emission rates for MY 2010+ HHD vehicles were much higher than MHD and LHD vehicles for the same model years from the same data set. In Section 2.1.3.2, EPA discusses a comment from a previous review about drift in CO emissions and their response to the comment where they say the data does not allow them to confirm or deny a drift.

Is there a reason for HHD vehicles to have much higher CO compared to MHD and LHD vehicles? What can EPA do to further probe the drift issue? Are there other data sets, for LHD, MHD, and HHD, that EPA can compare against? Are there any studies about the said drift in CO emissions that show emission rates with and without the drift?

Based on available data in this report, there is no reason to believe that HHD vehicles consistently suffered CO drift while LHD and MHD vehicles in the same data set did not, so I accept EPA's conclusion that HHD CO data is valid. To further evaluate the CO drift issue, EPA can investigate the specific instruments used for testing HHD vs MHD and LHD vehicles, to see if there was a significant difference (possible since HHD vehicles are typically manufactured by different companies than LHD and MHD vehicles). If HHD vehicles were consistently tested with different instruments, EPA should do a head-to-head comparison with the LHD/MHD instrument(s) to compare results.

A5. For the update to MY 2010+ HD gasoline vehicles THC, NO_x, CO, and CO_2 emission rates, EPA used data from an EPA-run test program that included two engine-certified and one chassis-certified HD gasoline vehicles (Section 3.1.1.6). Due to lack of data, EPA combined data from the three vehicles to update rates for all HD regClasses. Thus, EPA did not use the one chassis-certified vehicle to update emission rates for LHD2b3 (predominantly chassis-certified fleet) and the two engine-certified vehicles to update emission rates for LHD45, MHD, and HHD (entirely engine-certified fleet).

- **Do you know of any MY 2010+ HD gasoline 1 hz emissions data sets? Is EPA's current approach more reasonable or should EPA use the one chassis-certified vehicle to represent emission rates for the entire fleet of chassis-certified vehicles (regClass LHD2b3)?**

On its face, EPA's approach seems reasonable, given the limited set of available data. In general, it would not be reasonable to base emissions factors for any vehicle class on test data from a single vehicle. However, EPA does not state or provide information to show whether measured NOx, CO, and THC emissions rates from the single chassis-certified vehicle was comparable to measured emissions rates from the engine-certified vehicles. Data in Table 3-19 indicates that PM emissions were comparable from all three vehicles, but equivalent data on NOx, CO, and THC is not provided. It would help to justify EPA's chosen approach if they could state or show that emissions from the chassis-certified vehicle were similar to emissions from the other vehicles.

A6. The data set (described in Section 3.1.1.6) used to update the THC, NO_x, CO, and CO_2 rates for MY 2010+ HD gasoline vehicles did not have 1 hz PM emissions data. EPA decided to use the MY 2010+ HD diesel data from the HDIUT program to update the gasoline PM rates (Section 3.1.2.2) because the cycle average rates based on real-world diesel vehicle data compare well with the lab filter-based PM measurements from the gasoline vehicles. EPA used the diesel age effects to calculate rates for age 4+ vehicles. EPA used gasoline specific EC and nonEC split.

- **Do you know any HD gasoline 1 hz PM emission rate data sets that could be used? Are there any shortcomings with this current approach?**

The current approach seems reasonable given available data and correlation to cycle average results from lab testing.

A7. EPA added glider vehicles as a new source type. In Appendix H, EPA compares the emission rates from two glider vehicles tested at US EPA labs with MOVES base emission rates for various model year HD diesel vehicles. EPA selected MY 2000 HD diesel vehicles to be representative of current glider fleet.

- **Do you know of additional glider vehicle data sets? Is this current method and resulting emission rates for glider vehicles reasonable?**

I don't know of any other glider data. EPA's methodology to choose glider emissions rates is sound, and the resulting proposed emission rates are reasonable.

A8. EPA updated MY 2010+ CNG vehicle emission rates based on data from 11 vehicles from two CNG engine families in the HDIUT data set (see Sections 4.2.1.3 and 4.2.2.3). The zero-mile (age 0) rates are the same for all model years starting 2010.

- **Are there other MY 2010+ HD CNG emissions data sets that EPA can consult or incorporate?**

- **Have CNG vehicle emission rates, for one or more pollutants, changed significantly in recent model year engines and thus, EPA should consider splitting the model year groups as, for example, 2010-2013 and 2014+?**

I have no further information about this subject.

EPA applied the age-based deterioration derived from HD gasoline vehicles to the HD CNG vehicles due to lack of CNG specific deterioration effects and because both vehicle types use stoichiometric combustion with three-way catalyst.

- **Is this a reasonable assumption? Do you know of any data sets that can be used to derive CNG specific age-based deterioration ratios?**

Based on similarity in combustion regime and aftertreatment between HD gasoline and NG engines EPA's chosen approach to NG engine deterioration factors is reasonable.

B. Population and Activity

B1. Provide comments on the overall technical merit of each updated section listed above in the REVIEW MATERIALS. For example, do you have recommendation for better or alternate data sources used in this section? Do you have questions, concerns, or suggestions for the methods and procedures described in this section? Are the assumptions in this section (if there is any) appropriate and reasonable? Are the resulting model inputs appropriate and reasonable to the best of your knowledge and experience? If not, please explain why and provide examples and suggestions.

Section 5.2.6

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 10.3

In section 10.3.4, on page 78, it says: "Figure 10-4 and Figure 10-5 show the idle fraction values for weekends and weekdays, respectively. In both figures, the solid blue bars represent the off-network idle for each heavy-duty vehicle source type". Based on the first sentence above, other description in the text, and the titles of these figures, it appears to me that the blue bars do not represent "off-network idle", but rather represent "Total Idle Fraction" for each vehicle type. According to the description in Section 10.1, Off-network Idle = Total Idle - Source Hours Idle (SHI), with SHI the amount of idle included in MOVES driving schedules. The current text is therefore confusing and implies that total idle time is over-counted.

Section 11.2

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 12.1.2

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

Section 12.2

Section 12.2.2: Based on the data in Figure 12-7 and Table 12-3, it appears that EPA's proposed value for weekday starts/day for Source Type 52 (Single Unit, short) effectively assumes that at least 30% of this source category are parcel delivery trucks. This seems very high, and therefore starts/day for this source category are likely overstated, perhaps significantly. EPA should at least do a first order estimate to evaluate the reasonableness of this result, using available data. For example, it should be possible to identify the 10 largest national parcel delivery companies, and to use the IHS/Polk commercial truck data base to identify the number of single unit trucks registered by these companies. This number could then be compared to MOVES estimate of total vehicles in Source Type 52. Based on Figure 12-7, only parcel delivery trucks could have an outsized effect on the calculation of starts per day for source type 52, so this is the only specific vocation that requires additional analysis.

Section 15.1

On page 131, EPA states that for all medium heavy-duty and heavy heavy-duty buses "average source mass is the mid-point between the curb weight and fully-loaded weight", with curb and fully-loaded weights based on a report by APTA. This methodology likely overstates the average source mass of these vehicles by at least 1,500 pounds. From EPA's description it is not clear whether "fully-loaded weight" assumes only a seated load or a seated plus standing load. If based on seated load only, it is likely based on ~36 seats, so that average source mass would be based on curb weight plus the weight of ~18 passengers. If fully loaded weight includes standees, then average source mass would be based on curb weight plus the weight of even more passengers. However, according to data submitted by transit agencies to the National Transit Database, in 2017 the mile-weighted average passenger load for all bus transit service was 8.5 passengers, which accounts for all scheduled bus miles and dead-head miles. This number was calculated by dividing Passenger-miles by vehicle miles, for modes MB (motor bus), CB (commuter bus) and RB (rapid bus) as shown in the Annual Data Table 2017, Service, which can be down-loaded from the NTD website. It is standard in the transit industry to assume an average passenger load of 150 pounds, so EPA's assumed average source mass for buses is likely overstated by at least 1,500 pounds (10 passengers x 150 lb/passenger).

Appendix J

The assumptions in this section are appropriate and reasonable, and the resulting modeling inputs are appropriate and reasonable to the best of my knowledge and experience.

