Peer Review of *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES*

Prepared for

Assessment and Standards Division

Office of Transportation and Air Quality

U.S. Environmental Protection Agency

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Peer Review of *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES*

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TO: Kent Helmer, Connie Hart, U.S. Environmental Protection Agency, Office of Transportation and Air Quality (OTAQ)

FROM: Brian Menard, SRA International

DATE: May 4, 2012

SUBJECT: Peer Review of *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES,* prepared by EPA

1. Background

EPA MOVES 2010a contains diurnal evaporative emission data empirically based on data from 1995. The equations built into MOVES are simplistically fit to this data and not based on how canisters actually respond to vapor loading. The DELTA model embodies EPA's effort to more accurately predict vehicle fleet evaporative emissions, especially in light of future vehicle rulemakings and any changes to evaporative standards that might be considered.

This report documents the assumptions, data sources, calculations and limitations used to estimate on-road vehicle evaporative emissions due to multi-day diurnal cycles using the DELTA (Diurnal Emissions Leaving to Atmosphere) model. This new model is associated with on-going improvements to the evaporative emissions portion of EPA MOVES model in conjunction with the proposed Tier 3 rulemaking.

Although the 1994 and 1996 In-Use Vehicle Program (IUVP) evaporative emission data (SHED evaporative emissions (in grams) for a large set of vehicles undergoing a single diurnal cycle) in MOVES 2010a provided a large and robust dataset for one day of emissions, a new way of modeling evaporative emissions beyond one day of diurnal cycling was needed for future vehicle evaporative emission scenarios. Neither was using a quadratic equation to fit diurnal emission data in MOVES 2010a accurately representing the actual response of vehicle canister breakthrough to large vapor loads. In response to this need, EPA's DELTA model was developed to more accurately represent multiple-day canister loading and breakthrough of vehicle evaporative emissions. DELTA provides an updated, theoretical approach to diurnal evaporative emissions development based on the new data which EPA believes more closely matches real-world vehicle evaporative system performance.

The previous breakthrough emissions equations found in the MOVES database are being replaced with a new set of equations generated within the DELTA model. The DELTA model also introduces changes to the MOVES Java code in order to take into account the nature of multiple day diurnal cycles. These new features (including the DELTA equations) can be deactivated if running MOVES using the older evaporative model, as desired by the user.

EPA sought an expert peer review of *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES* report. In particular, EPA requested that reviewers comment on all aspects of the DELTA Model and documentations, with particular emphasis on assumptions, data sources, calculations and limitations used to estimate on-road vehicle evaporative emissions due to multi-day diurnal cycles using the model and any other key issues reviewers might identify. EPA encouraged reviewers to best apply their particular area(s) of expertise to review the overall study. This report documents the peer review.

Section 2 of this memorandum describes the process for selecting reviewers, administering the review process, and closing the peer review. Section 3 summarizes reviewer comments according to the series of specific questions set forth in the peer review charge. The appendices to the memorandum contain the peer reviewers' resumes, completed conflict of interest and bias questionnaires for each reviewer, and the peer review charge letter.

2. Description of Review Process

In October 2011, OTAQ contacted SRA International to facilitate the peer review of the *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES* report. EPA provided SRA with a short list of subject matter experts from academia, consulting, and industry to serve as a "starting point" from which to assemble a list of peer reviewer candidates. SRA selected three independent (as defined in Sections 1.2.6 and 1.2.7 of EPA's *Peer Review Handbook, Third Edition)* subject matter experts to conduct the requested reviews. SRA selected subject matter experts familiar with statistical analysis and vehicle emissions. To ensure the independence and impartiality of the peer review, SRA was solely responsible for selecting the peer review panel. Appendix A of this report contains the resumes of the three peer reviewers. A crucial element in selecting peer reviewers was to determine whether reviewers had any actual or perceived conflicts of interest or bias that might prevent them from conducting a fair and impartial review of *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES*. SRA required each reviewer to complete and sign a conflict of interest and bias questionnaire. Appendix B of this report contains an explanation of the process and standards for judging conflict and bias along with copies of each reviewer's signed questionnaire.

SRA provided the reviewers a copy of the most recent version of the *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES* report as well as the peer review charge containing specific questions EPA asked the reviewers to address. Appendix C of this report contains the memo to reviewers from SRA with the peer review charge.

SRA delivered the final review comments to EPA by the requested date. These reviews, contained in Appendix D of this report, included the reviewers' response to the specific charge questions and any additional comments they might have had.

3. Compilation of Review Comments

The *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES* report was reviewed by Mr. Rob Klausmeier (Principal, de la Torre Klausmeier Consulting, Inc.), Dr. Christian Lindhjem (ENVIRON), and Dr. Sam Reddy (Principal, Evaporative Emissions Consulting, Inc.). Appendix A contains detailed resumes for each of the reviewers. This section provides a compilation of their comments. The complete comments of the three reviewers may be found in Appendix D.

The reviewers were asked on the basis of their work experience and expertise to comment on the methodologies, analysis, conclusions, and narrative of the *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES* report. In particular, they were asked on to provide comment on assumptions, data sources, calculations and limitations used to estimate on-road vehicle evaporative emissions due to multi-day diurnal cycles using the model. All of the reviewers provided suggestions for editing, elaborating upon, and clarifying the report in certain sections. The comments in this compilation have been categorized as specific technical, general, and editorial.

3.1 Specific Technical Comments

The reviewers provided a significant number of specific technical comments on the *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES* report. Two reviewers were generally favorable in their comments about the report, while a third was more critical of the data used for analysis and correlation. This section divides their comments among those that specifically address either questions or requests contained in the peer review charge and additional technical comments that reviewers chose to provide.

3.1.a Klausmeier Comments

3.1.a(1) Section III.b.ii contains the following statement: *"Canister loading does not occur linearly throughout the carbon bed. While it is convenient to think of vapor loading into the canister similarly to a glass filling with water (and eventually overflowing when the glass is full), fuel vapors form a concentration gradient throughout the carbon bed. During short term loading events (such as ORVR), the fuel vapor does not have sufficient time to spread into a gradient before a clean-out event takes place. However, a diurnal lasting several days provides ample time for some vapor to move beyond the front of high concentration near the inlet to the canister."*

It is not clear if the bleed effect applies to the example of short-term loading events, such as ORVR, or multi-day diurnals. In addition, the magnitude of the bleed affect should be discussed, if it's significant.

The statement in the above quote concerning short-term loading effects, such as ORVR cases, raises the question about multi-day diurnal emissions after such an event. If, for example, the vehicle is refueled and then parked for several days, it's possible that available canister capacity will be lower than expected. This might be something EPA might want to explore either in MOVES or in the DELTA model.

3.1.a(2) Section IV.b contains the following statement: *"DELTA uses the same weighting factors applied to the single vehicle TVG – TVV curves to calculate a single weighted tank size and canister size based on the individual tank and canister sizes found in the fleet. These weighted average tank and canister sizes are then used in the fleet average model in a similar way to how they would be applied in the single vehicle models."*

A description should be provided on how weighted average tank and canister sizes were derived. This could be done as an appendix to the report or as a reference to another report. The source of the average tank and canister data should be provided. Is it from certification data or other sources? In addition, I was curious if the average tank and canister sizes varied by model year within a technology group.

3.1.a(3) Section IV.b contains the following statement: *"Cases such as a small number of passenger vehicles modeled in the same group as a large number of pickup trucks may produce larger breakthrough than expected due to a large average tank size producing high amounts of vapor while coupled with less storage due to a smaller average canister capacity. One vehicle breaking through significantly before other vehicles in the aggregate model may also cause higher than expected breakthrough due to a small but non-zero fleet average TVG – TVV line occurring well before the average canister capacity of the fleet is reached. Usually, tank volume and canister capacity are well correlated over an entire model year fleet and therefore the tank volume and canister capacity simplifications should largely not affect results."*

Can EPA certification data to determine relative number of these cases? Also, can the authors provide an estimate of the impacts of these situations? The authors further state that tank volume and canister capacity are well correlated, therefore, the tank canister simplification should not affect results. I think this is a key point and therefore should be supported by some data, such as a plot of canister capacity versus fuel tank capacity, based on certification data.

3.1.a(4) In Section V.c the authors compare the actual behavior using test results from CRC's E77 test program with theoretical behavior based on the DELTA model. The authors note that in most cases, the DELTA under predicts breakthrough emissions. The authors then proceed to explain the differences:

"A more thorough analysis of E77 vehicle breakthrough was completed to explain the differences seen between the ideal model and what was happening in real world testing. It is important to note that the preconditioning procedure performed on the E77 vehicles to ensure adequate purge between tests, while meant to emulate a standard FTP cycle, was performed on public roads with variable weather conditions. This real-world preconditioning may have contributed to the non-ideal behavior seen in the data. For each test conducted in the E77 multi-day diurnal study, the canister breakthrough point (which was determined as the point at which more than 2% of the total canister capacity had escaped the vehicle canister) was compared against the theoretical capacity for the canister on that particular vehicle. The results of this analysis are shown in the following tables, separated by certification class."

The tables that follow only present information on canister capacity, when breakthrough occurs, and the percent of rated capacity. The authors should investigate and identify vehicle factors that explain the loss of canister capacity, e.g., age, mileage, temperature, and possibly year, make and model. If factors cannot be identified, the authors should state so.

3.1.a(5) Section VI contains the following statement: *"Based on the results for each of the test/vehicle combinations from the E77 program, the TVV/TVG values were averaged across all 23 test/vehicle combinations to result in a single graph representing all of the Enhanced/Tier 1 vehicles."*

Information on the breakdown on the types of vehicles in the different technology categories would be useful in validating whether differences between theoretical versus actual values should be averaged or some weighting should be applied. For example, if a certain vehicle model that is much more prevalent in the fleet shows more deterioration, then results for that model might be given greater weighting.

Also, the authors should investigate the sensitivity of assuming a single graph over a multi-day diurnal. The impact of canister deterioration will be much greater on 2nd, 3rd, and subsequent days of a multi-day diurnal than on the 1st day. It may be necessary to add a time factor to the correction of DELTA for non-ideal behavior.

3.1.b Lindhjem Comments

3.1.b(1) Single Vehicle Modeling

3.1.b(1)(A) The method described for a single vehicle has two main issues that would affect the single vehicle model presented. These issues involve the apparent assumption that canister capture efficiency is a step function between full capture prior to breakthrough and no capture efficiency after breakthrough. This assumption influences how backpurge affects the canister condition and vapor venting. The breakthrough condition should also be defined as when the initial vapor venting occurs, not necessarily when the vapor venting reaches 2% of loaded weight in order to estimate lower emission events.

The first assumption that the canister will not collect vapor once the breakthrough condition is reached does not follow the basic understanding of how activated carbon captures vapor. For a number of reasons (e.g., pore size distributions, surface area coverage, and range of compounds in the vapor), the capture efficiency for a given partial pressure of vapor should slowly decline as shown in Figure 1 of this review. The effect of incorporating the post-breakthrough efficiency would be to lower the vapor venting until the canister is fully loaded.

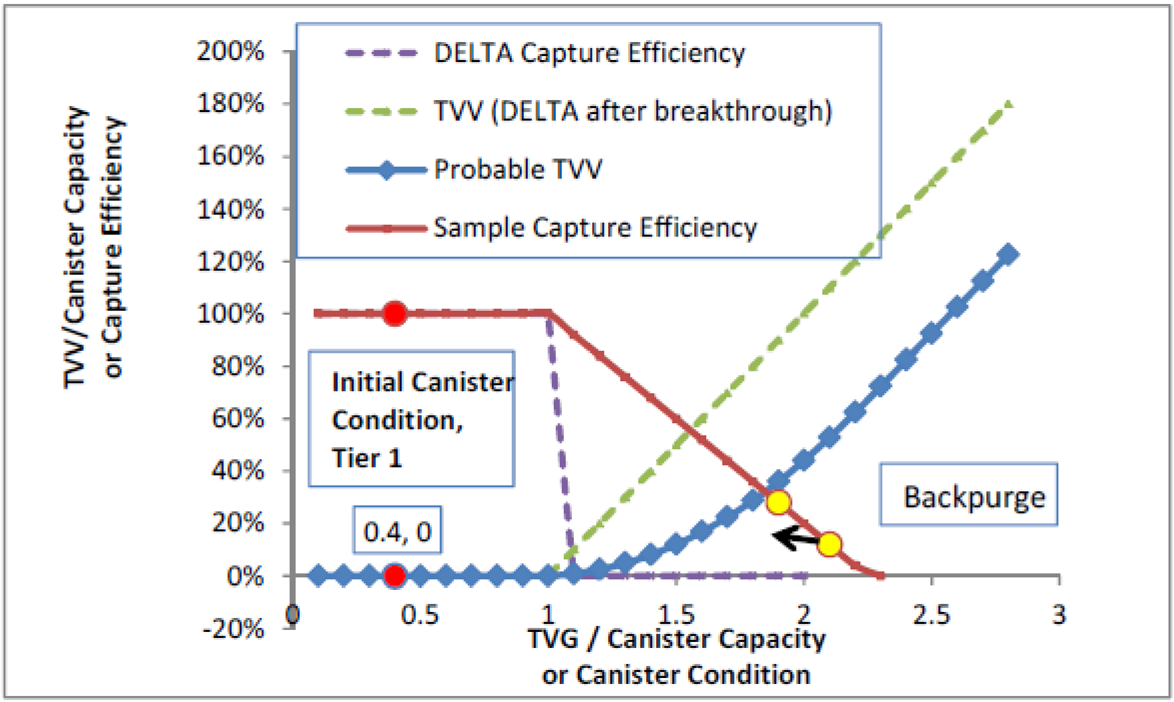


Figure 1. Post-Breakthrough Capture Efficiency for Single Vehicles.

The second assumption that backpurge will bring the canister to a pre-breakthrough condition appears to contradict the individual vehicle results presented in support of the method. Figures 14-17 of the paper demonstrate that vapor venting occurs from the beginning of the next day's vapor generation once the canister has been loaded past breakthrough. That vapor venting emissions would occur early in the next day's heat build indicates that the effect of backpurge is to lower the canister loading based on the day's peak temperature loaded condition, and not from the breakthrough point. The method shown in the report's Figure 6 then does not describe the post-breakthrough backpurge effect; if it had, then the vapor venting would be zero for the beginning vapor generation of each day. Rather, the effect of backpurge might better be modeled to reduce the canister loading in proportion to the ambient vapor drawn through the canister as the tank cools, as shown schematically in Figure 1 above. When the post-backpurged and post-breakthrough canister begins the next day's heat build, the efficiency would be less than 100% and exhibit some immediate vapor venting such as is shown in Figures 14-17.

