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Dear Ira
I would like to thank you for providing me the opportunity to review the MOVES update report prepared by USEPA. The report was very informative and I have suggested comments based on my experience and understanding of the methodologies documented in the report. Overall the approach, methodologies and data sources used for the development and upgrade of the MOVES model are very sound. The report identifies holes in the data, which published literature does not discuss and some of the information would require dedicated research to fill the gap.
I have attached a document with my detailed comments for both the general question and the specific questions.

Please let me know if you have any further question about the review I have submitted.

Thank you
Regards
Arvind Thiruvengadam

ORGANIZATIONAL CONFLICT OF INTEREST CERTIFICATE

Customer: U.S. Environmental Protection Agency

Contractor: ICF Incorporated, LLC, 9300 Lee Highway, Fairfax, VA 22031

Prime Contract: EP-C-16-020, Work Assignment 0-14

Subject Report: Heavy-Duty Emissions Update

Subcontractor/Peer Reviewer: Dr. Arvind Thiruvengadam, West Virginia University

In accordance with EPAAR 1552.209-70 through 1552.209-73, Subcontractor/Consultant certifies to the best of its knowledge and belief that:

___X____ No actual or potential conflict of interest exists.

_______ An actual or potential conflict of interest exists. See attached full disclosure.

Subcontractor/Consultant certifies that its personnel who perform work on this contract have been informed of their obligations to report personal and organizational conflicts of interest to Contractor, and Subcontractor/Consultant recognizes its continuing obligation to identify and report any actual or potential organizational conflicts of interest arising during performance under the referenced contract.

[signature]
Subcontractor/Consultant

9/26/17
Date

Review for Exhaust Emission Rates for Heavy-Duty Onroad Vehicles in MOVES201X

General Questions

Section 2.1 Heavy-Duty Vehicle Emissions

2.1.1.1: Data Sources: The EPA has used data from 3 main sources; a) ROVER, b) Consent Decree Testing, c) HDIU testing, d) Houston drayage data. The three data sources represent heavy-duty vehicle emissions for three distinct time periods of stringency in emission standards.

The quality of the data is representative of the analyzer technology available during the different time periods. Reviewer believes it is important to mention the accuracy levels of the analyzers that were used during the collection of data. If exact values are not available, reviewer believes it is important to caveat that "data collected during ROVER and Consent decree testing could have higher variation due to the use of prototype PEMS equipment". The current technology PEMS equipment are comparable to laboratory grade analyzers and maybe associated with lesser variations and errors. Are the emissions rates from in-use testing corrected for measurement errors? In other words, was a measurement allowance added to the reported values?

The report clearly explains the additional data processing (time alignment, completeness of data, etc.) and data filtering performed by EPA before incorporation into the model.

This section of the report does not seem to indicate the check for carbon balance versus ECU reported fueling as another sanity check to validate exhaust flow measurement and or CO2 measurement. Was this analysis performed by EPA or did the EPA rely only on the data providers to perform this analysis? I believe the exhaust flow measurement system is subject to a lot of errors associated with condensation and drift of pressure transducers, hence this analysis is important to check for accuracy of measuring mass flow of exhaust.

The methods and procedures employed to convert source data to model input is appropriate and detailed. The reviewer would like some clarification in regards to the activity distribution of the data and the data binning approach used in the calculation. In specific:

The data obtained from the HDIU testing will be primarily of long-haul truck operation characterized by predominant highway based operation. Although this might not affect emission rates of early model year vehicles, the use of this data could be biased towards high speed operation and lower NOx emissions from SCR. Is there a distribution of what percentage of data from HDIU testing consists of low-speed transients?

In this section the report does not adequately explain how the 1Hz or 5 Hz continuous data from the different sources are segregated into the different operating modes and emissions rates for the different operating modes are calculated. Is a moving average type binning method is applied?

Reviewer believes instantaneously assigning the emissions rate to different opmodes will lead to a lot of inaccuracies due to thermal inertia of aftertreatment systems, inaccuracies in broad cast torque of ECU, time alignment errors etc.

2.1.1.4.1 Hole-filling Missing Operating Modes

Figure 2-3 shows the missing real-world data in the different operating modes

The figure supports the fact that the opmodes 29, 30, 39, and 40 fall in the ranges that are beyond the power rating of most HD trucks. Also the speed combination of greater than 50 and between 25 and 50 at those high operating modes is probably not possible for a fully loaded truck at 80,000 lbs. Even if there is an engine rating that can deliver that high engine power, the operation has to occur on a positive grade, and during this operation the vehicle cannot physically reach those speed bins.