B2 With the updated start tables and algorithms (Section 12), EPA now has the ability to model the number of starts by vehicle age. For both light-duty (Section 12.1.2) and heavy-duty (Section 12.2.3), EPA adjusted the starts per day based on the mileage accumulation rates such that the starts/mile is constant as the vehicle ages.

- **Is this a defensible approach? Are there other datasets or methods you would recommend using to estimate starts as a function of vehicle age?**

The method EPA used to calculate number of starts by vehicle age implicitly assumes that annual mileage falls as vehicles age because vehicle owners takes fewer daily trips in older vehicle than in newer vehicles. I think it is equally plausible that annual mileage falls as vehicles age not because they are used for fewer total trips, but rather because they are used only for short trips (which dominate total trips) but not less frequent longer trips. If this alternate assumption is true, then EPA's method for calculating number of starts by vehicle age is faulty.

In section 10.2.1, which describes the Verizon Telematics Data used to calculate daily vehicle starts it says "In addition to the trip data, each trip was associated with a vehicle ID. For each vehicle ID, the model year and vehicle registration postal ZIP code was provided". Given that every trip, and therefore every start, in the Verizon database could be associated with a specific model year vehicle, why can't EPA separate the start data into vehicle age bins and directly calculate daily starts by vehicle age?

B3. EPA has also added the ability to model the starts operating mode distribution by vehicle age. As mentioned at the end of Section 12.1.4, MOVES_CTI_NPRM has the capability to model different soak distributions by vehicle age, but EPA is currently using the same soak distribution across all vehicle ages. In general, as vehicles age, it is expected that would be less vehicle starts on average and a soak distribution to shift towards longer soak times. Access to a large data set covering a wider range of ages would help EPA better quantify this.

- **Is using a single soak distribution across ages a defensible approach? As described in Section 12.2.1 the Fleet DNA dataset for heavy-duty vehicles is more limited, especially at older vehicle ages. Are there other datasets or methods you would recommend using to estimate soak distributions as a function of vehicle age?**

EPA's approach is defensible, and I don't know of any other data sets or methods that could be used to generate better data.

B4. As presented in Section 12.2.2, the starts per day between different vocations within single-unit short-haul trucks have substantial variation. As mentioned, EPA is treating their sample as being representative of the national fleet, because they have not been able to estimate national populations of different vocations represented by the FleetDNA data.

- **Are there any other datasets or methods you would recommend using to improve these estimates?**

Based on the data in Figure 12-7 and Table 12-3, it appears that EPA's proposed value for weekday starts/day for Source Type 52 (Single Unit, short) effectively assumes that at least 30% of this source category are parcel delivery trucks. This seems very high, and therefore starts/day for this source category are likely overstated, perhaps significantly. EPA should at least do a first order estimate to evaluate the reasonableness of this result, using available data. For example, it should be possible to identify the 10 largest national parcel delivery companies, and to us the IHS/Polk commercial truck data base to identify the number of single unit trucks registered by these companies. This number could then be compared to MOVES estimate of total vehicles in Source Type 52. Based on Figure 12-7, only parcel delivery trucks could have an outsized effect on the calculation of starts per day for source type 52, so this is the only specific vocation that requires additional analysis.

B5. Because glider vehicles have such high emissions, EPA's estimate of their population by model year (Section 5.2.6) is particularly important.

- **Do you have any suggestions for improving these estimates and projections?**

The proposed Glider population estimates assume that 1,500 new gliders will be produced each year in 2018 and subsequent years. The logic for calculating this population estimate is based on the revised glider rules contained in EPA's 2011 Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2 rulemaking, which restricted the number of new gliders that each manufacturer could produce each year to 300 or actual 2014 sales volume, whichever was smaller. However, in 2017 EPA issued a proposal to repeal these restrictions, and in fact to allow unlimited glider production moving forward. EPA then issued a no-action assurance saying it would not enforce the 2011 restrictions while the new rules were being finalized. While EPA has subsequently withdrawn this no action assurance, news reports indicate that EPA is still working on revised Glider rules, to be finalized by the end of 2019, and that the EPA Administrator has stated to congress that the final rules would "help protect the glider industry from going out of business or substantially reducing its economic growth potential".

Given the above facts, EPA should update their estimate of annual glider production for 2018 and subsequent years to reflect the revised final glider rules under development, or categorically state that the 2011 restrictions will be maintained in the forthcoming rulemaking.

B6. The average time that combination long-haul trucks spend hotelling, and the fraction of that time spent in extended idle mode both have important implications for emission inventories.

- **In addition to the work described here, what data sources or approaches could be used to improve these activity estimates in MOVES?**

The described approach to developing revised hoteling estimates - default hoteling rate and hoteling activity distributions - is reasonable, given the cited available data sources. Of these assumptions, the revised default hoteling rate is the most well supported, as it is based on three different, and consistent data sources. The proposed hoteling activity distributions - especially assumed future adoption rates for APUs and auxiliary battery/AC systems (Table 11-2) - are significantly less certain and should be the focus of future updates. EPA's decision to base these estimates on the regulatory analysis developed for the Heavy-Duty Greenhouse Gas Standards Phase 2 is reasonable, but in the future EPA should identify data sources that can be used to confirm or adjust these assumptions.

B7. As discussed in Appendix J, EPA evaluated different methods to summarize the heavy-duty telematics data for use in MOVES. EPA chose Method 3 – "Normalized Sum over Sum", as the method to calculate the idle fraction, start fraction, and soak fractions. In this method, the average fractions are weighted most heavily by the vehicles with the most daily average activity.

- **Do you agree with EPA using this approach to summarize the telematics data? Would you also recommend this approach as EPA incorporates additional datasets (e.g., CE-CERT study).**

I agree that "Normalized Sum over Sum" is the correct method for summarizing currently available data and should also be used in the future as additional data becomes available.

B8. As presented in Figure 12-7, there is substantial variation in the starts per day within the single-unit short-haul sourcetype among different vocations. Thus, the average activity inputs calculated by sourcetype (starts per day, idle fractions), can be very sensitive to the sample of vehicles instrumented. In Appendix J, EPA presents Method 4 –"Vocation and Activity Weighted fraction" as a method to weight the averages to be representative of the national population of vocational vehicles. This method would help control for this variability, by weighting the vehicles from each vocation, to their representative contribution in the national fleet. However, EPA discusses two challenges in being able to implement this approach in Appendix J. 1) Lack of national population data for truck vocations by clearly defined vocations. 2) Insufficient telematics data to represent all important truck vocations.

- **Do you have any recommendations of datasets or methods that could be used to address these challenges?**

I agree that data used in MOVES should be based on Vocation and Activity Weighted analysis of available in-use data, to better represent the national population of vocational vehicles. I agree that there is a lack of national population data for truck vocations, primarily because the best available data set is based on vehicle registrations and relies on data encoded in the vehicle VIN number. However, the VIN is assigned by the original OEM and usually does not include data on vocational bodies/configurations installed by secondary manufacturers.

For future updates EPA could consider issuing an Information Collection Request to truck OEMs and secondary manufacturers, to collect data on annual sales of vehicles in different vocational categories, to develop better data on the distribution of vocational vehicles.

For this update, as noted in B.4, the value of starts per day for Source Type 52 appears to be unduly influenced by the in-use data collected from parcel delivery trucks. EPA should conduct additional analysis to get a better estimate of the national population of these trucks, and correct Source Type 52 starts per day if warranted.

C. Additional Comments (if any)

- **Please provide any additional technical comments you would like to make regarding the review documents.**
- **Please provide any non-technical comments in a separate file (e.g., editorial, organization, formatting, and other minor issues).**

None.

COMMENTS RECEIVED FROM
DR. ARVIND THIRUVENGADAM

A. Exhaust Emission Rates for Heavy-Duty Onroad Vehicle

A1. Provide comments on the overall technical merit of each updated section listed above in the REVIEW MATERIALS. For example, do you have recommendation for better or alternate data sources used in this section? Do you have questions, concerns, or suggestions for the methods and procedures described in this section? Are the assumptions in this section (if there are any) appropriate and reasonable? Are the resulting model inputs appropriate and reasonable to the best of your knowledge and experience? If not, please explain why and provide examples and suggestions.