The report's Figures 14-17 also demonstrate that the single vehicle vapor venting as a function of vapor venting follows an increasing rate as the vapor generation increases. The vapor venting rate would presumably continue to increase until the canister capture efficiency reduces to zero, and from then on the vapor venting rate should equal the vapor generation. This relationship is better described by the suggested post-breakthrough capture efficiency relationship in Figure 1 above and schematically described in the equations below.

Canister condition = Vapor generation x average capture efficiency

Vapor venting = vapor generation x (1 – average capture efficiency)

Where capture efficiency = 100% before breakthrough and f(canister condition) after

Canister condition (beginning of each heat build) = Peak Daily Load - Backpurge

3.1.b(1)(B) The important finding of the report, demonstrated in Tables 4 and 5, that canister capacity is less than optimal, should be followed up to determine if the canister capacity has actually diminished from deterioration, or that the initial canister loading was responsible for the less than full canister capacity. One method to determine this might be to draw sufficient ambient air through in-use canisters until the weight does not change, record the weight reduced from the additional purge air, and use a loading method such as the one described in the report using butane to determine the in-use full capacity.

The determination of the deterioration and initial loading of canisters has a potential implication for the modeling such that either the canister capacity must be adjusted or the initial loading should be set to a value above zero. The weighted fleet average should account for the range of in-use initial canister loads. Figure 1 above shows how the initial canister load might be incorporated in calculation of the vapor venting emissions by setting an initial canister condition above a zero load.

The canister capacity as measured by the loading of butane may underestimate the canister capacity because, especially for lower RVP fuels, heavier (lower vapor pressure) compounds than butane would be found in the vapor generated. The model even assumes that the vapor has a higher average molecular weight (MW) of 66 than butane (which has a MW of approximately 58), for example. The canister capacity should also be determined for the peak diurnal temperatures to reflect the maximum load each day to account for any heat effects on the canister capacity.

There has been evidence that the tank temperature probably lags the ambient temperatures in most cases (when air circulation is low such as when the vehicle is in an enclosed space), so the modeled tank vapor generation should account for less than peak vapor generation.

3.1.b(2) Weighted Fleet Average

3.1.b(2)(A) The refinements suggested here when incorporated may lead to higher or lower emissions than the current approach, depending upon the conditions for which distributions are included for characteristics and in-use conditions. By using distributions of vehicle characteristics, emissions are likely to be nonzero for even low temperature difference heat builds because worst case conditions would be included in the averages. However, determining a fleet average using wide distributions would better reflect the overall fleet behavior by incorporating all situations.

3.1.b(2)(B) The report notes that determining a weighted fleet average emission rate needs to incorporate tank volume and individual vehicle canister properties (the report might refer to only canister capacity but should also account for the distribution of initial canister loads as well).

But there are several other factors that should be incorporated into the weighted average. One is that the distribution of fill volume fractions should be incorporated into the vapor generation and backpurged calculations. (The 40% fill volume used in the E77 program is not necessarily the in-use fleet average anyway, but rather it follows the official testing protocol.) Whether in DELTA or in MOVES, the frequency of multiple diurnals needs to be incorporated to calculate fleet averaged emissions. The use of all potential distributions of vehicle characteristics (canister capacity and initial day canister load) and fill volume fractions would reduce the chance that there would be a threshold vapor generation below which vapor venting emissions would be zero as described in Figures 21, 23, 24 and 25.

In addition, the researchers should determine if the canister capacity (full capacity compared to no load, regardless of the initial day loading) correlates with tank volume, and add tank volume to Tables 1-3 to describe the comparison. The proper canister capacity to tank volume may be important because the vapor generation (a function of tank and fill volume fraction as well as temperature and RVP) and canister capacity may be balanced and a function of the evaporative emission standards. The use of an average canister capacity, tank volume, and fill volume fraction ignores too many variables that affect emissions for in-use fleets.

3.1.c *Reddy Comments*

3.1.c(1) Assumption of 35% back-purge after each diurnal is not correct: real world back purge is less than 10% after first diurnal, then it slowly increases every subsequent day by about 10% and reaches 70% and then remains constant (70% of diurnal vapor back-purged after 8 or more consecutive diurnals). The model must take into account variable back-purge to avoid under estimation of emissions initially and over estimation of emissions later in multiple diurnals.

3.1.c(2) I am afraid that unsuitable diurnal test data from CRC E-77-2c was used to analyze and correlate the model. The data is unrealistic/unreasonable because it consisted of CARB diurnal tests (65-105F) with RVP9 and RVP10 fuels containing ethanol (correct CARB diurnal fuel is RVP7). The RVP9 and RVP10 test fuels may have been suitable for permeation studies but not for CARB diurnal tests. No evap system is designed to handle CARB diurnal vapor generation with RVP9 or RVP10 fuel and no evap system functions properly. The CARB diurnal vapor generation doubles with RVP9 fuel and leads to numerous problems/errors (e.g., fuel boiling and reduced canister purging because of high running loss vapor generation, canister rapid loading and premature breakthrough, etc.). CARB diurnal vapor generation increase by 260% with RVP10 fuel compared to RVP7 fuel. Let us look at Vehicle #207 in Table 5 (Delta model report) with actual canister working capacity of 153 g; your estimated Breakthrough Point (estimated canister working capacity) in different tests ranged from 49 g to 194 g. How can the estimated capacity of the same canister vary by 400% (49 g in one test and 194 g in another test)? This happened because of the use of extreme/unreal diurnal test data for the analysis.

3.1.c(3) The breakthrough trap canister in CRC E-77-2c tests, makes the diurnal testing unrealistic; the test does simulate real world diurnal process (back purging of main canister is affected by the trap canister).

3.1.c(4) Another minor problem with CRC E-77-2c data is, the breakthrough trap canister was not big enough to capture all the breakthrough in some of the tests with RVP10 fuel.

3.1.c(5) Some canister breakthrough emission data looks strange; Figure 15 shows canister breakthrough emission more than diurnal vapor generation – how is that possible?

3.1.c(6) Based on incorrect estimation of canister working capacity (e.g., 49 g estimated canister working capacity of Vehicle #207 in test #7150), it was concluded that the canisters were deteriorating and loosing working capacity. If we really believe that canisters are deteriorating, we have to verify with experimental data (measure butane working capacities of in use canisters). Also, the estimated working capacity of the same canister in another test was 194 g.

3.1.c(7) To avoid over estimation of emissions, the canister butane working capacities should be converted into canister gasoline vapor working capacities by multiplying with a factor F (e.g., F=1.2 or 1.3). Gasoline vapor consists of somewhat heavier molecules than butane; therefore, higher adsorption capacity for gasoline vapor.

3.1.c(8) As discussed below and illustrated in the following figure [below], multiple day diurnal emissions from a fuel tank follow a nice relationship consisting three straight lines, which might help to refine DELTA model.

If you use better data (real world and realistic/reasonable diurnals) and correct back purge numbers, the modeling will get back on the right track and it will become much simpler, more accurate and useful. The multiple diurnal EPA data published in EPA420-R-08-014, Chapter 5, is a good starting point. Even though it was not an automotive fuel tank, but it makes no difference and it captured all the essential information that you need for modeling multiple day real world diurnal breakthrough emissions. CRC E-77-2c data may be more detailed and thorough but it is artificial, unrealistic, and unreal; therefore, it is not suitable for the real world evap model development and/or verification.

I did some quick calculations using the data from EPA420-R-08-014, Chapter 5, as shown below.

30 gal tank 40% fill RVP9; EPA 72-96F diurnal; assuming total tank volume of 33 gal; from the diurnal equation, the vapor generation will be (2.12 g/gal vap sp)x(33-12) = 44.5 g

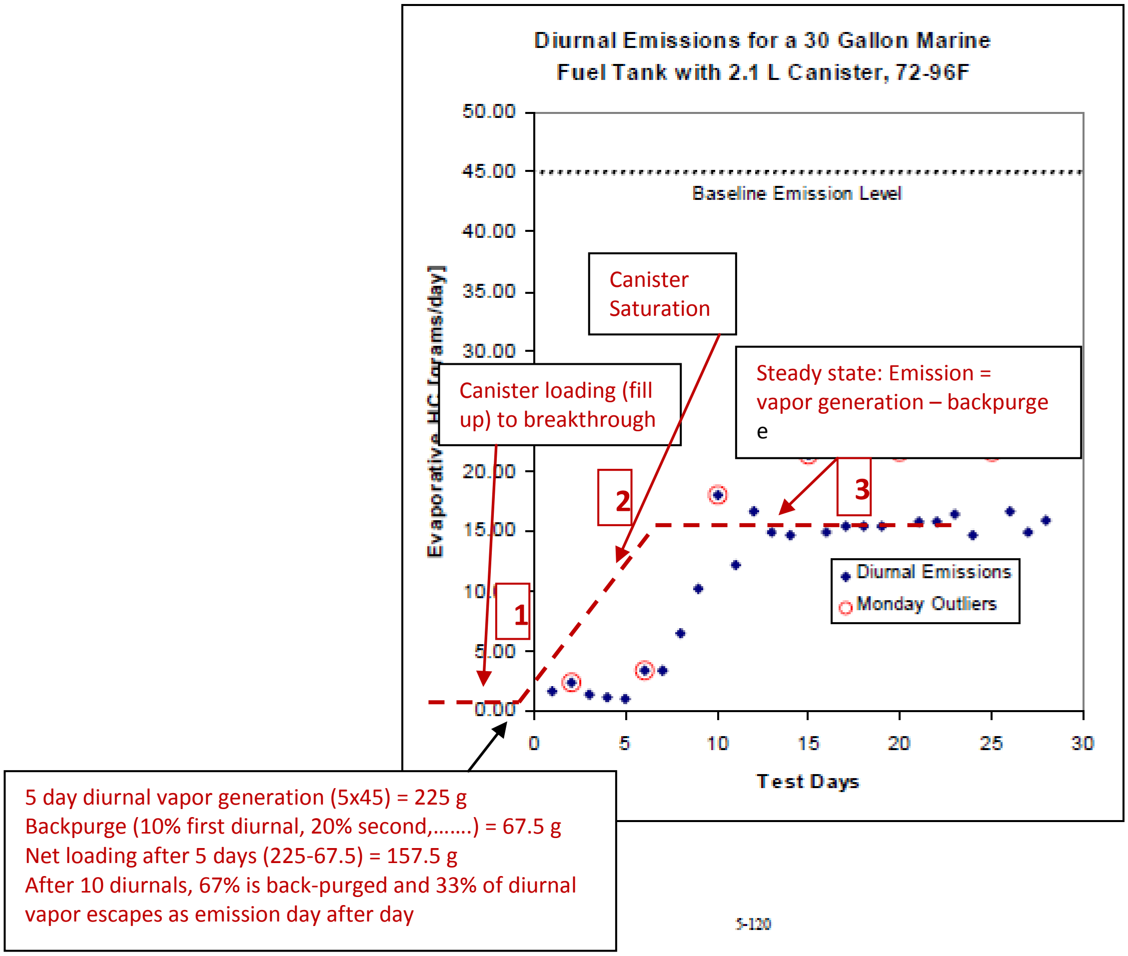
Measured diurnal vapor generation = 45 g (in the figure); good agreement with the diurnal equation.

2.1L 11BWC carbon canister; published butane working capacity is 120 g; gasoline vapor working capacity 1.3x(butane working capacity) = 156 g

It is expected that canister breakthrough occurs after 156 g vapor loading; the results in the figure show, the canister breakthrough did occur after 157.5 g loading (as shown in the figure, total vapor generation minus total back-purge in 5 diurnals).

Therefore, this data is suitable for DELTA model.

APPENDIX 5C: Diurnal Emission Results: Canister and Passive-Purge



3.1.c(9) The following approach might make it easier to develop a diurnal emission model.

Divide the TVV vs. TVG or Diurnal Emissions (g/day) E vs. No of Diurnals N, into three parts as shown in the figure [above].

Part 1: Canister loading to breakthrough; Total vapor generation < canister capacity

- Day 1 diurnal vapor generation (Wade-Reddy equation) = M grams
- Day 2 diurnal vapor generation = Net diurnal vapor generation = 0.9M (after accounting for backpurge)
- Day 3 diurnal vapor generation = Net diurnal vapor generation = 0.8M
- Or a linear back purge factor F = 1.1 – 0.1N where N is number of diurnals
- N^{th} day Net diurnal vapor generation = (1.1 - 0.1N)M
- Total net diurnal vapor generation in N days = 0.5N(M + (1.1 - 0.1N)M) = MN(1.05 - 0.05N)
- Note that without back purge, total vapor generation is MN; (1.05 - 0.05N) is a correction for back purge.
- Canister breakthrough will occur when total net diurnal vapor generation MN(1.05 - 0.05N) is greater than or equal to canister capacity C.
- MN(1.05 - 0.05N) = C knowing M and C for a given vehicle, solve for N (breakthrough day)
- Let us apply this equation to the above example: M=45 and C=156

  45N(1.05 - 0.05N) = 156

  N^2 - 21N + 69.4 = 0 solving quadratic equation gives N=4.1

  Which means, no canister breakthrough for 4 diurnals (4 days); breakthrough starts on 5^{th} day.

Part 2: Similar analysis using F=(1.1 - 0.1N)M for N < 8; F=0.3 for N>8

Part 3: Steady state

- Net Diurnal Vapor Generation/day = Diurnal emissions/day = FM where F=0.3 constant for N>8
- Which means only 30% of diurnal vapor generation (estimated by the diurnal equation) escapes as emission into the atmosphere after 8 multiple diurnals. And it's less than 30% if the multiple diurnals are less than 8.
- This is all assuming that they are real world diurnals (e.g., EPA diurnal RVP9 72-96F or CARB diurnal RVP7 65-105F). If we use extreme diurnals (high RVP fuels and high temperatures), everything falls apart.
- I will be glad to discuss the comments in person if it is helpful to the EPA team.

3.2 General Comments

The reviewers provided general comments on the *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES* report. Among these general comments were evaluations of the report's strengths, suggestions for improving and strengthening certain of its elements, and queries for further information.

3.2.a Klausmeier Comment

The report is well written; it clearly described the complex process of modeling vehicle evaporative emissions. Although I have several comments, I believe the DELTA model is significant enhancement to MOVES.