Should the EPA consider eliminating those speed bins, since they are not physically possible? Or is there any data to indicate otherwise to have those bins for HD application.

Figure 2-10 accurately represents the decreasing emissions rate with newer model year group.

Does the projection from 2013-2050 assume no change to emissions standard?

Post 2007 PM emissions from DPF equipped vehicles are below detection limits. Tampering and mal-maintenance adjustments seem appropriate. However, the report does not seem to address data related to DPF malfunctions or failures. Can data from manufacturers shed light on the level of DPF malfunction due to various engine related faults such as stuck EGR valves, injector failure, turbo failure etc. These types of failures are common, and although there is not enough published literature related to these, manufacturer warranty claims should suggest rates of failure. The reviewer believes, engine related DPF failure events could be more common that tampering or mal-maintenance.

The EC and OC fraction of PM from pre and post 2007 model year vehicles are accurately represented**. The report suggests that bulk of the EC/non-ECPM data was obtained from the ACES study. This study could be representative of just one engine model and the cycle used in this work was an extended 16 hr long cycle. Reviewer believes that the EPA should consider the use of data from chassis dynamometer testing from a wide range of drive cycles to compare the results obtained from the ACES study.**

Unregulated greenhouse gas and ammonia emissions from current technology heavy-duty vehicles, Arvind Thiruvengadam, Marc Besch, Daniel Carder, Adewale Oshinuga, Randall Pasek, Henry Hogo & Mridul Gautam, Journal of the Air & Waste Management Association Vol. 66 , Iss. 11,2016

Page 51: HC and CO emissions from 2010 and beyond base rates: The report suggests that the quality of HC and CO are not applicable here because instruments conform to requirements of 40 CFR part 1065. The measurement of HC with a FID detector has been standard and based on the reviewer's experience there hasn't been quality issues associated with FID measurement. However, one the frequently observed issues with PEMS measurement is related to CO. The use of a single cell NDIR for both CO and CO2 causes severe drifts in the analyzer during the test period. However, during the zero and span check the drift is nonexistent due to the use of dry calibration gas and zero gas. This drift readings have resulted in high CO emissions. Since, the standard for CO is high, and the focus has always been on NOx, the results of CO and issues related to the measurement of it using PEMS has been rarely documented.

Figure 2-21: The time-specific CO emissions rates seem to be very high. The report suggests that the figure includes the T&M effects, but he emission rates seem to be overestimated. The highest CO emissions form a post 2010 truck was observed from the non-SCR Navistar engine certified at 0.50 g/bhp-hr. The DOC is a robust aftertreatment system that shows little deterioration through the life of the engine. Furthermore, higher op-modes should technical show lower CO emissions due to

Section 2.1.4 Energy

Page 61 line 3:" Second, the truck weights and road load coefficients are updated to reflect lower vehicle weight…."

It should be made clear in this sentence that the "lower vehicle weight" is lowering of curb weight of truck and trailer by using light weight material. The sentence reads like that trucks will carrying lesser payload.

Table 2-21. Does the table represent the energy consumption reduction from the engine alone or a diesel engine+chassis+trailer combination?

In the study conducted by WVU and a report published by ICCT it is projected that by employing various engine based technology pathways HD engine will have a maximum fuel consumption reduction of 7.9% and 18.3% for the 2017 and 2020+ model years respectively. MHD will have a 10.6% and 19.5% reduction in fuel consumption for 2017 and 2020+ model years respectively.

http://www.theicct.org/sites/default/files/publications/HDV_engine-efficiency-eval_WVU-rpt_oct2014.pdf

The numbers in table 2-21 corroborates this projection. However, if the vehicle improvements are factored, then the projections in WVU study could be more.

2.2 Start Exhaust Emissions

The report does not clearly explain the definition of a fully warmed engine (is it just engine or engine and aftertreatment system). Also since the start emissions is a function of soak, what portion of the operation after the start is "start emissions"?

2.2.1.1: The report suggests no data available for HHD or MHD trucks for the start emissions.