The updates presented in this version of the MOVES report addresses some of the key questions that were raised in the previous version of the report. I had a chance to review the previous version of the report and my comments are attached in Appendix K of this updated version of this MOVES report.

In relation to the topic of emission rates of different regulated pollutants, the reviewer believes that the updates to the NOx, PM, CO and THC emissions rates due to the change in fscale value is appropriate. Since, the changes in the emission rates in the different op-modes is directly related to the change in fscale value for the newer MY vehicles, the reviewer would like to specifically focus on the approach used to update the fscale. Question A.2 is linked to this topic and the reviewer's comments in relation to fscale values is provided in detail in that section.

A2. For model year 2010+ HD vehicles, EPA updated the values for the fixed mass factor, fscale, so that the high-power operating modes (OpModes) are populated by the real-world emissions data. Previous to this update, many of the high-power OpModes, such as 29, 30, 39, and 40 would be unpopulated and require to be filled with data from lower-power OpModes using "hole-filling" methods. The selection of new fscale values is described in Appendix G and the previously used hole-filling methods are described in Section 2.1.1.4.1, where EPA also shows a comparison of how the old and new fscale values affect the OpMode rate trends.

- **Is EPA's method of selecting new f_{scale} values reasonable? Can you identify any shortcomings or areas for improvement?**

The current version of the report provides updated fscale values in an effort to fill the missing op-modes from the previous version. I had noted a similar comment in my previous review attached in Appendix K that some of the high-power and high-speed op-modes seem to be not representative of real-world operation and as a result they remain unpopulated. The reviewer understands that the choice of fscale could over populate or under populate these high-power op-modes, however, I believe some additional clarity is needed on what the basis or the need to fill these op-modes.

In real-world conditions, these op-modes could have data in them, however, due to the use of scaled tractive power we could be shifting data out of these bins. Therefore, the reviewer suggests analyzing the power from the ECU as a surrogate to scaled tractive power to assess whether these op-modes are truly significant and do indeed populate during chassis dynamometer testing or real-world in-use testing.

The reviewer feels that the explanation provided in the documents appears as if the choice of appropriate fscale value is motivated by the effort to fill these missing op-modes and not necessarily finding a fscale value that is indicative of the average mass of vehicle (as mentioned in Appendix G). the report clearly mentions in Page 24 of 2.1.1.4.1 that vehicles typically do not operate in those power-speed bins, but later does not provide an accurate explanation of why hole-filling is required for these bins.

Reviewing Appendix G, the explanation of how the fscale values are selected does not accurately summarize the scientific approach that may be used in deriving the final updated scale value. The description of the process seems to indicate that the fscale was chosen not to over populate or under populate the high power-speed bins. It would help if the report could suggest what is the definition of over populating or under populating the bins numerically mean in relation to real-world data.

Line 46, Page 213 mentions “fscale values between candidate values……. Look reasonably good”. The reviewer believes that the phrase reasonably has to be defined better. Reasonably, seems to be a very subjective phrase. There needs to be a real-world statistical perspective associated with “reasonably”

Line 9, Page 214: “We did not expect…….”. Again, the report needs to clarify what “expect” is based on a comparison to real-world data. “Expect” in that sentence seems very subjective and begs the question of what the expectation is?

One approach that could improve or provide support to the fscale choice is to use ECU data from some sample vehicles to compare actual power-speed bins with the scaled tractive power-speed bins and show a similar distribution and the choice of fscale value doesn’t induce an artifact in the way the emissions rate is distributed would be helpful. I believe many of the subjective statements in the Appendix G and fscale section of the report can be clarified by comparing it with the seed dataset, which in this case is HDIUT data and studies that were conducted by WVU (ARB sponsored study, in Southern California).

The cross-California study, which I will refer to in this review frequently, tested 5 heavy-duty vehicles from all OEMs over comparable vehicle weights during real-world operating conditions. This study can be a good data source to corroborate fscale and power-speed op-modes.

A3. EPA did not use the NO_x FEL grouping method (section 2.1.1.3.2) for PM because the PM emission data from HDIUT was sparse (section 2.1.2.3) and use of NO_x FEL groups was causing many OpModes to be unpopulated and under-populated. The PM rates in g/mile are comparable to what is reported by other studies, however, MHD rates are *comparatively* higher.

- **Are there other data sets, real-world or lab, that EPA can use for comparison or addition to their existing PM data? Is there a reason why MHD PM rates could be higher?**

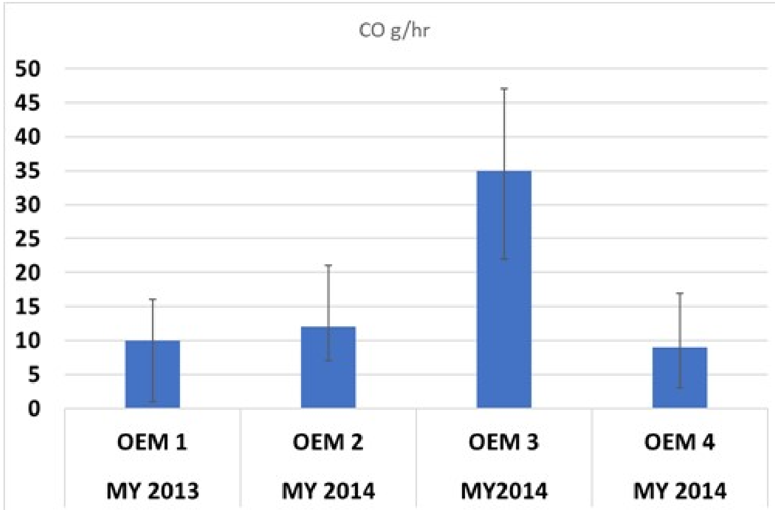
The reviewer is in agreement that the PM rates presented are similar to results observed during real-world studies. The DPF is highly efficient for most part of the vehicle operation that instantaneous PM measurements are subject to a lot of noise. Based on real-world emissions testing experience, the effect of passive regeneration is mostly observed during a steep hill climb operation, which would be characterized by speeds between 30-45 mph and close to full power. Based on the op-mode definition one would expect modes 28, 29, 30 and in some cases mode 38 and 39 to be characterized by highest PM emissions as a result of passive regeneration. The literature reference 157 is an excellent source of PM data for modern HHD vehicles. An array of PM instruments was employed and instantaneous PM measurements using micro-soot sensor, Pegasor tailpipe sensor and a Horiba SPCS was performed. This data set would uniquely differ from HDIUT dataset due to the steep hill climb routes tested in Southern California at a vehicle weight of 69,000 lbs.

The trend of MHD vehicle PM emissions rate being higher than HHD could be attributed to a different type of DPF. MHD diesel engines in my opinion would be mainly dominated by Cummins ISB platforms and Ford Navistar 6-liter engine platforms. I believe there is significant difference in the DPF material used between the two OEMS and the type of regeneration they would be subject to. In the reviewer's experience, some MHD OEM use SiC substrate while some use the Corderite based substrate. Although both substrates provide excellent filtration efficiency, backpressure management dictates the frequency of regeneration between the two substrates. From my experience, SiC substrate requires more frequent regeneration than corderite and the consequent drop in filtration efficiency could be attributed to higher PM rates. Furthermore, the highly catalyzed corderite substrates could also be subject to extended passive regeneration due to conducive exhaust temperatures unlike in HHD applications. This could also lead to higher PM emissions rate.

A4. The HDIUT-based CO emission rates for MY 2010+ HHD vehicles were much higher than MHD and LHD vehicles for the same model years from the same data set. In Section 2.1.3.2, EPA discusses a comment from a previous review about drift in CO emissions and their response to the comment where they say the data does not allow them to confirm or deny a drift.