3.2.b Lindhjem Comments

3.2.b(1) There are several changes that should be made to the DELTA model to better reflect the data, scientific theory, and fleet average behavior. The model appears to oversimplify the single vehicle modeling and does not incorporate all the potential conditions in the estimation of the weighted fleet average vapor venting emissions.

3.2.b(2) By not incorporating the relationship between vapor generation and canister capture efficiency, the DELTA model does not demonstrate its ability to model the data. The calculation of the effect of backpurge appears to ignore the behavior exhibited by the individual vehicle data provided.

3.2.b(3) By not incorporating the distributions of all in-use conditions, the weighted fleet average would not reflect the overall relationship between vapor generation and vapor venting emissions. Worst case conditions could provide emission rates at low temperature heat builds, while optimal situations would reduce vapor venting under higher temperature situations. Incorporating all potential in-use situations could markedly change the relationship between ambient conditions and fleet average vapor venting emission predictions currently modeled by DELTA.

3.2.b(4) One characteristic that has not been discussed is the fuel weathering that occurs. While the DELTA model can be used regardless of weathering, it should be noted that MOVES would need to incorporate fuel weathering in the estimation of in-use RVP (lower than fresh dispensed fuel RVP) or the range in-use in-tanks RVP. In addition, any other inputs (tank temperature, frequency of multi-diurnals, or other input factors) that MOVES may determine as inputs to the multi-diurnal emission calculation should be discussed.

3.2.c Reddy Comment

EPA Delta model is a good start in the right direction because it is based on evap canister working capacity, diurnal vapor generation, and canister back-purge. The modeling started on a right track but it was thrown off track because of the data used for the analysis and correlation.

3.3 Editorial Comments

All of the reviewers provided editorial comments on the *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES* report. They offered suggestions for strengthening the report through clarification and elaboration. In addition, the reviewers noted typographical and formatting errors, textual omissions, and sought citations for statements within the report.

3.3.a Klausmeier Comments

3.3.a(1) Section III contains the following statement: "*Ethanol effects vary in that vapor evaporation increases as ethanol concentration increases until approximately 15% ethanol content. At higher concentrations evaporation decreases with increasing ethanol due to nonlinear effects on fuel volatility, with volatility returning to E0 levels around 50% ethanol content and decreasing from there.*"

Please provide a reference for the statement concerning the impact of increasing ethanol content on fuel volatility.

3.3.a(2) Section III.b.ii contains the following statement: *"Canister adsorption is also affected by the temperature of the canister as well as the rate of vapor loading onto the canister. Activated carbon adsorption rates are inversely proportional to the temperature of the carbon bed. As the temperature of the canister rises, the rate of adsorption decreases while the rate of desorption increases. This has the effect of lowering the BWC with higher temperatures."*

Can the authors provide rough estimates of the relative impact of temperature on butane-working capacity for the canister? The temperature effect may have a big impact on emissions during 2^{nd}, 3^{rd}, and subsequent days of a multi-day diurnal. If the impact is significant, EPA may want to model the impact in MOVES or in DELTA.

3.3.a(3) Section III.c contains the following statement: *"Durring the cooling phase of a diurnal, fresh air from the atmosphere is drawn back into a vehicle fuel tank and across the carbon bed in the canister."*

The sentence has a typo in the word "during." Also, the statement is made that fresh air from the atmosphere is drawn back into the vehicle fuel tank and across the carbon bed in the canister. I think what the authors are referring to is canister backpurge where fresh air is drawn across the canister and into the vehicle fuel tank.

3.3.a(4) Section V.b contains the following statement: *"Note the above figure represents the reconstructed version of the original E77 data for the vehicle shown previously in Figure 14."*Do the authors mean Figure 13?

The report does not mention how vehicles with tampered or inoperative evaporative systems are modeled. I assume that they are modeled as TVV/TVG = 1.

3.3.b Lindhjem Comments

3.3.b(1) Figure 13 contains the following statement: *"Canister weight is plotted against vapor generation."*

Should the 'canister weight' be relabeled as vapor vented? This figure is difficult to follow because the vapor generation decreases at the end of each day's heat build, so should the vapor generation decreasing be plotted at all? This figure is also used to demonstrate how the data is transformed from canister weight to vapor venting in Figures 14-17, but it does not follow directly that canister weight can be converted to vapor venting.

3.3.b(2) Figure 14 contains the following statement: *"Vapor generation reduces between one day and the next."*

The vapor generation increases except (it appears) between one day and the next where it decreases. Should the vapor generation continue to increase, or is there an assumption that backpurge reduces the vapor generation during the cooling phase of the test? It appears that this occurs in the Appendix B code in the expression below where the TVG is subtracted by a datapoint[2]. Without the raw data, it is not possible to fully review the results to discern where vapor generation is shown to reduce from one day to the next.

else:

if test_Dict[key][i+1][1] >= highPointTVV and datapoint[8] - output_Dict[key][-1][7] > 120: highPointTVG = highPointTVG - datapoint[2]

3.3.b(3) Figures 15-17 contain comparisons between the fleet average prediction and the individual vehicle results.

The figures need to show calculated fleet averages for the individual vehicle results presented, so that the data and DELTA prediction can be compared on an equivalent weighted fleet average basis. I suspect that the data driven fleet average may show a different shape of the curve representing the relationship between vapor vented and vapor generation than the DELTA predicted fleet average, regardless of the effect of canister capacity (or the effect of initial canister loads).

3.3.b(4) Figures 18 and 19 are labeled as test vehicles from the E77 program.

Given the smooth regular curves, the figures are more probably DELTA estimates based on the canister conditions from the E77 program. The labels should clearly describe these as theoretical emission rates for various vehicle conditions and not actual data.

3.3.c Reddy Comments

3.3.c(1) The following correction should be made throughout the report. Section III.a *Tank vapor generation - The ~~Wade-Reddy model~~Reddy Diurnal Equation.*

Don't mean to disparage Wade but the equation has no relationship to Wade model; please see SAE papers 861556 and 892089, or just call it The Diurnal Equation. It is fine if you still want to call it The Wade-Reddy Model. Please change throughout the report.

3.3.c(2) The following corrections should be made in Section III.a:

The source of diurnal emissions we are concerned about in the DELTA model is ~~evaporation of gasoline vapor~~ diurnal vapor generation from a vehicle's tank during a rise in temperature. The ~~evaporation rate~~ diurnal vapor generation is dependent on how much temperature change has occurred, the volatility of the fuel (RVP), the ethanol content of the fuel (E0, E10, etc...) and the altitude of the vehicle over sea level. Generally as temperature change, fuel volatility, and altitude increase, vapor evaporation also increases. Splash blended e~~E~~thanol effects vary in that ~~vapor evaporation~~ diurnal vapor generation increases as ethanol concentration increases until approximately 15% ethanol content.

3.3.c(3) The following correction should be made in Section III.a:

$$tank\ vapor\ generated = Ae^{B*RVP}\left(e^{C*T_{high}} - e^{C*T_{low}}\right)$$

(grams per gallon vapor spae)

Where A, B and C are coefficients based on altitude and ethanol content; RVP in psi, T in ^{o}F

3.3.c(4) The following correction should be made in Section III.c: *"Since this phenomenon also occurs within vehicle canisters the rates derived from this study are appropriate for use with onroad vehicles as well, it also served as the basis for backpurge in the DELTA model."*

I am afraid that the back-purge in EPA420-R-08-014, Chapter 5, is not interpreted correctly. Backpurge is a function of canister loading; it is very low initially (<10%) and slowly increases to 65% (65% of the diurnal vapor is backpurged after about 6-10 days).

3.3.c(5) The following correction should be made in Section IV.a: "*This curve no longer has the characteristic rise at a specific canister capacity. This is due to some vehicles beginning to break through while others remain at zero breakthrough; caused by differences in canister properties expressed in the individual vehicle models. The method for handling the average canister breakthrough point on the weighted TVG - TVV curve is discussed in the next subsection*."

Not clear why the curve shape is so different. It might be easier to explain using three vehicles with different tank and canister sizes, first draw three TVG-TVV curves, then an average curve which will have a different shape. I did an example in excel; I got a straight line followed by a nice 2nd degree polynomial equation.

3.3.c(6) The following correction should be made in Section V.a: *"A tank volume headspace average of 10.5 gallons, a backpurge value of 35%, and equal weighting between vehicles was used for all three subsets."*

Too high; also, is it 35% diurnal vapor generated, or 35% of the vapor present in the canister – either way it is incorrect.

3.3.c(7) The following correction should be made to Figure 12 **-** *DELTA Model Results for Pre-Enhanced, Enhanced and Tier 2 Fleet Average.*

Green line is Tier2 / PZEV not ZEV; ZEVs are electric cars - no canister

3.3.c(8) The following correction should be made to Figure 13 **-** *Untransformed E77 Vehicle Breakthrough Data.*

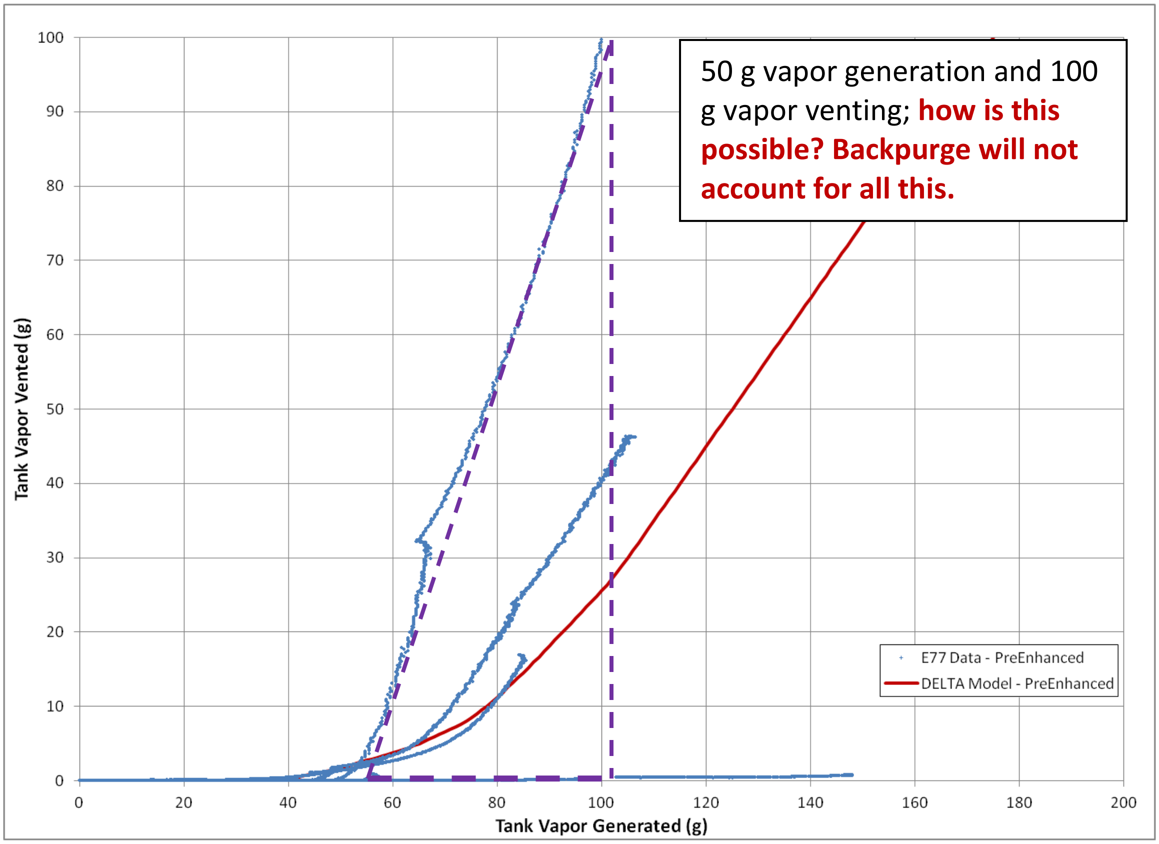
Y-axis label is very misleading; I think it is breakthrough emission measured using a trap canister – breakthrough or trap canister weight.

3.3.c(9) The following correction should be made to Figure 14 **-** *Transformed E77 Vehicle Breakthrough Data.*

Breakthrough emissions such as these shown in this graph never occur in real world with real vehicles. Unreasonable/unrealistic/artificial diurnal test data should not be used in these analysis. Please see more explanation in my written comments.

3.3.c(10) The following correction should be made to Figure 15:

Figure 1 - Pre-enhanced E77 / DELTA Model Comparison



3.3.c(11) The following correction should be made to Table 4 **-** *E77 Tier2/ZEV Premature Breakthrough.*

Please none these tests are with the right fuel (RVP7) for CARB diurnal. Use of this data for any analysis will cause problems.

3.3.c(12) The following correction should be made to Section V.c: *"The under-estimation of fleet breakthrough emissions is due to the fact that the DELTA model is reliant on ideal canister capacity for breakthrough calculations; because the fleet performed at only 72% of ideal canister capacity, the DELTA model cannot properly account for the non-ideal behavior."*

Underestimation may be occurring because of 35% backpurge and unsuitable data (CARB diurnal with RVP9 and 10)

3.3.c(13) The following correction should be made to Section V.c: *"A method of correcting the DELTA model to more correctly reflect the non-ideal behavior of a real-world fleet follows in the next section."*

To confirm all this, you have to measure real world canister working capacities and compare them with published working capacity.

3.3.c(14) The following correction should be made to Section V*I. Correcting DELTA for non-ideal behavior.*

All the analyses shown below may not be necessary if the modeling is done with better data as described in my written comments.

3.3.c(15) The following correction should be made to Section VI: *"While evaporative emission canister technology is relatively simple, deterioration of the charcoal in the canister can occur for a variety of reasons including if the canister is exposed to liquid or repeated dusty conditions."*

Premature conclusion – I think. Deterioration has to be verified with actual measurements – take some used canister and measure working capacities and compare with published working capacities. What liquid – fuel or water? I don't think dust does anything to canister working capacity – it will just plug the filter; can damage the tank in extreme dust filter plugging.

3.3.c(16) The following correction should be made to Section VI: *"Lower purge levels in the real-world could lead to temporary reduction in vapor storage capacity until the vehicles are driven for sufficient distances to purge the canister more completely."*

There was plenty of canister purging in the test procedure used in E-77. Also, the vehicles went through series of tests with ample opportunity for canister purging/clean-up/recovery – no possibility of deterioration. I think there is a problem in your Breakthrough Point (theoretical capacity) estimation in Table 5. Let us look at Vehicle #207 in Table 5 with canister capacity of 153 g; the estimated Breakthrough Point ranges from 49 g to 194 g. It is very confusing; how can the breakthrough point of the same canister vary by 400%. Breakthrough point is nothing but estimated canister capacity; why is it 49 g in one test and 194 g in another test. Either the test data is not interpreted properly or the calculation methodology is incorrect.