Can data from the OEMS and other research labs that perform FTP certification testing fill this gap? The first 100-200 seconds of the cold FTP will provide the start exhaust emissions for engines. Also, the cold start of an SET engine dynamometer cycle will provide the start idle emissions for pre-2010 model year engines. Although the duration of the start exhaust emissions would be small, it would give an understanding of the magnitude of emissions rate and the duration of engine warmup.

2.2.1.2: Is there a reference to the use of equation 2-24? Warm engine is defined as the opening of the thermostat, which corresponds to a certain coolant temperature. An integration of emissions until a coolant temperature that corresponds to the initial opening of the thermostat could be a better estimation of start emissions.

Data set from a CARB and SCAQMD funded project, published in the journal paper by Quiros et al. could provide real-world start emissions data from post MY 2013 HDD.

The reviewer believes that the method for estimation of start emissions can be revised. Inferring it from FTP data is not sufficient for actual start emissions characterization. In the real-world it is observed that, irrespective of soak time, the warmup period of engine and aftertreatment system is fairly quick and the negative impact on emissions is greatly reduced.

2.2.4 Start Energy Rates

Since fleet fuel consumption plays an important role in the HDD market, manufacturers mostly employ rapid engine warmup procedure to reduce fuel consumption. Intake throttling, higher fueling and intake manifold heating are some of the strategies that maybe used during start. The report correctly identifies that the fraction of start energy is very little compared to the total energy used by HDD, however it is also to be noted that significant auxiliary power loading can take place after a long start. Air compressor and alternator loading can be higher, particularly for applications such as urban bus. Data from OEM can shed light on the warm-up strategies employed and the energy consumption.

Section 2.3.2: Figure 2-46. Trucks certified to operate or idle in California must either be enabled with 5 minute auto idle shut-off or conform to the 30 g/hr optional idle NOx standard. The time-specific emissions rate shown in figure 2-46 show a small fraction of trucks with idle emissions at or below the 30 g/hr NOx.

Page 95 Line 16: The assumption of trucks under warranty will have substantially fewer aftertreatment failures need to be revisited. DPF failures do not occur because of faulty aftertreatment system A combination of engine control system failure leads to DPF failure. Frequently a stuck EGR valve causes increased soot loading leading to DPF failure. The OBD strategies in most cases do not pick up failed DPF or other system failures. Warranty data presented by David Quiros by ARB in CRC real-world workshop should shed light on DPF failure rates.

Chapter 4

The reviewer believes that the contribution of refuse trucks would be similar to that of transit buses fueled by CNG. These two captive fleets are largest in CNG usage in California.

Table 4-1: Is there a reason has listed only literature pertaining to pre-2—7 CNG transit buses.

Below studies funded by CARB and SCAQMD shows emissions rate from newer natural gas transit buses

Criteria pollutant and greenhouse gas emissions from CNG transit buses equipped with three-way catalysts compared to lean-burn engines and oxidation catalyst technologies, Seungju Yoon, John Collins, Arvind Thiruvengadam, Mridul Gautam, Jorn Herner & Alberto Ayala, Journal of the Air & Waste Management Association Vol. 63 , Iss. 8,2013

SCAQMD funded study conducted by WVU and UCR tested CNG transit buses over multiple driving cycles.

Section 4.2.13 Table 4-2. For 2007-2009. Were there lean-burn NG engines certified above 0.20 g/bhp-hr during that time period. Cummins ISLG achieved 0.20 as early 2007?

Specific Questions:

2.1.1.3.2 The study by Quiros et al has limited data that supports the fact that since the inception of SCR control in 2010, significant advancements in thermal management , urea dosage strategy, SCR formulations have taken place. Real-world emissions rates have in general reduced since MY 2010. Although Quiros et al. discuss a very limited dataset, this CARB and SCAQMD funded study compared to other previous chassis dynamometer work, documented in (Thiruvengadam et al, Dixit et al.) has shown considerable reduction in NOx emissions rate from MY 2013, and 2014 HD diesel engines.

Real-world emissions from modern heavy-duty diesel, natural gas, and hybrid diesel trucks operating along major California freight corridors. DC Quiros, A Thiruvengadam, S Pradhan, M Besch… - Emission Control Science and Technology, 2016

Emission rates of regulated pollutants from current technology heavy-duty diesel and natural gas goods movement vehicles. A Thiruvengadam, MC Besch, P Thiruvengadam… - Environmental science & technology, 2015

Poornima Dixit, J. Wayne Miller, David R. Cocker, Adewale Oshinuga, Yu Jiang, Thomas D. Durbin, Kent C. Johnson, Differences between emissions measured in urban driving and certification testing of heavy-duty diesel engines, In Atmospheric Environment, Volume 166, 2017, Pages 276-285, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2017.06.037.