- **Is there a reason for HHD vehicles to have much higher CO compared to MHD and LHD vehicles? What can EPA do to further probe the drift issue? Are there other data sets, for LHD, MHD, and HHD, that EPA can compare against? Are there any studies about the said drift in CO emissions that show emission rates with and without the drift?**

The CO emissions rate presented in this report does seem high compared to results observed during real-world testing. The cross California study conducted by WVU measured regulated emissions using a CVS and simultaneously with two different commercially available PEMS instrumentation. The figure below shows the average CO emissions rate over all the routes operated on each test vehicle with error bars showing maximum and minimum values. The figure shows CVS CO emissions rate are close to half the emissions rate shown for a MY 2015 vehicle in Figure 2-26 of the Moves report. The CO analyzer measuring from the CVS can be considered to be a laboratory grade analyzer that is not subject to drift issues such as the PEMs instrumentation.



Furthermore, a sample dataset from the same study reveals that for a test when the CVS CO emissions rate was calculated to be 10.65 g/hr, CO emissions rate from PEMS 1 was reported to be 46.64 g/hr and PEMS 2 reported it to be 247.35 g/hr. From a brake-specific emissions CO emission are well below the certification value and hence these variations are not given importance. However, from an inventory standpoint, the reviewer believes that dataset such as the cross California study and the current study funded by AQMD, executed by UC Riverside and WVU will lend a wealth of data to correct for the PEMS inaccuracy.

A5. For the update to MY 2010+ HD gasoline vehicles THC, NO_x, CO, and CO_2 emission rates, EPA used data from an EPA-run test program that included two engine-certified and one chassis-certified HD gasoline vehicles (Section 3.1.1.6). Due to lack of data, EPA combined data from the three vehicles to update rates for all HD regClasses. Thus, EPA did not use the one chassis-certified vehicle to update emission rates for LHD2b3 (predominantly chassis-certified fleet) and the two engine-certified vehicles to update emission rates for LHD45, MHD, and HHD (entirely engine-certified fleet).

- **Do you know of any MY 2010+ HD gasoline 1 hz emissions data sets? Is EPA's current approach more reasonable or should EPA use the one chassis-certified vehicle to represent emission rates for the entire fleet of chassis-certified vehicles (regClass LHD2b3)?**

Do you know of any MY 2010+ HD gasoline 1 hz emissions data sets? Is EPA's current approach more reasonable or should EPA use the one chassis-certified vehicle to represent emission rates for the entire fleet of chassis-certified vehicles (regClass The reviewer agrees that gasoline fueled vehicles in the heavy-duty category are sparse and chassis dynamometer studies of gasoline vehicles are not common. Given the availability of data, I believe EPA's approach is reasonable to incorporate emissions rates from gasoline HD vehicles. Many of the current and previous studies of spark ignited HD vehicles include only Propane and natural gas vehicles which is not appropriate for this category of vehicles.

A6. The data set (described in Section 3.1.1.6) used to update the THC, NO_x, CO, and CO_2 rates for MY 2010+ HD gasoline vehicles did not have 1 hz PM emissions data. EPA decided to use the MY 2010+ HD diesel data from the HDIUT program to update the gasoline PM rates (Section 3.1.2.2) because the cycle average rates based on real-world diesel vehicle data compare well with the lab filter-based PM measurements from the gasoline vehicles. EPA used the diesel age effects to calculate rates for age 4+ vehicles. EPA used gasoline specific EC and nonEC split.

- Do you know any HD gasoline 1 hz PM emission rate data sets that could be used? Are there any shortcomings with this current approach?

The EPA's approach to use 2010+ HD diesel data to update gasoline PM rates seems reasonable comparing a DPF-SCR equipped Diesel with a TWC equipped gasoline. However, operational characteristics could incorporate significant difference in PM emissions rate from gasoline engines. In specific low-load operation could lead to higher PM rates from lubrication oil combustion from aged gasoline vehicles. However, due to the lack of 1 Hz data, diesel PM emissions rate with a EC/OC split pertaining to gasoline is an appropriate approach.

A7. EPA added glider vehicles as a new source type. In Appendix H, EPA compares the emission rates from two glider vehicles tested at US EPA labs with MOVES base emission rates for various model year HD diesel vehicles. EPA selected MY 2000 HD diesel vehicles to be representative of current glider fleet.

- **Do you know of additional glider vehicle data sets? Is this current method and resulting emission rates for glider vehicles reasonable?**

For the glider vehicle emissions rate, the use of MY 2000 HD vehicle emissions rate in my opinion would be the most representative. From a traditional trucker perspective, EGR is perceived to be the biggest issue with modern emissions control systems. Most legacy truckers would prefer vehicles without EGR. The glider vehicle platform caters specifically to this need. A new chassis on a pre-emissions control, re-built diesel engine. The section related to updating glider vehicle emissions rate is very concise and detailed. The assumptions are sound and, in my opinion, would reasonably reflect the emissions rates of in-use glider vehicles. There is a deviation in the emissions rate in the extrapolated regions of the higher op-modes. However, since these vehicles do not have an aftertreatment system and in-cylinder combustion control, its reasonable to extrapolate the time-specific emissions with higher load.

The reviewer does feel that the CO emissions rate exhibits an uncharacteristic behavior compared to OEM engines of MY 1998-2006. The reviewer is not sure if this could be attributed to the effect of rebuilt components in the engine, for instance non-OEM fuel injectors, modified piston-bowl profile etc.

A8. EPA updated MY 2010+ CNG vehicle emission rates based on data from 11 vehicles from two CNG engine families in the HDIUT data set (see Sections 4.2.1.3 and 4.2.2.3). The zero-mile (age 0) rates are the same for all model years starting 2010.

- **Are there other MY 2010+ HD CNG emissions data sets that EPA can consult or incorporate?**

- **Have CNG vehicle emission rates, for one or more pollutants, changed significantly in recent model year engines and thus, EPA should consider splitting the model year groups as, for example, 2010-2013 and 2014+?**

EPA applied the age-based deterioration derived from HD gasoline vehicles to the HD CNG vehicles due to lack of CNG specific deterioration effects and because both vehicle types use stoichiometric combustion with three-way catalyst.

- **Is this a reasonable assumption? Do you know of any data sets that can be used to derive CNG specific age-based deterioration ratios?**

There are three studies that have a wealth of information related to HD CNG vehicles emissions rate for different vocations, mainly for urban buses.

1) 22 vehicle AQMD chassis dynamometer testing study (2011): Study jointly conducted by WVU and Ce-CERT tested CNG vehicles from different vocation over chassis dynamometer. The vehicle population would include vehicles from MY 2007-2010.

2) WVU-CARB CNG Bus Study in Sacramento: This study involved the real-world testing of two CNG buses in Sacramento using PEMS. The study employed both an FTIR and a commercial PEMS to quantify both ammonia, N2O and regulated pollutants.

3) WVU Cross California study (Reference #157): This study tested one MY 2013 CNG tractor, with a 12-liter Cummins engine. This study will also present accurate 1 Hz PM emissions rate for CNG tractor.

In addition, the currently on-going study jointly conducted by WVU and Ce-CERT funded by AQMD that will result in data for close to 50 CNG vehicles of different vocations will be an important addition. The current study will feature much newer CNG platforms.

Deterioration rates of CNG vehicles is an important parameter. The use of gasoline vehicle deterioration rates for CNG vehicles may not be appropriate for all vocations. Results from the 22 vehicle AQMD study has shown that transit buses and refuse haulers show higher rate of deterioration compared to Class7-8 tractor applications. CNG vehicles exhibit duty-cycle based aging which is not a function of years. The aging results in higher NOx and PM emissions. Data showing the deterioration effect of same vehicle over a long period is probably not available, however a comparison of vehicles with same model years with different engine hours accumulated or miles accumulated could exhibit the deterioration trend. Limited data pointing towards this trend is available in the 22 vehicle study, but a more in-depth analysis will be available at the end of the on-going AQMD funded study.

B. Population and Activity

B1. Provide comments on the overall technical merit of each updated section listed above in the REVIEW MATERIALS. For example, do you have recommendation for better or alternate data sources used in this section? Do you have questions, concerns, or suggestions for the methods and procedures described in this section? Are the assumptions in this section (if there is any) appropriate and reasonable? Are the resulting model inputs appropriate and reasonable to the

best of your knowledge and experience? If not, please explain why and provide examples and suggestions.