4. References

U.S.EPA (2011). *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES*

Appendix A: Resumes of Peer Reviewers

dKC de la Torre Klausmeier Consulting

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Austin, TX 78704
(512) 447-3077
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ROB KLAUSMEIER
de la Torre Klausmeier Consulting, Inc. - dKC

5. EDUCATION

M.B.A., Business Administration, University of Michigan, Ann Arbor, MI, 1973.
B.S.M.E., Mechanical Engineering, University of Michigan, Ann Arbor, MI, 1973.

6. PROFESSIONAL EXPERIENCE

Consultant, de la Torre Klausmeier Consulting, Inc, 1994 to present.
Principal Scientist/Group Leader, Radian Corporation, Austin, TX, 1991-1994.
Senior Staff Engineer, Radian Corporation, Austin, TX, April 1988-1990.
Program Manager, Radian Corporation, Austin, TX, 1984-1988.
Senior Mechanical Engineer, Radian Corporation, Austin, TX, 1977-1984.
Refinery Engineer, Standard Oil of California, Richmond, CA, 1974-1976.
Co-op Engineer, General Motors Corporation, Oldsmobile Division, Lansing, MI, 1967-1972.

7. AREAS OF EXPERTISE

Rob Klausmeier specializes in the analysis and implementation of air pollution control strategies, particularly strategies for mobile sources. In 1994, Rob formed his own consulting company, de la Torre Klausmeier Consulting, Inc (dKC). Prior to this, he was employed by Radian Corporation. During Rob's 17 years with Radian and 16 years with dKC, he has performed a range of programs with an emphasis on the following:

- Development of Air Pollution Control Strategies:
  - Modeling vehicle and stationary source emissions
  - Developing control strategies for attainment of the National Ambient Air Quality Standards
  - Costs and cost-effectiveness evaluations of control strategies
  - Training on Mobile Source controls
- Emission Controls for Large Stationary Engines:
  - Identification of control strategies
  - Emission reduction assessments
  - Cost effectiveness evaluations of controls for gasoline and diesel

powered engines.

  - Renewable alternatives: Wind, solar, bio-fuels

- Inspection/Maintenance (I/M) programs:
  - Assessment of emissions test procedures
  - Design of I/M test lanes
  - Request for Proposals (RFPs) for I/M programs
  - Rules and regulations for I/M programs
  - Negotiation of contracts for centralized I/M programs
  - Quality Assurance (QA) Programs - quality control, data analysis, program evaluation, acceptance tests
  - Cost estimates of I/M programs

Specific examples of Mr. Klausmeier's experience are listed below.

Air Pollution Control Strategies

Mobile Source 101. The best example of Mr. Klausmeier's broad experience in mobile source controls is his Mobile Source 101 course. In 2001, Mr. Klausmeier developed the curriculum and presented a four day course on mobile sources. Since then, he has continued to update the course as mobile sources evolve. The course covers the following: 1) environmental impact of mobile sources with particular emphasis to ozone attainment and air toxics, 2) vehicle emission standards for on-road and non-road sources, 3) state and local mobile source control programs such as inspection/maintenance (I/M) programs and alternative fuels, 4) the impact of fuel properties on emissions, and 5) modeling mobile source emissions. To date, he has presented the course to NESCAUM, EPA, MARAMA, Thailand Pollution Control Department, and several states.

Investigation and Evaluation of Potential Diesel Inspection Programs. In 2003 under contract to the Texas Commission on Environmental Quality (TCEQ), dKC investigated in-use NOx control strategies for diesel-fueled motor vehicles. dKC surveyed inspection programs in other states and provinces, the Manufacturers of Emissions Controls Association (MECA), and emissions testing experts. dKC also collected and reviewed data obtained for diesel testing research. dKC then developed a report that addressed the following:

1. Equipment requirements, including costs of, for example, opacimeters, dynamometers, remote sensing units, on-board analyzers, on-board diagnostics (OBD) equipment, etc.;
2. Test methods, for example, opacity test, chassis dynamometer test, etc., including descriptions of, for example, proposed driving traces or driving procedures such as the snap-idle or acceleration past a remote sensing unit;
3. Field deployment scenarios, including number, frequency and method of, for example, fleet self-testing, roadside pullovers, remote sensing units, existing I/M stations, etc.;
4. Potential target fleets, including:
5. Staffing requirements, both field and administrative;
6. Estimates of costs and benefits for each potential inspection program.

Study of Diesel Vehicle Emissions and Control Strategies. The New Hampshire Department of Environmental Services (NHDES) contracted with de la Torre Klausmeier Consulting (dKC) to study vehicle diesel emissions. This study was divided into the following six tasks:

- Review health and environmental risks associated with diesel emissions;
- Review emission factors and emission estimates for diesel powered vehicles;
- Assess the effect of current and future regulations;
- Summarize activities of other states in controlling emissions from diesel powered vehicles;
- Design and evaluate diesel I/M concepts for New Hampshire; and
- Review other control measures for diesel powered vehicles.

Mr. Klausmeier prepared a comprehensive report reviewing all major issues related to the assessment and control of diesel emissions**.**

Colorado Diesel Retrofit Study. Under contract to the State of Colorado, Mr. Klausmeier identified control strategies to reduce emissions from in-use diesel vehicles. The strategies evaluated include retrofitting emission controls such as trap oxidizers, regulating fuels, and the use of alternate fuel such as methanol.

Cost Effective VOC and NOx controls. Mr. Klausmeier directed this project to assess alternatives to meeting the Reasonable Further Progress mandates for VOC and NOx. Alternatives concentrated on better controls for area and point sources. Both VOC and NOx controls were evaluated.

Assessment of the Cost and Emission Reductions from Adopting the California LEV Program in Virginia. Mr. Klausmeier directed this project to study the costs of different emission control strategies, including the California LEV Program, that could be used to help the Northern Virginia area attain the National Ambient Air Quality Standards for ozone. As part of this project, Mr. Klausmeier developed a modified version of EPA's MOBILE5 model for different LEV and federal scenarios. Mr. Klausmeier estimated the cost and cost-effectiveness of different strategies and projected future emissions to determine if Northern Virginia can meet the Reasonable Further Progress mandates.

Assistance in Evaluating the Cost and Benefits of Adopting the California LEV Program in Pennsylvania. Mr. Klausmeier provided technical assistance to the LEV Study Commission in evaluating the cost and emission reductions from adopting the California LEV program in Pennsylvania. As part of this project, he worked with Pennsylvania's contractor, MidAtlantic's Universities Transportation Center to train them on how to perform appropriate mobile source emissions modeling. He specifically evaluated ways to evaluate the emission reductions from the LEV program with and without adoption of the zero emission vehicle (ZEV) mandate.

Estimating Emission Reductions from Reducing Gasoline Sulfur and RVP. Mr. Klausmeier estimated the emission reductions from reducing the sulfur content and RVP level of gasoline sold in Texas and Alabama. Low sulfur/low RVP fuel has been proposed as an alternative to reformulated gasoline (RFG) as a means of complying with the national ambient air quality standards for ozone and demonstrating transportation plan conformity. Mr. Klausmeier developed a procedure to estimate the emission reductions from low sulfur/low RVP fuel. He then analyzed the cost-effectiveness of this approach versus RFG.

Mexico City Air Pollution Control Program. Mr. Klausmeier directed this project to assist the government of Mexico City (DDF) in developing a plan to reduce air pollution from vehicles operated in Mexico City. He was responsible for helping the DDF review technical findings on candidate control measures, performing a cost-effectiveness analysis of the most promising control measures, and preparing reports for the World Bank and the public. He recently participated in a similar project for the Monterrey Metropolitan Area.

Technical Assistance in the Development of Emission Control Strategies for Existing and New Vehicles in Thailand. Mr. Klausmeier provided technical support to the Royal Thai Government in implementing emission control programs for existing and new vehicles. This project concentrated on the development of an inspection/maintenance (I/M) program for existing vehicles. He provided technical assistance in defining emission test procedures for diesels, motorcycles, three-wheel motorcycles, automobiles and other vehicle types used in Bangkok. He also provided assistance in the development of a comprehensive oversight program for the I/M program. Mr. Klausmeier also assisted the Royal Thai Government in developing emission standards for new vehicles and evaluating other emission control alternatives.

Assessment of Mobile Source Emission Control Strategies for Bermuda. Recognizing the increasing concern over motor vehicle pollution, the Bermuda Ministry of Transport and Aviation and the Ministry of Environment joined forces to contract de la Torre Klausmeier Consulting (dKC) to study the motor vehicle problem and recommend solutions. As part of this study, Mr. Klausmeier addressed the following issues:

- Current and future motor vehicle emission regulations in Europe and the United States;
- Health and environmental risks associated with vehicle emissions;
- Appropriate inspection/maintenance (I/M) concepts for Bermuda; and
- Other control measures, particularly for diesel powered vehicles and motorcycles, that could be implemented to further reduce pollution.

Bermuda is implementing most of Mr. Klausmeier's recommendations.

Estimating Emission Reductions from Reducing Gasoline Sulfur and RVP. Mr. Klausmeier estimated the emission reductions from reducing the sulfur content and RVP level of gasoline sold in Texas and Alabama. Low sulfur/low RVP fuel has been proposed as an alternative to reformulated gasoline (RFG) as a means of complying with the national ambient air quality standards for ozone and demonstrating transportation plan conformity. Mr. Klausmeier developed a procedure to estimate the emission reductions from low sulfur/low RVP fuel. He then analyzed the cost-effectiveness of this approach versus RFG.

Assessment of Emission Reduction Strategies for Heavy-Duty Gasoline Trucks. Under contract to the State of New York, Mr. Klausmeier evaluated control alternatives and then performed an in-depth analysis of the feasibility of inspection/maintenance for heavy-duty gasoline trucks.

Development of a Mobile Emission Credit Program for Alternative Fueled Vehicles. Mr. Klausmeier provided technical assistance in a project, to develop a mobile emission reduction credit program for alternatively fueled vehicles. He estimated emissions from alternatively fueled vehicles and identified ways to enforce emission control compliance in actual use. He also helped to develop emission reduction credit development protocols.

Assessment of Alternative Fuel Options for Affected Fleets. Mr. Klausmeier assisted in evaluating different options for meeting the Clean Air Act requirements and the Energy Policy

Act requirements for alternative fuel use in centrally fueled fleets. In this project, Mr. Klausmeier helped to evaluate options for using methanol, CNG and LPG fueled vehicles to meet the requirements.

Emission Reductions from Alternative Fuels. Mr. Klausmeier directed this project sponsored by the Texas Air Control Board, where Radian estimated the emission reductions possible from an aggressive alternative fuels conversion program. As part of this project, Mr. Klausmeier developed appropriate emission factors for alternatively fueled vehicles. Mr. Klausmeier also made several MOBILE5 runs to generate emission estimates for conventionally fueled vehicles.

Assessment of Environmental, Health, and Safety Issues Related to the Use of Alternative Transportation Fuels. As principle investigator for this GRI funded project, Mr. Klausmeier assessed the impact alternative fuels will have on environmental health and safety issues. As part of this project, Mr. Klausmeier developed a detailed database of information on emission impacts of alternative fueled vehicles. This database was used to compare the different alternative fuels and how they will affect non-attainment problems.

Controls for Large Stationary Engines

Assessment of the Use of Bio-Diesel in Diesel Engines and Combustion Turbines. In 2007, Maui Electric Co. (MECO) contracted Mr. Klausmeier to oversee a test program to evaluate the use of bio-diesel in diesel engines and combustion turbine generators at MECO's Maalaea Power Plant. Mr. Klausmeier reviewed the test plan, observed testing and reported on test results. He prepared two reports: one was for the Department of Health (DoH); it summarized emissions and fuel consumption results. The report was for internal use by MECO; it provided details on the impact of bio-diesel on emissions, fuel consumption, performance and reliability. In 2009, Hawaiian Electric Co. (HECO) contracted Mr. Klausmeier to manage a test program where 100% bio-diesel was used in a large (135 MW) combustion turbine. He developed the test plan, supervised testing and prepared reports on test results.

Assessment of Emission Reduction Strategies for Large, Low-Speed Stationary Diesel Engines. In 2003, Maui Electric Co. (MECO) contracted Mr. Klausmeier to evaluate control measures to reduce exhaust smoke from several large, low speed diesel engines. In performing this study, Mr. Klausmeier compiled information on control measures for marine diesels, since they are similar in design to those used by MECO. Mr. Klausmeier identified an effective and inexpensive control strategy using bio-diesel and combustion modifications to bring the units below required standards, saving MECO over a million dollars per year in non-compliance fines.

Best Available Control Technology (BACT) Assessments for Stationary Diesel Generators. Mr. Klausmeier performed these projects to evaluate emission control alternatives for diesel generators to be installed on the Hawaiian Islands. He evaluated combustion modifications and after treatment devices. He prepared a comprehensive report summarizing the cost and emission reductions of a wide variety of control alternatives for generators on Lanai and Molokai.

Battery Energy Storage System (BESS) for Wind Farms. As a manufacturers' representative for a company that offers an innovative Battery Energy Storage System (BESS), Mr. Klausmeier facilitated the installation of a 1 MW/MW-Hr BESS at a 30 MW wind farm in Maui. The system demonstrates that wind farm output can be effectively controlled to avoid power fluctuations and outages in areas like Hawaii that have limited grids. Much larger BESS applications are now being implemented on Oahu and Maui. These systems will allow wind energy to displace energy from diesel engines and combustion turbines.

Assessment of NO_x Controls for Exploratory Drilling Vessels. Under contract to the California Coastal Commission, Mr. Klausmeier evaluated control strategies including alternate fuels and retrofit of emission control technologies. Mr. Klausmeier identified short-term as well as long-term control technologies.

I/M for Heavy-Duty Diesels. Under contract to the California Air Resources Board, Mr. Klausmeier investigated the excess emissions from diesel vehicles due to malmaintenance and tampering. After quantifying the percentage increase in fleet emissions due to these causes, Mr. Klausmeier then developed procedures to identify high-emitting diesel vehicles. The resulting procedures identified the majority of the excess particle and hydrocarbon emissions.

BACT Analysis for Large Diesel Engines. Mr. Klausmeier directed two projects that investigated BACT for large diesel engines. One project summarized the state-of-art of NO_x controls for large diesel engines. Mr. Klausmeier summarized BACT for several recently permitted diesel engines.