2.1.1.2 and 2.1.1.4.1: The current fscale of 17.1 results in STP values significantly higher than the maximum engine rating available in the HD segment. The reviewer believes that the fsacle can be chosen that the maximum tractive power is always less than the average maximum available power rating of all the engine models. This would also be able to fill some of the high power opmodes of downsized engines working at full load. Fscale could be calculated as a linear fit between vehicle power and co2 emissions should provide a better estimate of fscale relevant to each regulatory category.

2.1.2.2.6 The PM data from the HDIU program would be primarily in the NTE region. Depending on the type of PM PEMS employed the variation in PM measurement could be significant. Since, both gravimetric and the PM sensor measure below detection limit, the use of in-use PM emissions rate must be avoided.

Figure 3 in attachment B shows an appropriate trend with slightly increasing PM concentrations at higher load opmodes. This has been observed in many in-use studies and can be attributed to the slight drop in filtration efficiency due to the passive regeneration of DPF at high exhaust temperatures.

For the post 2007 engines, the use of the AVL soot sensor data could be useful to update PM numbers at a higher confidence level. Although the soot sensor only records soot mass, this would still account for bulk of PM emissions and even marginal drop in filtration efficiency.

Section 2.3.1: The data collected by EPA for extended idling emissions seems to be comprehensive. The practice of using high idle is very subjective and depends on the truck driver and their practices. There is increase in idle speed as hoteling loads are added to the engine, and this may result in engine rpm going up to 1000 rpm. The best method to establish the practice of using high idle would be to conduct a survey of fleets. Also, telemetry based data collection (PAMS) can also shed light on the percentage of time high idle is being used.

In the case of vehicles equipped with auto idle shut-off, reviewer believes the high idle switch disables the auto-idle shut-off and hence could prompt drivers to use it more often.

Section 2.3.1 Reviewer believes that the extended idle emissions rate will be different for MHD and HHD due to the engine size difference and the thermal inertias associated with the engine and aftertreatment system. The HDIU program from OEM should have sufficient data characterizing extended idling from MHD. One of the main differences in a MHD idle activity is that, in general MHD are used for short delivery applications and do not necessarily idle like a HHD vehicle.

Review for Emission Adjustments for Temperature, Humidity, Air Conditioning, and Inspection and Maintenance for On-road Vehicles in MOVES201X

Chapter 3

The report indicates that moves applies the humidity correction factor to all base exhaust emissions. When EPA receives data from the different sources, is the uncorrected NOx values used or is the corrected NOX values used. If the data source already performed the humidity correction (which is standard procedure according 40 CFR Part 1065) then the MOVES calculation will be double correcting it.

The reviewer believes there is more info needed about how source data is processed. When our research group provides data for modeling, we provide the humidity corrected data.

Specific Question

The reviewer is not aware of any study that was aimed at studying the effect of intake air humidity on tailpipe emissions of NOx from modern HDD engines/vehicles. However, this information can be extracted from any real-world testing exercise or PEMS measurement project. Few of the studies are noted below

SCAQMD and CARB funded study on 7 HD trucks in California has vast amount of data that can provide accurate links between ambient humidity and tailpipe NOx emissions from both modern HDD and HD CNG trucks.

Using raw NOx data uncorrected for humidity from the HDIU data and plotting tailpipe NOx emissions against ambient humidity should also provide an excellent dataset to examine the effect of intake air humidity on tailpipe NOx emissions.

In-use emissions testing work performed by CARB on heavy-duty refuse trucks in Sacramento, CA will also provide an excellent dataset for analyzing humidity effects. Results from this work was published by Misra et al.

In-Use NOx Emissions from Diesel and Liquefied Natural Gas Refuse Trucks Equipped with SCR and TWC, Respectively
Chandan Misra, Chris Ruehl, John Collins, Don Chernich, and Jorn Herner
Environmental Science & Technology **2017** *51* (12), 6981-6989
DOI: 10.1021/acs.est.6b03218