The estimation of the glider truck population seems appropriate. It is almost imperative to get the data directly from the glider kit manufacturers on the volume of vehicles sold. Is there a justification for the use of 2014 numbers were used for 2017?

The use of Ce-CERT data for the estimation of HD Off-Network idle activity is a valuable source. However, the reviewer believes that California clean-idle requirements might underestimate idle running of vehicles in other parts of the country. Trucks not registered in California may not have auto idle shut-off enabled and as a result may exhibit a longer idle activity.

B2 With the updated start tables and algorithms (Section 12), EPA now has the ability to model the number of starts by vehicle age. For both light-duty (Section 12.1.2) and heavy-duty (Section 12.2.3), EPA adjusted the starts per day based on the mileage accumulation rates such that the starts/mile is constant as the vehicle ages.

- **Is this a defensible approach? Are there other datasets or methods you would recommend using to estimate starts as a function of vehicle age?**

I agree with the EPA's approach to model starts/mile as constant even as vehicle ages. The reviewer agrees that vehicle miles accumulated will decrease as vehicle ages. The decrease in mileage accumulated would be more significant with older vehicles than relatively new ones. Since the Verizon data shows clearly that starts per day is decreasing with increasing age of vehicle, while the mileage accumulated is also decreasing with age, I believe its defensible approach to consider a constant start/mile.

B3. EPA has also added the ability to model the starts operating mode distribution by vehicle age. As mentioned at the end of Section 12.1.4, MOVES_CTI_NPRM has the capability to model different soak distributions by vehicle age, but EPA is currently using the same soak distribution across all vehicle ages. In general, as vehicles age, it is expected that would be less vehicle starts on average and a soak distribution to shift towards longer soak times. Access to a large data set covering a wider range of ages would help EPA better quantify this.

- **Is using a single soak distribution across ages a defensible approach? As described in Section 12.2.1 the Fleet DNA dataset for heavy-duty vehicles is more limited, especially at older vehicle ages. Are there other datasets or methods you would recommend using to estimate soak distributions as a function of vehicle age?**

The soak-time distribution provided in Table 12-2 has adequate resolution to include vehicles of all ages. The current approach of using the same soak distribution for all ages is justified. One addition to the existing soak distribution could be the inclusion of a finer resolution between 120 and 360 minutes to incorporate some older vehicle soak times with lesser starts. Telemetry data such as the Verizon data would be the appropriate source.

The incorporation of the CE-CERT activity data should provide a wealth of information on soak times for heavy-duty vehicles and number of starts per day. However, the CE-CERT data would include only long-haul or delivery trucks. Also, the report details that start is defined as “engine speed transitioning from zero to greater than zero”. Again, the auto-idle-shut-off feature in California vehicles could potentially bias the data for the national average. In the reviewer’s opinion out of state trucks in California do not undergo auto-idle-shut-off as trucks registered in California. The ongoing study funded by AQMD is also an excellent source of telemetry data for various HD vocations that can provide information on start and soak times for HD vehicles.

WVU is working with EMA on a telemetry data collection for 100 HD vehicles of long-haul, construction and delivery applications. Although the data may not be publicly available, the telemetry data recorded will be a rich dataset to strengthen and improve estimates of start and soak time.

B4. As presented in Section 12.2.2, the starts per day between different vocations within single-unit short-haul trucks have substantial variation. As mentioned, EPA is treating their sample as being representative of the national fleet, because they have not been able to estimate national populations of different vocations represented by the FleetDNA data.

- **Are there any other datasets or methods you would recommend using to improve these estimates?**

The only comment the reviewer has w.r.t using CE-CERT data or the upcoming AQMD funded study data would be to consider the bias of California registered vehicles to possibly be associated with more frequent starts/day compared to other regions in the country. Similarly, the Soak times could be biased towards shorter intervals due to high traffic density, and engine shut-off during frequent stops in high traffic.

Most OEMs have large fleet of their vehicles instrumented with data loggers. Ideally this would be this most appropriate source of data, since, OEM instrumented vehicles are spread throughout the country. However, the reviewer is not sure if “non-sensitive” information such as vehicle starts and soak-time would be something that is shareable by the OEM, or if any partnership such as this exists between OEM and USEPA.

B5. Because glider vehicles have such high emissions, EPA’s estimate of their population by model year (Section 5.2.6) is particularly important.

- **Do you have any suggestions for improving these estimates and projections?**

Given the importance of glider vehicle emissions a large-scale surveying process is required to assess the model year-based population model. Furthermore, the chassis model year will not be indicative of the engine model year used in the glider vehicle. Nevertheless, remote sensing studies can offer an excellent source of information for model year population from glider vehicles. Dr. Bishop’s research in University of Denver, with FEAT remote sensing studies have published studies that show excessive NOx emissions from newer chassis model year. These excessive NOx emissions from new model year trucks have been attributed to Glider vehicles. Remote sensing studies usually result in a large population set and analyzing the data for high NOx emissions from newer model year chassis will indicate the glider vehicle population distribution.

B6. The average time that combination long-haul trucks spend hotelling, and the fraction of that time spent in extended idle mode both have important implications for emission inventories.

- **In addition to the work described here, what data sources or approaches could be used to improve these activity estimates in MOVES?**

Telemetry data collected by Ce-CERT, and the on-going AQMD funded study carried out by WVU and CE-CERT will be a good source of large-scale vehicle activity data that can improve extended idling mode estimations. Specifically, for drayage and delivery applications that are characterized by extended idle. However, in my opinion both these datasets may not be helpful in providing better estimates for hoteling time fraction. Fleet surveys of long-haul fleets could be an efficient way of gathering hoteling information. Fleet surveys could potentially give clarity to the fraction of fleets that use relief drivers or use APUs for hoteling loads.

B7. As discussed in Appendix J, EPA evaluated different methods to summarize the heavy-duty telematics data for use in MOVES. EPA chose Method 3 – "Normalized Sum over Sum", as the method to calculate the idle fraction, start fraction, and soak fractions. In this method, the average fractions are weighted most heavily by the vehicles with the most daily average activity.

- **Do you agree with EPA using this approach to summarize the telematics data? Would you also recommend this approach as EPA incorporates additional datasets (e.g., CE-CERT study).**

The reviewer agrees with the "normalized sum over sum" approach to calculate idle emissions fraction. Figure J-1 is indicative of the differences between Method 1 and Method 3. For the refuse truck application, Method 1 under represents the idle fraction. The idle fraction calculated using Method 3 is much more representative of real-world idle fraction of refuse trucks. Similarly, for the case single short trucks that are typically used for delivery operation, Method 3 provides a better estimation. This would be an appropriate approach for future datasets as well.

B8. As presented in Figure 12-7, there is substantial variation in the starts per day within the single-unit short-haul sourcetype among different vocations. Thus, the average activity inputs calculated by sourcetype (starts per day, idle fractions), can be very sensitive to the sample of vehicles instrumented. In Appendix J, EPA presents Method 4 –"Vocation and Activity Weighted fraction" as a method to weight the averages to be representative of the national population of vocational vehicles. This method would help control for this variability, by weighting the vehicles from each vocation, to their representative contribution in the national fleet. However, EPA discusses two challenges in being able to implement this approach in Appendix J. 1) Lack of national population data for truck vocations by clearly defined vocations. 2) Insufficient telematics data to represent all important truck vocations.

- **Do you have any recommendations of datasets or methods that could be used to address these challenges?**

The issue of lack of information for national averages for vocation population of vehicle is an interesting one to solve. I believe there is no one single approach to gather data of this magnitude. As the report indicates, vehicle registration can offer accurate data for some vocations, however some vehicle registration category does not indicate the intended use of the vehicle. The only way to possibly get this information would be to request fleets to register their company in the USEPA database and share the number of vehicles and the type of application vehicles are used for. The reviewer is of the opinion that only a targeted fleet survey type approach could provide this lack of information. The problem with this approach is to get the fleet participation to provide this information. In the state of California, incentive programs like the Carl Moyer Fleet Modernization programs require, fleets to provide annual reports of vehicle activity. If the USEPA can leverage some of these economic incentive programs in different states to add the requirement of "incentive receiving fleets" to share the fleet population categorized as vocation, this would result in a large periodic dataset that will be constantly updated.