Vehicle Inspection/Maintenance (I/M) Programs

Assistance in Implementing OBDII Inspections. Honda of America was required under a Consent Decree with USEPA to perform several Supplemental Environmental Programs (SEPs) related to implementing OBDII inspections in I/M programs. Honda contracted Mr. Klausmeier to be the program manager for the SEPs. As program manager for Honda, Mr. Klausmeier has been extensively involved in all aspects of OBDII implementation in I/M programs. Following is a summary of the SEPs that have been completed:

- Vermont -- Extensive training assistance to inspection stations.
- New York Upstate -- Pilot OBDII test program in selected decentralized safety inspection stations in Upstate New York. This program piloted stand-alone OBDII test analyzer systems. Rob worked with Ease Diagnostics to develop a PC system for this program that automates the inspection process and automatically stores data. The system piloted methods for preventing “clean scanning” by collecting data that can identify specific vehicle makes and models.
- Texas -- Pilot OBDII test program at selected decentralized safety inspection stations in the Austin area. This program also piloted stand-alone OBDII test analyzer systems. This program focused on high volume facilities and rental car fleets. Data from rental car fleets allows us to track readiness status for new vehicles.
- Connecticut -- Pilot OBDII test program at selected decentralized safety inspection stations in the Hartford area.
- Oregon -- Pilot OBDII test program at DEQ’s centralized inspection facilities. This program allowed us to relate OBDII test results with transient emission test results. Oregon implemented OBD inspections as a result of this project.
- Maine and New Hampshire – Like Vermont, focus was on providing training assistance to inspection stations.

Analysis of the Effectiveness of OBDII System as a means of Identifying High Emitting Vehicles, Mr. Klausmeier investigated the relationship between OBDII system status and vehicle emissions. California aims to simplify Smog Check inspections for 1996 and newer vehicles with OBDII systems. Instead of the current practice of subjecting these vehicles to both ASM (exhaust emissions tests) and OBDII inspections, California wants to use OBDII system parameters and vehicle history to screen-out likely low emitting vehicles that only must comply OBDII standards. In this study, Mr. Klausmeier analyzed data from test programs and I/M programs where both exhaust emissions tests and OBDII inspections were done on 1996+ vehicles. Exhaust emissions tests included FTP, IM240, IM147, and ASM. Mr. Klausmeier identified OBDII parameters that correlated well exhaust emission test results.

Task Support to California Bureau of Automotive Repair (BAR). Mr. Klausmeier performed several task level assignments to the BAR, including the following:

- **Remote Sensing --** As a subcontractor to Sonoma Tech Inc. (STI), Mr. Klausmeier evaluated the feasibility of establishing standards for remote sensing equipment, certifying remote sensing equipment operators, and licensing remote sensing service providers to operate RSD to clean screen vehicles.

- **Alternative I/M Tests --** Mr. Klausmeier performed a detailed evaluation of alternative I/M tests that could be implemented in the Smog Check program.

- **OBD –** Mr. Klausmeier has been assisting BAR in the collection and evaluation of data from OBDII I/M tests.

Enhanced I/M Assistance to Connecticut DMV -- Mr. Klausmeier is under contract to the state of Connecticut, Department of Motor Vehicles, to assist in implementing and operating their enhanced I/M program. He defined and performed acceptance tests on the new loaded mode test facilities. He has assisted the State in resolving contractual issues with their testing contractor.

Literature and Best Practices Scan: Vehicle Inspection and Maintenance (I/M) Programs -- dKC is currently helping Wisconsin develop a database to plan future changes to its I/M program. As part of this review, dKC is collecting a database of information on the technical, political, and an economic feasibility of changes to Wisconsin's I/M program.

The Greeley Remote Sensing Device Study. Mr. Klausmeier developed and implemented a detailed work plan for the Greeley Remote Sensing Device Study. As part of this project, he first defined the goals for the remote sensing program. He then defined data required to meet the broad goals of the project including data from remote sensing devices, vehicle registrations, the local I/M program, and other control programs in Colorado. From this he developed a detailed task breakdown addressing tasks such as site selection, data collection, data analysis and reporting. Colorado then implemented the work plan. Mr. Klausmeier was later retained to analyze and report on the data generated by the project.

Connecticut I/M Program Evaluation. Since 1999, dKC has been under contract to the state of Connecticut, Department of Environmental Protection, to assist them in implementing and evaluating their enhanced I/M program. Mr. Klausmeier has analyzed data collected from Connecticut's I/M program and developed quality assurance guidance for the new program. Mr. Klausmeier recently completed a detailed report evaluating Connecticut's I/M program. EPA refers to the method dKC used to evaluate Connecticut's I/M program as the Connecticut Method. His current assignment is to develop and implement procedures that will address the following issues:

- What are the actual emission reductions for the new I/M program?
- How well is compliance with testing requirements enforced?
  - Overall motorist enforcement
  - Adherence to correct inspection procedures by stations
- What measures can be used to identify fraudulent inspections?
- How should the OBD inspection be evaluated?
- How much deterioration in vehicle emissions occurred while the program was down?

Management of Data from the California I/M Pilot Program. Mr. Klausmeier assisted California in evaluating data collected in its pilot enhanced I/M program. California performed a massive study to determine if its enhanced I/M approach (targeting high emitters and requiring that these vehicles be inspected at centralized facilities) can meet EPA's enhanced I/M performance standard. Mr. Klausmeier directed the development of a model to profile the emission characteristics of each vehicle (termed High Emitter Profile, HEP). He also directed the data collection and analysis efforts, which included a comprehensive evaluation of remote sensing, alternative test procedures and alternative inspection networks.

Evaluation of California's I/M Program – Mr. Klausmeier is assisting the California Bureau of Automotive Repair (BAR) in evaluating its I/M program and developing protocols for future evaluations of the Smog Check Program. Mr. Klausmeier is investigating the performance of different types of Smog Check stations in assuring that vehicles meet Program Standards. He is developing ways to identify Test-and-Repair stations that have equivalent performance to Test-Only stations. He recently prepared a report on Station Performance that has been posted on BAR's website. He has prepared detailed procedures to automate the analysis and reporting of data from roadside tests and Smog Check stations.

Development of an I/M Program for Alternatively-Fueled Vehicles in California. Mr. Klausmeier directed this project, funded by BAR, to develop an I/M program for alternatively-fueled vehicles. As part of this project he has reviewed data on the environmental impacts of alternatively-fueled vehicles to identify specific exhaust components that must be targeted in an I/M program. He has also identified analytical ways to sense these components. He directed a field test evaluation of different I/M procedures.

Assistance to the Ontario Ministry of Environment in Implementing an I/M Program. Mr. Klausmeier served as a consultant to the Ontario Ministry of Environment in implementing an I/M program in the Greater Toronto Area. He helped the Government draw on the experience of U.S. I/M programs and implement a state-of-the-art program. He helped develop request for proposals (RFPs) and evaluated responses submitted.

Audit of the British Columbia I/M Program. Mr. Klausmeier evaluated British Columbia's I/M program. He estimated the emission reductions from the program, evaluated enforcement of program provisions, and evaluated emission test procedures. BC's I/M program was one of the first to test vehicles under loaded modes (ASM2525). Data from the program provide valuable insights of enhanced I/M programs in the U.S.

I/M Implementation Assistance for Delaware. Mr. Klausmeier is providing technical assistance to Delaware in implementing an enhanced I/M program. He evaluated testing alternatives, defined facility requirements, designed inspection lanes, prepared the request for proposals for a contractor to equip and operate the I/M lanes, and prepared acceptance procedures. As part of this project, Mr. Klausmeier identified and evaluated ways to prescreen vehicles so that only the high emitters undergo the complete emission test. As part of this effort, he prepared a SIP submittal for the State on the proposed clean screen program. This included running EPA's Clean Screen Credit Utility to develop SIP credits for the program. He is currently helping Delaware implement the clean screen program and OBDII inspections.

Acceptance Testing of Emission Analyzer Systems for I/M Programs in Georgia, Virginia and Texas. Mr. Klausmeier defined procedures to perform acceptance tests for analyzers certified to meet Texas and Georgia specifications. He then performed acceptance tests for the three major equipment manufacturers. He recently certified analyzers for the Northern Virginia and Texas I/M programs.

Analysis of Enhancements to Oregon's I/M Program. Mr. Klausmeier evaluated test procedures and repair initiatives that could be incorporated in Oregon's enhanced I/M program. He evaluated a promising new transient test- the BAR31 test - and negotiated emission reduction for this credits with EPA. He also prepared an RFP to privatize Oregon's I/M program.

Analysis of I/M Testing Alternatives. The Georgia Environmental Protection Department contracted Mr. Klausmeier to help define unresolved aspects of Georgia's enhanced I/M plan including the following:

- X The specific loaded mode emission test option (whether it be single mode ASM, dual mode ASM, two speed idle, or other tests).
- X Specific evaporative system functional checks that will be performed.
- X The dividing line between which vehicles must be tested at test-only stations and which can be tested at any station.

Development of Fast-Pass to Full IM240 Conversions/ Evaluation of Colorado's New I/M Program. Mr. Klausmeier was contracted by the Colorado Department of Health to develop a method to convert Fast-Pass IM240 results to full test values. Mr. Klausmeier also developed new fast-pass algorithms for the IM240 test. The new algorithms are appropriate for phase-in cutpoints. They appear capable of reducing test times by up to 50 % without sacrificing program effectiveness. Mr. Klausmeier also performed a peer review of Colorado's estimate of the benefits of its new I/M program.

Christian E. Lindhjem

EDUCATION

1987	PhD, Chemical Engineering, Rensselaer Polytechnic Institute
1981	MS, Chemical Engineering, University of Michigan
1980	BS, Chemical Engineering, Rose-Hulman Institute of Technology
1980	BS, Chemistry, Rose-Hulman Institute of Technology

EXPERIENCE

Dr. Christian E. Lindhjem, a Senior Consultant at ENVIRON, is an expert on emissions from highway and nonroad vehicles and engines and fuels used in those engines. With ENVIRON for 12 years and with EPA's Office of Transportation and Air Quality (previously named Office of Mobile Sources) for 8 years, Dr. Lindhjem has worked on on-road and off-road mobile source regulation development, emission measurements and analysis, emission control strategies, and emission inventory modeling including regulated pollutants and chemical compositional analysis to estimate toxic emissions and other components of concern. Dr. Lindhjem has evaluated and continues to consult on a broad range local and national mobile source emission issues including both emission estimates and potential emissions reductions from a variety of planned or demonstrated control strategies for on-road vehicles and off-road equipment (such as construction equipment, locomotive, marine vessels, and other harbor sources) and heavy-duty diesel vehicles. He works with local, regional and national officials and private clients to improve on-road and off-road (including agricultural, commercial marine, locomotive, construction and mining, recreational marine, and lawn and garden equipment types) emission inventories for regional evaluation as well as individual facilities including ports and rail yards. His other national experience included assistance for EPA in the development of the NONROAD model and a national commercial marine emission inventory and spatial allocation for deep draft vessels. Dr. Lindhjem holds a Ph.D. degree in Chemical Engineering from the Rensselaer Polytechnic Institute and a M.S. degree in Chemical Engineering from the University of Michigan.

<u>Commercial Marine, Rail, and Intermodal Emissions Evaluations</u>: Conducted in depth analysis and method formulation to revise locomotive and commercial marine emissions for ports and railroads, states, and national agencies including those for the States of Arkansas, Illinois, Indiana, Michigan, Ohio, Wisconsin, and Wyoming and the metropolitan areas of Kansas City and Boise. Prepared a grid scale national emissions inventory from Category 3 (ocean-going vessels) commercial marine engines for EPA combining near port and open-ocean emissions. Other projects include emissions and control strategy evaluations for the Ports of Long Beach, San Francisco, Oakland, San Diego and others, including the emission reduction potential from shore power and other control strategies. Evaluated averaging strategies to comply with the Canadian and U.S. Emission Control Area (ECA) designation for ocean-going vessels using highly resolved activity and emissions calculations. Conducted detailed rail yard activity and emissions evaluations in California and Kansas including locomotive and other off-road and on-road source categories within the yards.

<u>On-Road Emission Inventories</u>: Managed projects to estimate metropolitan area and project level emissions estimates using the EPA MOVES2010 and California ARB EMFAC models. Managing projects to incorporate CONCEPT link level modeling for Detroit, Atlanta, and Philadelphia including MOVES2010 model adjustments and vehicle volume and mix of heavy and light-duty vehicles adjusted by time of data and road type. Performed evaluations of the on-road vehicle mix and vehicle weight data from Automatic Traffic Recorders to better estimate on-road emissions for EPA, Illinois, Ohio, Wisconsin, and Minnesota. Led programs to develop new strategies and uses for alternative data to evaluate on-road vehicle emissions for EPA and the Coordinating Research Council in preparation of the MOVES model.

<u>On and Off-Road Mobile Source Control Strategies</u>: Provides detailed technical analyses and planning and day to day support of on-road and off-road mobile source control strategies for local and state government agencies including the Houston-Galveston, Dallas-Ft. Worth, and East Texas nonattainment areas' SIPs, for the Houston-Galveston Area Council (HGAC), the East

Texas Council of Governments (ETCOG), North Central Council of Governments (NCTCOG), and the Texas Commission on Environmental Quality (TCEQ). Also assisting in revisions/updates to the mobile source emission inventory in Texas and Las Vegas. Providing the plan and technical guidance for the HGAC Voluntary Mobile Source Emission Reduction Program (VMEP) including marketing and online database and interactive programs, and reviews and evaluation of the Texas Emission Reduction PLAN (TERP) for the Houston Advanced Research Center (HARC).

Off-Road Emission Inventories: Provided service to state agencies by improving air emissions inventories from all nonroad mobile sources. Conducted in-depth locomotive and other emissions evaluations for BNSF railyards in California in preparation for dispersion modeling impact analysis on the local community. For the Lake Michigan Air Directors Consortium (LADCO), a plan was developed and implemented for revising and developing activity estimates for all off-road emission sources, incorporate such estimates in the emissions inventory, and spatially allocate those emissions. Innovative methods were used for commercial marine to quantify the Lake and river commercial marine emissions, locomotive emissions from large and small railroads, and a unique method for recreational marine spatial allocation specifically. Prepared revised emissions inventories some categories or all nonroad (including aircraft, commercial marine, and locomotive sources) for the States of Arizona, Texas, Arkansas, Oklahoma, Wyoming, Wisconsin, Illinois, Indiana, Michigan, Ohio, New Jersey, and the Western Regional Air Partnership (WRAP). Assisted EPA in improvements to the NONROAD model for off-road emissions estimation including for instance detailed technical comparisons of EPA and CARB models for estimating emissions from nonroad mobile sources and providing revisions to modeling structure, activity data inputs and assumptions, and emission factors for nonroad spark-ignition and compression ignition engines. Another example of activity includes providing technical guidance to Northeast States for Coordinated Air Use Management (NESCAUM) for the development of surveys and analysis of survey data to derive improved estimates of construction equipment activity in the Northeast U.S.

Scientific Emissions Research and Analysis: Performed scientific evaluation of emission modeling methods such as critically reviewing the project plan and available data for EPA's new MOVES model in an extensive report (E-68) for the Coordinating Research Council (CRC). This report outlined the general method, specifics of data handling, and many other areas of interest in implementing this new modeling approach for on-road mobile sources. The CRC project followed the previous work for EPA, which developed and executed a method using on-board emissions monitor data to estimate emissions from onroad and offroad vehicles and equipment for the Office of Transportation and Air Quality (OTAQ) of EPA. Driving behavior and emissions were related to the physical and operating parameters experienced of the vehicle or engine. Scientific evaluation of the effects of humidity and temperature on mobile source emissions was conducted and incorporated into Texas emissions for HARC and TCEQ. A scientific assessment of the emissions response from hybrid-electric urban buses for the New York State Energy Research and Development Agency (NYSERDA).

Chemical Constituents of Mobile Source Emissions: Performed a literature review and evaluation of the chemical constituents including potential toxic components of mobile source emissions for the EPA. Estimated the emission reduction potential and impacts on air quality and toxicity from replacing diesel with biodiesel fuel in heavy-duty diesel vehicles for the Department of Energy's National Renewable Energy Laboratory.

Mobile Source Emissions Air Quality Impact Evaluation: Providing limited and innovative plans to evaluate and mitigate mobile source emissions at a project level. For instance, the City of Hawthorne, California, provided an evaluation of the impact and provided an innovated contracting method to mitigate air quality effects for garbage collection vehicles. Provided technical support for estimating on-road emissions and air quality impacts for the expansion of an amphitheater and casino including preparing a report for the Environmental Impact Statement and an assessment of General Conformity.

Prior to joining ENVIRON, Dr. Lindhjem held the following positions:

Engineer, U.S. Environmental Protection Agency (EPA), National Vehicle and Fuel Emissions Laboratory, Office of Mobile Sources, Ann Arbor, MI (1990 - 1998), 8 years

Nonroad Mobile Emissions

Evaluation of rail and port intermodal yard emissions including emission activity from ships, locomotive, cargo handling equipment, and on-site truck movements.

Responsible for the theoretical framework behind EPA's NONROAD model, the next inventory modeling tool for nonroad engines, analogous to EPA's MOBILE model for highway vehicles, including nonroad industrial, construction, commercial, residential, and marine engines and vehicles.

Developed the input estimates for the EPA's NONROAD model for population, activity, load factor, average life, and compression and spark-ignition emission factors for nonroad engines as well as estimates for the hydrocarbon speciation.

Project engineer on a variety of test programs measuring emissions from nonroad engines, specifically construction and agricultural diesel engines, outboard and inboard recreational marine motors, and lawn & garden engines.

Evaluated of the effect of test cycle on various diesel and gasoline nonroad engines through regulatory and nonregulatory steady-state and transient comparisons.

Developed a methodology to estimate emissions from commercial marine engines.

Highway Mobile Emissions Model

Incorporated MOVES into emission inventory development tools such as SMOKE, CONCEPT, and project level emissions development.

Have provided emission estimates for light-duty and heavy-duty vehicles exhaust and evaporative emissions, and fuel effects for MOBILE4.1, MOBILE5, and MOBILE6.

Specific areas of emissions modeling were estimating the effects of reformulated gasoline, evaporative emissions, and diesel engines emissions for heavy-duty highway trucks and buses.

Other modeling efforts include analyzing chemical characterizations of exhaust and evaporative emissions to provide estimates currently used in EPA's Speciate Database.

Managed up to $1.4 million in contract funding per year.

Research included lean NOx-reduction catalyst evaluations, test cycle comparisons for highway and nonroad engines, and novel emission modeling techniques for diesel engines.

Engine Testing Project Management

Managed the heavy-duty, marine, evaporative, and light-duty chassis testing programs with five technicians, two engineers, and a budget of about $500k per year.

Multidisciplinary approach combining mechanical, electrical, computer, and chemical analysis.

Supplied test results for a variety of EPA projects using a variety of engines and vehicles; most notably, nonroad and highway diesel, inboard and outboard marine, and lawn and garden engines.

Clean Fuels Development

Developed the Reformulated Gasoline Simple Model; evaluated the effect of fuel oxygen and volatility control on primary and toxic pollutants from gasoline vehicles.

Team member for the Reformulated Gasoline Complex Model and Final Rulemaking providing estimates for effects of fuel parameter changes on primary and toxic pollutants.

Conducted testing programs investigating the effects of reformulated fuels on vehicles and nonroad engines.

Facilitated fuel additive emission testing and registration.

Research Engineer, Westvaco Corporation, (1988 - 1990), Laurel Research Center, Laurel, MD

Designed coating formulations and products for the fine papers division.

Successfully quantified subjective criteria of product quality and determined the mechanisms of in-use deterioration of our products during printing.

Determined rheological failures in the production of coated papers and developed novel coating formulations for improved production.

Managed 2 technicians and interactions with research and production.

EPA AWARDS

EPA Bronze Medal for Commendable Service for Nonroad Engine Emission Controls Development, 1995

EPA Bronze Medal for Commendable Service for Highway Heavy-Duty Engine Emission Reduction, 1995

EPA Science Achievement Award in Air Quality, 1992

EPA Silver Medal for Superior Service for Clean Fuels Development, 1991

TEACHING EXPERIENCE

University of Michigan, (1991), “Pollution Control for Chemical Engineers,” Department of Chemical Engineering

Rensselaer Polytechnic Institute, (1985-1987), “Air Pollution Control,” Department of Chemical Engineering

PROFESSIONAL MEMBERSHIPS

Air and Waste Management Association

National Cooperative Highway Research Program Panelist

EPA’s Mobile Source Technical Review Subcommittee for Nonroad Engine Emissions

PUBLICATIONS AND PRESENTATIONS

Lindhjem C.E. 2010 "Use of MOVES2010 in Link Level On-Road Vehicle Emissions Modeling Using CONCEPT-MV," C. E. Lindhjem, A. DenBleyker, M. Jimenez, J. Haasbeek, A. K. Pollack, ENVIRON International Corporation, CA; Z. Li, Clark County, Las Vegas, NV. 19th International Emission Inventory Conference, San Antonio, Texas, September 27 - 30, 2010.

Lindhjem C.E. 2010 "Development of Drivers and Post-Processing Scripts to Incorporate MOVES2010 Emission Factors with the Smoke Emissions Model,"C. E. Lindhjem, A. DenBleyker, M. Jimenez and A. K. Pollack, ENVIRON International Corporation. 19th International Emission Inventory Conference, San Antonio, Texas, September 27 - 30, 2010.

Lindhjem, C. 2009. “Mobile Source Particulate And Semi-Volatile Organic Carbon Ambient Modeling.” Presented at the 18th International Emissions Inventory Conference, Baltimore, MD, April 15, 2009.

Lindhjem, C. 2009 “Mobile Source Emissions: Adjustments to MOBILE6,” 19th CRC On-Road Vehicle Emissions Workshop, March 23-25, 2009.

Lindhjem, C. 2008. “Intermodal Yard Activity and Emissions Evaluations.” Presented at the 17th International Emissions Inventory Conference, Portland, OR. June.

Lindhjem, C.E. and Russell, J., 2006. “Development Of Gridded Ocean-Going Vessel Emission Inventories,” Presented at the Air and Waste Management Association Emission Inventory Conference, New Orleans, LA, May 17.

Lindhjem, C.E. and Shepard S. 2005. “Estimation and Effects of Vehicle Mix on On-Road Emission Estimates,” Air and Waste Management Association Emission Inventory Conference, Las Vegas, Nevada, April 14.

Lindhjem, C.E. and Chan L-M. 2004. “Emission Control Technologies and Programs for Heavy-Duty Diesel Vehicle Fleets in North America,” Paper No. 371. Air and Waste Management Association Annual Meeting, Indianapolis IN.

Lindhjem, C.E., Chan, L-M., Pollack, A.K., and Kite C. 2004. “Applying Humidity and Temperature Corrections to On and Off-Road Mobile Source Emissions,” Air & Waste Management Association Emission Inventory Conference, St. Petersburg Florida.

Lindhjem, C.E., T. Stockenius. 2002. “On-Board Emissions Data Analysis,” Presented at the12th CRC On-Road Vehicle Emissions Workshop, San Diego, California, April.

Lindhjem, C.E., A.K. Pollack, R. Chi. 2001. “Comparison Of Highway Mobile Source Emissions Inventory From MOBILE1 through MOBILE6,” 11th CRC On-Road Vehicle Emissions Workshop, San Diego, California, March.

Lindhjem, C.E., and D.A. Guerrieri. 1998. “Evaluation of Lean NOx Reduction Catalysts for Controlling Emissions from Diesel Engines”, *Environmental Progress*, Spring, 1998, page 48.

Lindhjem, C.E., D.M. Swain, C.J. Jackson, and G.J. Hoffman. 1998. “A Method for Comparing Transient NOx Emissions with Weighted Steady State Test Results,” *Society of Automotive Engineers, SAE-980408.*

Lindhjem, C.E., D.J. Korotney, V. Rao, and M.S. Sklar. 1995. “Reformulated Gasoline Effects on Exhaust Emissions: Phase III: Investigation on the Effects of the Oxygenate ETBE, Sulfur, Olefins, Volatility, and Aromatics and the Interactions Between Olefins and Volatility or Sulfur,” *Society of Automotive Engineers, SAE-950782.*

Lindhjem, C.E. 1995. “The Effect of Gasoline Reformulation and Sulfur Reduction on Exhaust Emissions from Post-1983 and Pre-1990 Vehicles,” *Society of Automotive Engineers, SAE-950778.*

Lindhjem, C.E., S.C. Mayotte, V. Rao, and M.S. Sklar. 1994. “Reformulated Gasoline Effects on Exhaust Emissions: Phase II: Continued Investigation of the Effects of Fuel Oxygenate Content, Volatility, Sulfur, Olefins, and Distillation Parameters,” *Society of Automotive Engineers, SAE-941974.*

Lindhjem, C.E., S.C. Mayotte, V. Rao, and M.S. Sklar. 1994. “Reformulated Gasoline Effects on Exhaust Emissions: Phase I: Initial Investigation of Oxygenate, Volatility, Distillation and Sulfur Effects,” *society of Automotive Engineers, SAE-941973.*

Lindhjem, C.E., D.J. Korotney. 1993. “Running Loss Emissions from Gasoline-Fueled Motor Vehicles,” *Society of Automotive Engineers, SAE-931991.*

Lindhjem, C.E. 1991. “The Particle Packing and Shape Effects on the Rheological Characteristics of Paper Coating Pigments,” *Proceedings of the 1991 TAPPI Coating Conference*, Montreal, Quebec, Canada, TAPPI Press, Atlanta, Georgia.

Lindhjem, C.E., E.R. Altwicker. 1988. “Absorption of Gases by Drops,” *AICHE Journal*, v. 34. pp. 329-332.

SELECTED REPORTS

Lindhjem, C.E. and Sturtz, T.M., "Development of Emission Estimates for Locomotives in the Kansas City Metropolitan Statistical Area," Prepared for Kansas Department of Health and Environment (KDHE), May 13, 2010.

Parker, L., Lindhjem, C.E. and others, "Implement Port of Houston's Current Inventory and Harmonize the Remaining 8-county Shipping Inventory for TCEQ Modeling" Prepared for: Texas Commission on Environmental Quality, August 18, 2010.

Lindhjem, C.E. and Sturtz, T.M., "Development of Link-Level Spatial Allocation Methodology for Line-Haul Locomotive Emissions in Texas," Prepared for Texas Commission on Environmental Quality, August 15, 2009.

Lindhjem, C.E. 2008. "Evaluation Of Mobile Source Control Strategies For The Houston-Galveston-Brazoria State Implementation Plan," Draft Report, December 2008.

Lindhjem, C.E. 2008. "Emission Profiles for EPA SPECIATE Database, Part 2: EPAct FUELS." Prepared for EPA; Office of Transportation and Air Quality, Ann Arbor, MI. September.

Bar-Ilan, A., C. Lindhjem. 2008. "Port of Oakland Berthing Load Study." Prepared for the Port of Oakland, Oakland, CA. April.

Lindhjem, C.E. 2008. "Emission Profiles for EPA SPECIATE Database." Prepared for US Environmental Protection Agency. January.

Bar-Ilan, A., C. Chandler-Nogales, C. Lindhjem. 2007. "Massachusetts Diesel PM Emissions Reduction: Retrofit Technical Feasibility Analysis." Prepared for NESCAUM, Boston, MA. October.

Lindhjem, C.E. 2007. "Port of Oakland 2005 Seaport Air Emissions Inventory," Prepared for the Port of Oakland, Available online at http://www.portofoakland.com/environm/airEmissions.asp, August.

Lindhjem, C.E. 2007. "LADCO Nonroad Emission Inventory Project for Locomotive and Commercial Marine Emission Sources," Prepared for Lake Michigan Air Director Consortium by ENVIRON, February.

Lindhjem, C.E. 2006. "Los Angeles - Hobart Railyard Toxic Air Containment Emissions Inventory," "Commerce Eastern Railyard Toxic Air Containment Emissions," "Commerce – Mechanical Railyard Toxic Air Containment Emissions," "Wilmington Watson Railyard Toxic Air Containment Emissions," Stockton Railyard Toxic Air Containment Emissions," "Richmond Railyard Toxic Air Containment Emissions," "Barstow Railyard Toxic Air Containment Emissions," " San Diego Railyard Toxic Air Containment Emissions," Prepared for BNSF Railway, Available Online at http://www.arb.ca.gov/railyard/hra/hra.htm

Lindhjem, C.E. 2006. "Evaluation Of Mobile Source Control Strategies For The Houston-Galveston-Brazoria State Implementation Plan," Prepared for the Houston-Galveston Area Council, May.