C. Additional Comments (if any)

- Please provide any additional technical comments you would like to make regarding the review documents.
- Please provide any non-technical comments in a separate file (e.g., editorial, organization, formatting, and other minor issues).

None.

APPENDIX C

PEER REVIEWER RESUMES

MJB & A

M.J. Bradley & Associates LLC

Dana M. Lowell
Senior Vice President & Technical Director
(978) 405-1275
dlowell@mjbradley.com

Areas of Expertise

- Advanced vehicle emissions reduction technologies
- Vehicle technology development and deployment
- Transit maintenance management
- Vehicle emissions testing
- Diesel inspection and maintenance programs
- Transit vehicle specification and procurement support
- Life cycle cost modeling and financial analysis
- Project management

Dana has worked in MJB&A's advanced vehicle technology group since 2004, providing strategic analysis, project management, and technical support to mobile source emissions reduction programs. His mobile source project work includes evaluation and implementation of advanced diesel emissions controls, alternative fuels, and advanced hybrid, battery electric and fuel cell electric drives, as well as development and implementation of diesel emissions testing programs for a range of onroad and nonroad heavy-duty vehicle types. Dana brings to clients a wealth of practical knowledge and experience, the real-world perspective of a major fleet operator, and a proven track record in technology implementation.

Dana has 25 years professional experience in the transportation and government sectors. Prior to joining MJB&A, Dana spent seven years as the Assistant Chief Maintenance Officer for Research & Development at MTA New York City Transit's Department of Buses. In his role with NYC Transit, Dana was responsible for both evaluation and implementation of clean fuel technology programs, including technology and vehicle testing, emissions testing and fleet emissions modeling, component/vehicle specification, maintenance program analysis, applications engineering support, financial analysis, budget development and planning, procurement support, and project management. Under his leadership, NYC Transit developed and executed an aggressive program to implement new technologies fleet-wide, resulting in the creation of NYC Transit's Clean Fuel Bus Program to reduce exhaust emissions from the fleet of 4,500 fixed-route transit buses.

With MJB&A Dana has continued to provide similar support to transit agencies and other large fleet operators. He has managed emissions and in-use testing programs for school and transit buses, re-power programs for marine vessels, and electrification programs for transportation refrigeration units. Mr. Lowell also provides regulatory support to heavy duty diesel engine manufacturers, and for the U.S. Federal Motor Carrier Safety Administration has evaluated safety issues associated with hydrogen fuel cell, natural gas, and electric and hybrid-electric commercial trucks.

From 2005 to 2011 Mr. Lowell developed and managed a four-Phase Transit Bus Technology Demonstration and Evaluation Program for TransLink in Vancouver, British Columbia, Canada. Dana also has extensive, recent experience supporting transit agencies and other organizations with planning for fleet electrification. As a sub-consultant to Ramboll, Dana led MJB&A's development of cost-benefit and fleet transition analyses which supported the Los Angeles County Metropolitan Transportation Authority's strategic plans for fleet-wide zero emission bus implementation. Dana led a similar analysis for TransLink in Vancouver, British Columbia, and their operating subsidiary Coast Mountain Bus Company. This work supported TransLink's decision to pursue full electrification for their fleet of 1,400 transit buses. Dana is now leading a follow-on project to develop detailed plans for necessary charging infrastructure, and to develop an implementation roadmap for TransLink. Dana is also currently providing technical support to MTA New York City Transit, to evaluate data from an existing battery bus pilot fleet, and to develop analytical tools that will allow NYCT to plan for a wider fleet roll-out of battery buses.

A recognized electric drive and clean fuel expert within transit, Dana has made numerous presentations at industry conferences and workshops sponsored by APTA, TRB, SAE, US EPA, the Canadian Urban Transit Association, the Electric Power Research Institute, the National Parks Service and the World Bank. He has also served on advisory committees for the Harvard Center for Risk Analysis and the US EPA's Environmental Technology Verification Program.

Representative MJB&A Projects

- *MTS Electric Bus Feasibility Study*
- *TransLink Low Carbon Fleet Plan, Phase 1 and Phase 2*
- *NYC Transit Battery Bus Technical Support*
- *Santa Monica Electric Bus Analysis (Big Blue Bus)*
- *ATVC/LACMTA Transit Bus Technology Technical Support*
- *New York City E^3 Electric Truck Project*
- *New York Electric Vehicle Charging Infrastructure Roadmap*
- *NYSERDA Electric Vehicle Benefit-Cost Analysis*
- *Ceres Plug-in Vehicle Charging Infrastructure Analysis*
- *State-Level Plug-in Electric Vehicle Cost-Benefit Analyses*
- *Milwaukee County Department of Transportation Alternative Fuels Analysis*
- *New York Power Authority, Hybrid School Bus Demonstration Program*
- *New York Power Authority, Green Fleet Options Analysis*
- *Translink/GVTA, Bus Technology Demonstration Program, Phase 1, 2, 3 & 4*
- *TCI Northeast Charging Infrastructure Gap Analysis*
- City of Pittsburgh Fleet Sustainability Analysis
- New York State Energy Research & Development Authority, Pricing Strategies to Reduce Grid Impacts of Electric Vehicles in New York
- New York Power Authority Fleet Analysis – Options to Reduce GHG Emissions
- EDF/Ceres, Effect of EPA Phase 2 Fuel Efficiency Regulations on Freight Rates
- Federal Motor Carrier Safety Administration, Recommended Updates to Safety Regulations to Accommodate Electric Drive Vehicles
- Federal Motor Carrier Safety Administration, Training Program for Commercial Vehicle Inspectors in Detecting Fuel Leaks from CNG, LNG, and LPG Vehicles
- BAE Systems, Hybrid Bus Fuel Economy Testing

- New York City Business Integrity Commission, Analysis of “Age-out” Policy Options to Reduce Emissions from Commercial Refuse Trucks in New York City
- New York Power Authority, Hybrid School Bus In-Service Demonstration Program
- Federal Motor Carrier Safety Administration, Recommended Updates to Safety Regulations to Accommodate Natural Gas Vehicles
- Regulatory Support to Heavy-duty Diesel Engine Manufacturers for Transition from EPA Tier 2 to EPA Tier 3/4 Regulations

Prior Work Experience

July1996 – May 2004	MTA New York City Transit, Department of Buses *Assistant Chief Maintenance Officer, Research & Development*
March 1993 – June 1996	MTA New York City Transit, Dept. of Capital Programs *Manager of Capital Investment Analysis*
Feb 1990 - Feb 1993	City of New York, Office of Management and Budget *Supervising Project Manager, Value Engineering*
Sept 1985 – Sept 1989	United States Army, 299th Engineer Battalion *Battalion Adjutant; Combat Engineer Platoon Leader*

Education

Leonard N. Stern School of Business, New York University, New York, NY

Master of Business Administration; co-major in Management and Operations Management, 1995
Mayor's Graduate Scholarship; Dean’s Award for Academic Excellence

Princeton University, Princeton, NJ

Bachelor of Science in Mechanical Engineering, 1985
Summa Cum Laude; Phi Beta Kappa; Tau Beta Pi
Four-year R.O.T.C. scholarship; Distinguished Military Graduate

Arvind Thiruvengadam

Assistant Professor

West Virginia University, 279 Engineering Sciences Building Addition, Morgantown, WV 26506-6106

Ph: (304)-293-0805 (Voice); (304) 293 6689 (fax); Email: arvind.thiruvengadam@mail.wvu.edu

EDUCATION

Bachelor of Engineering (B.E) in *Mechanical Engineering* University of Madras, India	2004
M.S in *Mechanical Engineering* Department of Mechanical and Aerospace Engineering Benjamin M Statler College of Engineering and Mineral Resources West Virginia University, Morgantown, WV	2007
Ph.D. in *Mechanical Engineering* Department of Mechanical and Aerospace Engineering Benjamin M Statler College of Engineering and Mineral Resources West Virginia University, Morgantown, WV	2012