Lindhjem, C.E. and Yarwood, G. 2004. "Humidity and Temperature Effects on On-road and Off-road Emissions and Ozone Formation (HARC Project H8B), Prepared for Houston Advanced Research Center (HARC), November.

Lindhjem, C.E., Shepard, S. 2004. "Development Work For Improved Heavy-Duty Vehicle Modeling Capability Data Mining – FHWA Datasets Phase II: Final Report," EPA Contract No. 68-C-02-022 Work Assignment No. 2-6 Prepared for Evelyn Sue Kimbrough, Atmospheric Protection Branch, Office of Research and Development, U.S. Environmental Protection Agency, September.

Lindhjem, C.E., Shepard, S., Pollack, A.K. 2004. "LADCO/MPCA Total Volume And Vehicle Classification Temporal Profiles," Prepared for Lake Michigan Air Directors Consortium, September.

Lindhjem, C.E. and Pollack, A.K. 2004. "Analysis of EPA's Draft Plan for Emissions Modeling in MOVES and MOVES GHG, Project E-68, Prepared for Coordinating Research Council, Inc., May.

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A. Pollack, R. Chi, C. Lindhjem, C. Tran, P. Chandraker. 2004. "Development of WRAP MOBILE Source Emission Inventories". Prepared for Western Governors' Association, Denver, Colorado. February.

A. Pollack, C. Lindhjem, T.E. Stoerckenius , C. Tran,G. Mansell, M. Jimenez, G. Wilson, and S. Coulter-Burke 2003. “CRC Project E-64 Evaluation of the U.S EPA MOBILE6 Highway Vehicle Emission Factor Model,” Prepared for Coordinating Research Council, Inc., December.

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Lindhjem, C.E., A.K. Pollack, T.E. Stoerckenius, C. Tran, G. Mansell, M. Jimenez, G. Wilson, S.Coulter-Burke. 2003. “Evaluation of the US EPA MOBILE6 Highway Vehicle Emission Factory Model. December.

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Lindhjem, C.E., R.E. Morris, A.K. Pollack, G.E. Mansell, Ph.D., Y. Jia, G. Wilson. 2002. “ Impact of Biodiesel Fuels on Air Quality and Human Health.” Summary Report. Prepared for National Renewable Energy Laboratory. Golden, CO. November.

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Lindhjem, C.E., M. Beardsley, C. Harris. 1998. “Exhaust Emission Factors for Nonroad Engine Modeling--Spark Ignition.” Report No. NR-010, Documentation Supporting EPA’s Draft Release of the NONROAD Model. February.

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Lindhjem, C.E., 1997. “Nonroad Engine Population Estimates.” Report No. NR-006, Documentation Supporting EPA’s Draft Release of the NONROAD Model. December.

Lindhjem, C.E., M. Beardsley. 1997. “Average Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling.” EPA/OMS Report NR-005, Documentation Supporting EPA’s Draft Release of the NONROAD Model. December.

Lindhjem, C.E., 1997. “Exhaust Emission Effects of Fuel Sulfur and Oxygen on Gasoline Nonroad Engines.” Report No. NR-003, Documentation Supporting EPA’s Draft Release of the NONROAD Model. November.

Lindhjem, C.E., 1997. “Conversion Factors for Hydrocarbon Emission Components.” Report No. NR-002, Documentation Supporting EPA’s Draft Release of the NONROAD Model. November.

Lindhjem, C.E., T. Jackson. 1997. “Update on Heavy-Duty Emission Levels (Model Years 1988-2004+) for Use in MOBILE6.” Draft Report M6HDE.001. October.

Lindhjem, C.E., 1997. “Nonroad Mobile Emissions Modeling.” Air & Waste Management Conference on Emission Inventory: Planning for the Future, RTP, NC. October.

Lindhjem, C.E., 1997. “Heavy-Duty Diesel Emissions Modeling.” Air & Waste Management Conference on Emission Inventory: Planning for the Future, RTP, NC. October.

Lindhjem, C.E. 1997. “Emission Rates from Highway and Nonroad Diesel Engines.” World Car Conference, Riverside, California. January.

Lindhjem, C.E., 1995. “Heavy-duty Engine Testing Report; Emissions from Idling Truck Engines.” EPA Technical Report. May.

Lindhjem, C.E., 1994. "The Effect of Fuel Reformulation on 4-stroke Lawn and Garden Engines." EPA Technical Report. July.

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Lindhjem, C.E., 1993. "Speciation of Evaporative Emissions." EPA Technical Report. April.

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Lindhjem, C.E., 1992. "Vapor Pressure at 130^{o}F as the Parameter of choice for Running Loss and Hot Soak Emissions Correlation." EPA Technical Report. April.

Lindhjem, C.E., 1992. "Effect of Oxygenates on Emissions." EPA Technical Report (for use in EPA's Rulemaking on Reformulated Gasoline using the Simple Model). January.

Lindhjem, C.E., 1991. "Multiple Day Diurnal, Purge Failure, and Pressure Failure Evaporative Emissions." EPA Technical Report (for use in EPA's MOBILE emission factors model for mobile source emission estimations). November.

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Education: Ph. D. in Chemical Engineering, University of Michigan, Ann Arbor, 1979.
M. S. in Chemical Engineering, University of California, Los Angeles, 1976.
B. S. in Chemical Engineering, Osmania University, India, 1974.
Licensed professional engineer (P.E.) in the state of Michigan

Experience: 2009 – Present
Currently an independent evaporative emissions consultant; started own consulting company (Evaporative Emissions Consulting, Inc., www.EvapConsulting.com) after retiring from General Motors R&D Center with 30 years of experience in fuels and fuel vapor emission control research and development. The company provides engineering and consulting services in the area of evaporative fuel vapor emission control. I have extensive experience in finding solutions to difficult evaporative emission control problems involving the development of mathematical models to predict evaporative (diurnal, hot-soak, running loss, and refueling) fuel vapor generation from fuel tanks, fuel vapor storage in activated carbon canister, canister purging, vapor redistribution, canister back-purge, and permeation losses. Other unique modeling skills are: mathematical prediction of evaporative emissions from complex mixtures of gasolines and oxygenates (ethanol, methanol, butanol, MTBE, ETBE, etc.); and development of evaporative and refueling emission control systems for range extended electric vehicles and plug-in hybrid electric vehicles involving sealed/pressurized fuel tanks.

Developed evaporative and refueling emission control system for Fisker Karma plug-in hybrid vehicle. I was responsible for concept development, system design, sourcing and supplier selection, evap OBDII system and strategy development, and production implementation. Also, I have been an evaporative emissions consultant to Attwood Marine, TI Automotive, YAPP Automotive Parts China, Deltronix India, and General Motors.

I have developed a mathematical model (computer software tool) called "ReddyEvap" for predicting evaporative and refueling emissions as a function of fuel properties, ambient conditions, system hardware, etc.

Taught 2-day evaporative emission training class/workshop to the following:
1. Honda R&D, Raymond, OH, for 12 engineers on July 28&29, 2009
2. Attwood Marine at Lowell, MI, for 32 engineers on January 12&13, 2010
3. CARB Sacramento for 34 engineers on February 7&8, 2010
4. CARB El Monte for 80 engineers on February 22&23, 2010
5. EPA Ann Arbor for 53 engineers on April 21&22, 2010
6. Denso International for 10 engineers on May 6&7, 2010

7. Continental Automotive (Chatham, Canada) for 25 engineers on May 17&18, 2010
8. Mahindra&Mahindra Motors, India, for 17 engineers on August 26&27, 2010
9. TATA Motors, India, for 15 engineers on September 3&4, 2010
10. TI Automotive, for 23 engineers, January 6&7, 2011
11. McLaren Automotive, UK, February 14&15, 2011
12. DONGFENG Automotive and DONGFENG Motors, China, May 2011
13. YAPP Automotive Parts, China, September 5&6, 2011
14. Deltronix, Inidia, September 8&9, 2011
15. Bombardier Recreational Products, Canada, September 23&24, 2011
16. Norit Activated Carbon, the Natherlands, November 14&15, 2011

1979 - 2009
General Motors Research and Development Center
Chemical and Environmental Sciences Laboratory

1984 – 2009: Research and development in the area of fuel vapor emissions. Developed mathematical models and PC programs to predict vehicle evaporative and refueling emissions. Developed several new concepts/methods to improve vehicle fuel vapor emission control systems including 2011 Chevrolet Volt evaporative emission control system.

1979 – 84: Studied low temperature wax formation and filter plugging properties of diesel fuels and diesel fuel stability and its effects on vehicle operation.

<u>Awards:</u> 2002 Boss Kettering Award (GM's top honor for technical innovations) for Engine off Natural Vacuum Fuel System Leak Detection.

1995 Boss Kettering Award for Innovations in Fuel Systems.

2002 Charles L. McCuen Special Achievement Award (GM R&D's top honor for technical innovations) for Evaporative Emission Control System Leak Detection.

1993 Charles L. McCuen Special Achievement Award for Innovative Components for Reduced Vehicle Evaporative Emissions.

1989 Charles L. McCuen Special Achievement Award for EVAP-PC Model for Predicting Vehicle Vapor Emissions.

<u>Patents:</u> 26 US patents + 5 pending; several defensive publications

<u>Publications:</u> 12 SAE & Other Technical Papers
2 papers in international journals
6 graduate studies/research publications in international journals

Appendix B: Conflict of Interest Statements

Conflict of Interest and Bias for Peer Review

Background

Identification and management of potential conflict of interest (COI) and bias issues are vital to the successes and credibility of any peer review consisting of external experts. The questionnaire that follows is consistent with EPA guidance concerning peer reviews.[1]

Definitions

Experts in a particular field will, in many cases, have existing opinions concerning the subject of the peer review. These opinions may be considered bias, but are not necessarily conflicts of interest.

Bias: For a peer review, means a predisposition towards the subject matter to be discussed that could influence the candidate's viewpoint.

Examples of bias would be situations in which a candidate:

1. Has previously expressed a position on the subject(s) under consideration by the panel; or

2. Is affiliated with an industry, governmental, public interest, or other group which has expressed a position concerning the subject(s) under consideration by the panel.

Conflict of Interest: For a peer review, as defined by the National Academy of Sciences,[2] includes any of the following:

1. Affiliation with an organization with financial ties directly related to the outcome;

2. Direct personal/financial investments in the sponsoring organization or related to the subject; or

3. Direct involvement in the documents submitted to the peer review panel... that could impair the individual's objectivity or create an unfair competitive advantage for the individual or organization.

---

[1] U.S. EPA (2009). Science Policy Council Peer Review Handbook.
OMB (2004). Final Information Quality Bulletin for Peer Review.

[2] NAS (2003). "Policy and Procedures on Committee Composition and Balance and Conflict or Interest for Committees Used in the Development of Reports" (www.nationalacademies.org/coi).

Policy and Process

- Candidates with COI, as defined above, will not be eligible for membership on those panels where their conflicts apply.

- In general, candidates with bias, as defined above, on a particular issue will be eligible for all panel memberships; however, extreme biases, such as those likely to impair a candidate's ability to contribute to meaningful scientific discourse, will disqualify a candidate.

- Ideally, the composition of each panel will reflect a range of bias for a particular subject, striving for balance.

- Candidates who meet scientific qualifications and other eligibility criteria will be asked to provide written disclosure through a confidential questionnaire of all potential COI and bias issues during the candidate identification and selection process.

- Candidates should be prepared, as necessary, to discuss potential COI and bias issues.

- All bias issues related to selected panelists will be disclosed in writing in the final peer review record.

Conflict of Interest and Bias Questionnaire

DELTA Evaporative Model Report Peer Review

Instructions to Candidate Reviewers

1. Please check YES/NO/DON'T KNOW in response to each question.

2. If your answer is YES or DON'T KNOW, please provide a brief explanation of the circumstances.

3. Please make a reasonable effort to answer accurately each question. For example, to the extent a question applies to individuals (or entities) other than you (e.g., spouse, dependents, or their employers), you should make a reasonable inquiry, such as emailing the questions to such individuals/entities in an effort to obtain information necessary to accurately answer the questions.

Questions

1. Are you (or your spouse/partner or dependents) or your current employer, an author, contributor, or an earlier reviewer of the document(s) being reviewed by this panel?

   YES___ NO_✓_ DON'T KNOW___

2. Do you (or you spouse/partner or dependents) or your current employer have current plans to conduct or seek work related to the subject of this peer review following the completion of this peer review panel?

   YES___ NO_✓_ DON'T KNOW___

3. Do you (or your spouse/partner or dependents) or your current employer have any known financial stake in the outcome of the review *(e.g.,* investment interest in a business related to the subject of peer review)?

   YES___ NO_✓_ DON'T KNOW___

4. Have you (or your spouse/partner or dependents) or your current employer commented, reviewed, testified, published, made public statements, or taken positions regarding the subject of this peer review?

   YES_✓_ NO___ DON'T KNOW___

   [In 2009, I peer reviewed the EPA report "Development of Evaporative Emissions Calculations for MOVES."]

5. Do you hold personal values or beliefs that would preclude you from conducting an objective, scientific evaluation of the subject of the review?

   YES___ NO_✓_ DON'T KNOW___

6. Do you know of any reason that you might be unable to provide impartial advice or comments on the subject review of the panel?

   YES___ NO_✓_ DON'T KNOW___

7. Are you aware of any other factors that may create potential conflict of interest or bias issues for you as a member of the panel?

   YES___ NO_✓_ DON'T KNOW___

Acknowledgment

I declare that the disclosed information is true and accurate to the best of my knowledge, and that no real, potential, or apparent conflict of interest or bias is known to me except as disclosed. I further declare that I have made reasonable effort and inquiry to obtain the information needed to answer the questions truthfully, and accurately. I agree to inform SRA promptly of any change in circumstances that would require me to revise the answers that I have provided.

Rob Klausmeier______________
Name

Rob Klausmeier
Signature

December 7, 2011___
Date

Conflict of Interest and Bias Questionnaire

EPAct Study Analysis Peer Review

Instructions to Candidate Reviewers

1. Please check YES/NO/DON'T KNOW in response to each question.

2. If your answer is YES or DON'T KNOW, please provide a brief explanation of the circumstances.

3. Please make a reasonable effort to answer accurately each question. For example, to the extent a question applies to individuals (or entities) other than you (e.g., spouse, dependents, or their employers), you should make a reasonable inquiry, such as emailing the questions to such individuals/entities in an effort to obtain information necessary to accurately answer the questions.

Questions

1. Are you (or your spouse/partner or dependents) or your current employer, an author, contributor, or an earlier reviewer of the document(s) being reviewed by this panel?