APPOINTMENTS

Assistant Professor (Tenure Track) Center for Alternative Fuels, Engines and Emissions (CAFEE) Department of Mechanical and Aerospace Engineering Benjamin M Statler College of Engineering and Mineral Resources West Virginia University, Morgantown, WV	2016-Present
Research Assistant Professor Center for Alternative Fuels, Engines and Emissions (CAFEE) Department of Mechanical and Aerospace Engineering Benjamin M Statler College of Engineering and Mineral Resources West Virginia University, Morgantown, WV	2013 - 2016
Research Assistant Center for Alternative Fuels, Engines and Emissions (CAFEE) Department of Mechanical and Aerospace Engineering Benjamin M Statler College of Engineering and Mineral Resources West Virginia University, Morgantown, WV	2012-2013

SKILLS

- Expertise in United States emissions regulation for light-duty, heavy-duty, off-road internal combustion engines. Expert in emissions measurement system, data analysis and experimental procedure for regulatory certification process
- Expert in various engine and aftertreatment technologies. Research experience include development of state-of-the-art engine and aftertreatment solutions for emissions and fuel consumption reduction.
- Hands-on experience in testing heavy-duty diesel engines and heavy-duty diesel vehicles for performance and emissions characterization.
- Research expertise in the field of diesel particulate matter, real-world emissions characterization and development of strategies for robust on-board diagnosis of engine and aftertreatment system malfunction
- Experience in securing research funding, manage a large research group that include students, faculty and technicians.

PUBLICATIONS

- Tianyang Wang, David C. Quiros, **Arvind Thiruvengadam**, Saroj Pradhan, Shaohua Hu, Tao Huai, Eon S. Lee, and Yifang Zhu, Total Particle Number Emissions from Modern Diesel, Natural Gas, and Hybrid Heavy-Duty Vehicles During On-Road Operation. Environmental Science & Technology 2017 51 (12), 6990-6998
- **Thiruvengadam, A.;** Besch, M.; Carder, Gautam, M.; Oshinuga, A.; Hogo, H; Pasek, R. Unregulated greenhouse gas and ammonia emissions from current technology heavy-duty vehicles. Journal of Air Water and Waste Management Association 2016, 66 (11): 1045-1060.
- Quiros, D.C., **Thiruvengadam, A.**, Pradhan, S. et al. Real-World Emissions from Modern Heavy-Duty Diesel, Natural Gas, and Hybrid Diesel Trucks Operating Along Major California Freight Corridors. Emission Control Science and Technology 2016, 2 (3): 156-172
- **Thiruvengadam, A.;** Besch, M.; Thiruvengadam, P.; Pradhan, S.; Carder, D.; Kappanna, H.; Gautam, M.; Oshinuga, A.; Hogo, H.; Miyasato, M., Emission Rates of Regulated Pollutants from Current Technology Heavy-Duty Diesel and Natural Gas Goods Movement Vehicles. Environmental Science and technology **2015,** *49* (1), 5236-5244.
- Besch, M.; Israel, J.; **Thiruvengadam, A.;** Kappanna, H.; Carder, D., Emissions Characterization from Different Technology Heavy-Duty Engines Retrofitted for CNG/Diesel Dual-Fuel Operation. SAE International Journal of Engines **2015,** *8* (3)
- Pradhan, S.; **Thiruvengadam, A.;** Thiruvengadam, P.; Besch, M.; Carder, D, 2015. Investigating the Potential of Waste Heat Recovery as a Pathway for Heavy-Duty Exhaust Aftertreatment Thermal Management. *SAE,* 2015-01-1606.
- **Thiruvengadam, A.;** Besch, Yoon, S.; Collins, J., Herner, J.; Ayala, A.; Carder, D.; Gautam, M, Characterization of Particulate Matter Emissions from a Current Technology Natural Gas Engine. Environmental Science and Technology, 2014, 48 (14), 8235-8242.

- **<u>Thiruvengadam, A.;</u>** Besch, C. M.; Carder, D.; Oshinuga, A.; Gautam, M., Influence of Real-World Engine Load Conditions on Nanoparticle Emissions from a DPF and SCR Equipped Heavy-Duty Diesel Engine. <u>Environmental Science and Technology</u> 2011, 46 (3), 1907-1913
- **<u>Thiruvengadam, A.;</u>** Carder, D. K.; Krishnamurthy, M.; Oshinuga, A.; Gautam, M., Effect of an economical oxidation catalyst formulation on regulated and unregulated pollutants from natural gas fueled heavy duty transit buses. <u>Transportation Research Part D: Transport and Environment</u> 2011, 16 (6), 469-473
- Yoon, S.; Collins, J.; **<u>Thiruvengadam, A.</u>**; Gautam, M.; Herner, J.; Ayala, A.; Criteria pollutant and greenhouse gas emissions from CNG transit buses equipped with three-way catalysts compared to lean-burn engines and oxidation catalyst technologies. <u>J Air Waste Manag Assoc</u>. 2013, 63 (8), 926-933
- Yoon, S.; Shaohua, H.; Kado, N.; **<u>Thiruvengadam, A.</u>**; Collins, J.; Gautam, M.; Herner, J.; Ayala, A.; Chemical and Toxicological Properties of Emissions from CNG Transit Buses Equipped with Three-Way Catalysts Compared to Lean-Burn Engines and Oxidation Catalyst Technologies. <u>Atmospheric Environment</u>, 2014, 83, 220-228.
- Littera, D.; Cozzolini, A.; Besch, C. M.; **<u>Thiruvengadam, A.</u>**; Gautam, M., High Temperature Sampling System for Real Time Measurement of Solid and Volatile Fractions of Exhaust Particulate Matter. <u>SAE International Journal of Engines</u> 2011, 4 (2), 2477-2489.
- Ardanese, R., Ardanese, M., Besch, M. C., Adams, T. R., **<u>Thiruvengadam, A</u>**., Shade, B. C., et al. (2009). PM Concentration and Size Distributions from a Heavy-duty Diesel Engine Programmed with Different Engine-out Calibrations to meet the 2010 Emission Limits. *<u>SAE</u>* , 2009-01-1183.

<u>CONFERENCES AND WORKSHOPS</u>

Presented research findings in over 20 national and international conferences, and invited seminars. Few of the recent presentations are listed below:

- **<u>Thiruvengadam, A. (Invited Speaker)</u>**, (2017). Investigation of DPF Failure Modes and cation Strategies, *Conference on Combustion generated nanoparticles, Cambridge, U.K*
- **<u>Thiruvengadam, A. (Speaker)</u>**, (2017). Evaluation of In-Use Emissions Using On-Board NOx Sensors On Heavy-Duty Diesel Trucks, *27th CRC ON-ROAD VEHICLE EMISSIONS WORKSHOP.* Long Beach, CA
- **<u>Thiruvengadam, A. (Invited Seminar)</u>**, (2017) Light-Duty Diesel Vehicle Emissions Under Real-World Driving Conditions, *NASA Goddard Space Flight Center.* Greenbelt, MD
- **<u>Thiruvengadam, A. (Speaker)</u>**, (2016) Light-Duty Diesel Vehicle Emissions Under Real-World Driving Conditions, *2016 DOE Crosscut Lean/Low-Temperature Exhaust Emissions.* Ann, Arbor, MI
- **<u>Thiruvengadam, A. (Speaker)</u>**, (2016) Alternative Fuels In Vehicles: A Look At Regulated Emissions, *9th Integer Emissions Summit & DEF forum.* Chicago, IL
- **<u>Thiruvengadam, A. (Speaker)</u>**, (2016). In-use Emissions from Current Model Year Heavy-Duty Trucks-NTE VS alternative Metrics, *26th CRC ON-ROAD VEHICLE EMISSIONS WORKSHOP.* Newport Beach, CA
- **<u>Thiruvengadam, A. (Invited Speaker)</u>**, (2015). Natural Gas in Heavy-Duty Trucks: A Look at Regulated Emissions, *UC Davis Sloan Natural Gas Workshop.* Davis, CA
- **<u>Thiruvengadam, A. (Invited Speaker)</u>**, (2015). Real-world on-road particulate matter emissions from latest technology heavy-duty vehicles using a mobile cvs laboratory, *Conference on Combustion generated nanoparticles, ETH Zurich, Switzerland*

- **Thiruvengadam, A. (Invited Speaker)**, (2015). Real-world on-road particulate matter emissions from latest technology heavy-duty vehicles using a mobile cvs laboratory, *Conference on Combustion generated nanoparticles, Cambridge, U.K*
- **Thiruvengadam, A. (Invited Speaker)**, (2015). Effeciency Limitations of Current Traffic Management Strategies Aimed at Reducing Air Pollutions, *Horiba Seminar, SAE World Congress, Detroit, MI*

SYNERGISTIC ACTIVITIES

- Development of one-of-a-kind on-board diagnostic (OBD) research platform for heavy-duty engines.
- Co-principal investigator in funded programs that have contributed to policy making and refinement of emissions inventory of regulatory agencies such as South Coast Air Quality Management District and the California Air Resources Board.
- Supervising and mentoring a large group of undergraduate, graduate (Ph.D. and M.S), exchange students from Italy (University of Rome, Perugia University) to pursue research activities in CAFEE.
- Development of a database for the dissemination of emissions inventory of a large population heavy-duty vehicles characterized by different fuels, vocation and engine technology.
- Development of a web based portal for continuous tracking of ambient and vehicle pollution through mobile on-board communication system.
- Development of graduate course work for heavy-duty engine emissions and regualtions.

COLLABORATORS & OTHER AFFILIATIONS

Collaborators

- Adewale Oshinuga, South Coast Air Quality Management District
- Dr. Alberto Ayala, Sacramento Metropolitan Air Quality Management District
- Dr. John Collins, California Air Resources Board
- Dr. Kent Johnson, University of California, Riverside
- Dr. Yoon Seungju, California Air Resources Board
- Dr. Tao Huai, California Air Resources Board

Graduate Advisor

Dr. Mridul Gautam, West Virginia University

RECENT RECOGNITION

- Core member of the team that uncovered the Volkswagen emissions scandal, that resulted in a $14.7 billion settlement with the USEPA
- Ranked 2 on the Motor trend power list in the automotive industry for 2016
- Named 2016 All-Stars in the Automotive News for the Environmental team

SELECT RECENT SPONSORED RESEARCH:

- **Title:** "Estimation of Fuel Consumption and Emissions for Representative Heavy-Duty Vehicles in the US" **Principal Investigator**

  Funding Agency: ICCT (June 1, 2017 – Dec 31, 2017); **Amount:** $ 60,000
- **Title:** "In-Use Emissions Testing and Fuel Usage Profile of On-Road Heavy-Duty Vehicles" **Principal Investigator**

  Funding Agency: South Coast Air Quality Management District (Jan 1, 2017 – May, 2018); **Amount:** $ 1,600,000
- **Title:**"Development of Ammonia Retrofit Solution for Stoichiometric Natural Gas Engines", **Principal Investigator**
  Funding Agency: South Coast Air Quality Management District (Nov 1, 2014 – August 31, 2015); **Amount:** $ 240,000
- **Title:**"Diesel Engine Modeling Development for Heavy-Duty Vehicle Simulation Tool", **Principal Investigator**
  Funding Agency: International Council for Clean Transportation (ICCT) (Nov 1, 2013 - May, 2014); **Amount:** $ 59,943
- **Title:**" Real-World Evaluation of Modern Heavy-Duty Truck Emissions Using PEMS and a Transportable CVS Emissions Measurement System", **Co-Principal Investigator**
  Funding Agency: California Air Resources Board and South Coast AQMD (Nov 1, 2013 – Nov 30, 2015); **Amount:** $ 190,000
- **Title:**" In-use Emissions Testing and Demonstration of Retrofit Technology for Control of On-Road Heavy-Duty Engines"**, Co-Principal Investigator**
  Funding Agency: South Coast Air Quality Management District (July, 2011 - Oct, 2013); **Amount:** $ 734,742

TEACHNING EXPERIENCE

- **MAE 320: Thermodynamics**; The course presents the introduction to thermodynamic principles, closed and open systems, entropy, enthalpy, properties of pure substances and ideal gases.
- **MAE 525: Heavy-duty diesel vehicle emissions: T**he course introduces the basics of emissions formation from diesel engines, regulations governing the certification of heavy-duty diesel engines in the US, gaseous and particulate matter measurement principles, data analysis, performing emissions calculations and the fundamentals of emissions control strategy used in modern heavy-duty diesel engines
- **MAE 321: Applied Thermodynamics**; The course presents the introduction to thermodynamic cycles, exergy, refrigeration cycles, air standard cycles, and combustion

APPENDIX D

PEER REVIEWER CONFLICT OF INTEREST STATEMENTS

Attachment 2
Conflict of Interest Certification
(REV 04/2019)

Order Conflict of Interest Certification (EPA Prime Contracts)
(REV 12/2017)

Subcontractor/Consultant: M.J. BRADLEY & ASSOCIATES

EPA Contract No. 68HE0C18C0001

Order No.: WA 1-08

In accordance with EPAAR 1552.209-71 (Organizational Conflicts of Interest), EPAAR 1552.209-73 (Notification of Conflicts of Interest Regarding Personnel), and the terms and conditions of the subcontract agreement for services, before submitting this certification, Subcontractor/Consultant shall search its records accumulated, at a minimum, over the past three years immediately prior to receipt of the order to determine if any conflicts exist. Subcontractor/Consultant makes the following certifications/warranties:

ORGANIZATIONAL AND PERSONAL CONFLICTS OF INTEREST:

☒ To the best of our knowledge and belief, no actual or potential organizational conflicts of interest exist. In addition, none of the individuals proposed for work under this order has any personal conflicts of interest.

OR:

☐ To the best of our knowledge and belief, all actual or potential organizational and personal conflicts of interest have been reported to the ERG Technical Contract Manager. This disclosure statement must include a summary of the potential conflict with respect to the work proposed to be performed, any reasons why Subcontractor/ Consultant does not believe the potential work would be a conflict, and/or a proposed strategy for mitigating any potential conflict of interest.

This is to certify that our personnel who perform work under this order, or relating to this order, have been informed of their obligation to report personal and organizational conflicts of interest. Subcontractor/Consultant recognizes its continuing obligation to search for, identify, and report to the ERG Technical Contract Manager any actual or potential organizational or personnel conflicts of interests that may arise during the performance of this work order or work relating to this order.

Authorized Signature

DANA LOWELL
Printed Name/Title

11/4/19
Date

Attachment 2
Conflict of Interest Certification
(REV 04/2019)

Order Conflict of Interest Certification (EPA Prime Contracts)
(REV 12/2017)

Subcontractor/Consultant:	Arvind Thiruvengadam
EPA Contract No.	68HE0C18C0001
Order No.:	WA 1-08

In accordance with EPAAR 1552.209-71 (Organizational Conflicts of Interest), EPAAR 1552.209-73 (Notification of Conflicts of Interest Regarding Personnel), and the terms and conditions of the subcontract agreement for services, before submitting this certification, Subcontractor/Consultant shall search its records accumulated, at a minimum, over the past three years immediately prior to receipt of the order to determine if any conflicts exist. Subcontractor/Consultant makes the following certifications/warranties:

ORGANIZATIONAL AND PERSONAL CONFLICTS OF INTEREST:

☒ To the best of our knowledge and belief, no actual or potential organizational conflicts of interest exist. In addition, none of the individuals proposed for work under this order has any personal conflicts of interest.

OR:

☐ To the best of our knowledge and belief, all actual or potential organizational and personal conflicts of interest have been reported to the ERG Technical Contract Manager. This disclosure statement must include a summary of the potential conflict with respect to the work proposed to be performed, any reasons why Subcontractor/ Consultant does not believe the potential work would be a conflict, and/or a proposed strategy for mitigating any potential conflict of interest.

This is to certify that our personnel who perform work under this order, or relating to this order, have been informed of their obligation to report personal and organizational conflicts of interest. Subcontractor/Consultant recognizes its continuing obligation to search for, identify, and report to the ERG Technical Contract Manager any actual or potential organizational or personnel conflicts of interests that may arise during the performance of this work order or work relating to this order.

Authorized Signature

Arvind Thiruvengadam
Printed Name/Title

11/11/2019
Date