   YES___ NO_X_ DON'T KNOW___

2. Do you (or you spouse/partner or dependents) or your current employer have current plans to conduct or seek work related to the subject of this peer review following the completion of this peer review panel?

   YES___ NO___ DON'T KNOW_X_

   [ENVIRON is not pursuing opportunities at the present time, but may do so after completing the review, if new opportunities become available, and will not share deliberative (not yet publicly released) information provided for this review. During the period of the review, ENVIRON will not work on this subject for any other entity than EPA.]

3. Do you (or your spouse/partner or dependents) or your current employer have any known financial stake in the outcome of the review *(e.g.,* investment interest in a business related to the subject of peer review)?

   YES___ NO___ DON'T KNOW_X__

   [Chris Lindhjem does own shares in publicly traded oil and refining companies, but he does not believe that this constitutes a financial stake in the outcome of the review.]

4. Have you (or your spouse/partner or dependents) or your current employer commented, reviewed, testified, published, made public statements, or taken positions regarding the subject of this peer review?

   YES___ NO___ DON'T KNOW_X_

   [Chris Lindhjem has published on this subject, evaporative emissions, while working at EPA in the 1990s, and is co-author on a paper in review comparing emission rates with field data. However, neither Chris Lindhjem nor ENVIRON has commented or taken positions regarding the specific subject of this peer review.]

5. Do you hold personal values or beliefs that would preclude you from conducting an objective, scientific evaluation of the subject of the review?

   YES___ NO_X_ DON'T KNOW___

6. Do you know of any reason that you might be unable to provide impartial advice or comments on the subject review of the panel?

   YES___ NO_X_ DON'T KNOW___

7. Are you aware of any other factors that may create potential conflict of interest or bias issues for you as a member of the panel?

   YES___ NO__X_ DON'T KNOW___

Acknowledgment

I declare that the disclosed information is true and accurate to the best of my knowledge, and that no real, potential, or apparent conflict of interest or bias is known to me except as disclosed. I further declare that I have made reasonable effort and inquiry to obtain the information needed to answer the questions truthfully, and accurately. I agree to inform SRA promptly of any change in circumstances that would require me to revise the answers that I have provided.

Christian E. Lindhjem
Name

Signature

November 14, 2011
Date

Conflict of Interest and Bias Questionnaire

DELTA Evaporative Model Report Peer Review

Instructions to Candidate Reviewers

1. Please check YES/NO/DON'T KNOW in response to each question.

2. If your answer is YES or DON'T KNOW, please provide a brief explanation of the circumstances.

3. Please make a reasonable effort to answer accurately each question. For example, to the extent a question applies to individuals (or entities) other than you (e.g., spouse, dependents, or their employers), you should make a reasonable inquiry, such as emailing the questions to such individuals/entities in an effort to obtain information necessary to accurately answer the questions.

Questions

1. Are you (or your spouse/partner or dependents) or your current employer, an author, contributor, or an earlier reviewer of the document(s) being reviewed by this panel?

   YES___ NO_✓_ DON'T KNOW___

2. Do you (or you spouse/partner or dependents) or your current employer have current plans to conduct or seek work related to the subject of this peer review following the completion of this peer review panel?

   YES___ NO_✓_ DON'T KNOW___

3. Do you (or your spouse/partner or dependents) or your current employer have any known financial stake in the outcome of the review *(e.g.,* investment interest in a business related to the subject of peer review)?

   YES___ NO_✓_ DON'T KNOW___

4. Have you (or your spouse/partner or dependents) or your current employer commented, reviewed, testified, published, made public statements, or taken positions regarding the subject of this peer review?

   YES___ NO_✓_ DON'T KNOW___

5. Do you hold personal values or beliefs that would preclude you from conducting an objective, scientific evaluation of the subject of the review?

   YES___ NO_✓_ DON'T KNOW___

6. Do you know of any reason that you might be unable to provide impartial advice or comments on the subject review of the panel?

   YES___ NO_✓_ DON'T KNOW___

7. Are you aware of any other factors that may create potential conflict of interest or bias issues for you as a member of the panel?

   YES___ NO_✓_ DON'T KNOW___

Acknowledgment

I declare that the disclosed information is true and accurate to the best of my knowledge, and that no real, potential, or apparent conflict of interest or bias is known to me except as disclosed. I further declare that I have made reasonable effort and inquiry to obtain the information needed to answer the questions truthfully, and accurately. I agree to inform SRA promptly of any change in circumstances that would require me to revise the answers that I have provided.

Sam R. Reddy________________
Name

*Sam R. Reddy*________________ December 7, 2011___
Signature Date

Appendix C: Peer Review Charge

Charge to Peer Reviewers of *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES*

EPA MOVES 2010a contains diurnal evaporative emission data empirically based on data from 1995. The equations built into MOVES are simplistically fit to this data and not based on how canisters actually respond to vapor loading. The DELTA model embodies EPA's effort to more accurately predict vehicle fleet evaporative emissions, especially in light of future vehicle rulemakings and any changes to evaporative standards that might be considered.

This report documents the assumptions, data sources, calculations and limitations used to estimate on-road vehicle evaporative emissions due to multi-day diurnal cycles using the DELTA (Diurnal Emissions Leaving to Atmosphere) model. This new model is associated with on-going improvements to the evaporative emissions portion of EPA MOVES model in conjunction with the proposed Tier 3 rulemaking.

Although the 1994 and 1996 In-Use Vehicle Program (IUVP) evaporative emission data (SHED evaporative emissions (in grams) for a large set of vehicles undergoing a single diurnal cycle) in MOVES 2010a provided a large and robust dataset for one day of emissions, a new way of modeling evaporative emissions beyond one day of diurnal cycling was needed for future vehicle evaporative emission scenarios. Neither was using a quadratic equation to fit diurnal emission data in MOVES 2010a accurately representing the actual response of vehicle canister breakthrough to large vapor loads. In response to this need, EPA's DELTA model was developed to more accurately represent multiple-day canister loading and breakthrough of vehicle evaporative emissions. DELTA provides an updated, theoretical approach to diurnal evaporative emissions development based on the new data which EPA believes more closely matches real-world vehicle evaporative system performance.

The previous breakthrough emissions equations found in the MOVES database are being replaced with a new set of equations generated within the DELTA model. The DELTA model also introduces changes to the MOVES Java code in order to take into account the nature of multiple day diurnal cycles. These new features (including the DELTA equations) can be deactivated if running MOVES using the older evaporative model, as desired by the user.

EPA is seeking your expert opinion on the *DELTA Evaporative Model and Documentation* described above. EPA requests that you comment on all aspects of the DELTA Model and documentations, with particular emphasis on assumptions, data sources, calculations and limitations used to estimate on-road vehicle evaporative emissions due to multi-day diurnal cycles using the model and any other key issues the reviewer may identify. EPA encourages you to best apply your particular area(s) of expertise to review the overall study.

In your comments you should distinguish between recommendations for clearly defined improvements that can be readily made based on data or literature reasonably available to EPA and improvements that are more exploratory or dependent on information not readily available to EPA. Your comments should be sufficiently clear and detailed to allow readers to thoroughly understand their relevance to the DELTA model. ***Please deliver your final written comments to SRA by January 13, 2012.***

All materials provided to you as well as your review comments should be treated as confidential, and should neither be released nor discussed with others outside of the review panel. Once EPA has made its report and supporting documentation public, the Agency will notify you that you may release or discuss the peer review materials and your review comments with others.

Should you have questions about what is required in order to complete this review or need additional background material, please contact Brian Menard at SRA (Brian_Menard@sra.com) or (434-817-4133).

Appendix D: Reviews

Comments on the DELTA Model

dKC **de la Torre Klausmeier Consulting**

1401 Foxtail Cove
Austin, TX 78704
(512) 447-3077
E-mail: delaklaus@aol.com

Technical Note

Date: January 11, 2012

To: Brian Menard, SRA International, Inc.

From: Rob Klausmeier, de la Torre Klausmeier Consulting, Inc.

Subject: **Peer Review of *DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES***

As requested by SRA International, I have performed a peer review of the above mentioned report. I have been involved in mobile source emissions modeling since 1985. I managed the development of the CRC Evaporative Emissions Model, which had many elements that were used in later versions of EPA's MOBILEx models. I do not have any real or perceived conflict of interests with MOVES or the DELTA Model.

The report is well written; it clearly described the complex process of modeling vehicle evaporative emissions. Although I have several comments, I believe the DELTA model is significant enhancement to MOVES. Following are my comments on the report:

1. Section III.

   "*Ethanol effects vary in that vapor evaporation increases as ethanol concentration increases until approximately 15% ethanol content. At higher concentrations evaporation decreases with increasing ethanol due to nonlinear effects on fuel volatility, with volatility returning to E0 levels around 50% ethanol content and decreasing from there.*"

   Please provide a reference for the statement concerning the impact of increasing ethanol content on fuel volatility.

2. Section III.b.ii

   "Canister adsorption is also affected by the temperature of the canister as well as the rate of vapor loading onto the canister. Activated carbon adsorption rates are inversely proportional to the temperature of the carbon bed. As the temperature of the canister rises, the rate of adsorption decreases while the rate of desorption increases. This has the effect of lowering the BWC with higher temperatures."

Can the authors provide rough estimates of the relative impact of temperature on butane-working capacity for the canister? The temperature effect may have a big impact on emissions during 2nd, 3rd, and subsequent days of a multi-day diurnal. If the impact is significant, EPA may want to model the impact in MOVES or in DELTA.

3. Section III.b.ii

   "*Canister loading does not occur linearly throughout the carbon bed. While it is convenient to think of vapor loading into the canister similarly to a glass filling with water (and eventually overflowing when the glass is full), fuel vapors form a concentration gradient throughout the carbon bed. During short term loading events (such as ORVR), the fuel vapor does not have sufficient time to spread into a gradient before a clean-out event takes place. However, a diurnal lasting several days provides ample time for some vapor to move beyond the front of high concentration near the inlet to the canister."*

   It is not clear if the bleed effect applies to the example of short-term loading events, such as ORVR, or multi-day diurnals. In addition, the magnitude of the bleed affect should be discussed, if it's significant.

4. Section III.b.ii

   The statement in the above quote concerning short-term loading effects, such as ORVR cases, raises the question about multi-day diurnal emissions after such an event. If, for example, the vehicle is refueled and then parked for several days, it's possible that available canister capacity will be lower than expected. This might be something EPA might want to explore either in MOVES or in the DELTA model.

5. Section III.c

   "Durring the cooling phase of a diurnal, fresh air from the atmosphere is drawn back into a vehicle fuel tank and across the carbon bed in the canister."

   The sentence has a typo in the word "during." Also, the statement is made that fresh air from the atmosphere is drawn back into the vehicle fuel tank and across the carbon bed in the canister. I think what the authors are referring to is canister backpurge where fresh air is drawn across the canister and into the vehicle fuel tank.

6. Section IV.b

   "DELTA uses the same weighting factors applied to the single vehicle TVG – TVV curves to calculate a single weighted tank size and canister size based on the individual tank and canister sizes found in the fleet. These weighted average tank and canister sizes are then used in the fleet average model in a similar way to how they would be applied in the single vehicle models."

   A description should be provided on how weighted average tank and canister sizes were derived. This could be done as an appendix to the report or as a reference to another report. The source of the average tank and canister data should be provided. Is it from certification data or other sources? In addition, I was curious if the average tank and canister sizes varied by model year within a technology group.

7. Section IV.b

"Cases such as a small number of passenger vehicles modeled in the same group as a large number of pickup trucks may produce larger breakthrough than expected due to a large average tank size producing high amounts of vapor while coupled with less storage due to a smaller average canister capacity. One vehicle breaking through significantly before other vehicles in the aggregate model may also cause higher than expected breakthrough due to a small but non-zero fleet average TVG – TVV line occurring well before the average canister capacity of the fleet is reached. Usually, tank volume and canister capacity are well correlated over an entire model year fleet and therefore the tank volume and canister capacity simplifications should largely not affect results."

Can EPA certification data to determine relative number of these cases? Also, can the authors provide an estimate of the impacts of these situations? The authors further state that tank volume and canister capacity are well correlated, therefore, the tank canister simplification should not affect results. I think this is a key point and therefore should be supported by some data, such as a plot of canister capacity versus fuel tank capacity, based on certification data.

8. Section V.b

"Note the above figure represents the reconstructed version of the original E77 data for the vehicle shown previously in Figure 14."

Do the authors mean Figure 13?

9. Section V.c.

The authors compare the actual behavior using test results from CRC's E77 test program with theoretical behavior based on the DELTA model. The authors note that in most cases, the DELTA under predicts breakthrough emissions. The authors then proceed to explain the differences:

"A more thorough analysis of E77 vehicle breakthrough was completed to explain the differences seen between the ideal model and what was happening in real world testing. It is important to note that the preconditioning procedure performed on the E77 vehicles to ensure adequate purge between tests, while meant to emulate a standard FTP cycle, was performed on public roads with variable weather conditions. This real-world preconditioning may have contributed to the non-ideal behavior seen in the data. For each test conducted in the E77 multi-day diurnal study, the canister breakthrough point (which was determined as the point at which more than 2% of the total canister capacity had escaped the vehicle canister) was compared against the theoretical capacity for the canister on that particular vehicle. The results of this analysis are shown in the following tables, separated by certification class."

The tables that follow only present information on canister capacity, when breakthrough occurs, and the percent of rated capacity. The authors should investigate and identify vehicle factors that explain the loss of canister capacity, e.g., age, mileage, temperature, and possibly year, make and model. If factors cannot be identified, the authors should state so.

10. Section VI

"Based on the results for each of the test/vehicle combinations from the E77 program, the TVV/TVG values were averaged across all 23 test/vehicle combinations to result in a single graph representing all of the Enhanced/Tier 1 vehicles."

Information on the breakdown on the types of vehicles in the different technology categories would be useful in validating whether differences between theoretical versus actual values should be averaged or some weighting should be applied. For example, if a certain vehicle model that is much more prevalent in the fleet shows more deterioration, then results for that model might be given greater weighting.

Also, the authors should investigate the sensitivity of assuming a single graph over a multi-day diurnal. The impact of canister deterioration will be much greater on 2^{nd}, 3^{rd}, and subsequent days of a multi-day diurnal than on the 1^{st} day. It may be necessary to add a time factor to the correction of DELTA for non-ideal behavior.

11. General Comment

The report does not mention how vehicles with tampered or inoperative evaporative systems are modeled. I assume that they are modeled as TVV/TVG = 1.

February 27, 2012

MEMORANDUM

To: Brian Menard
From: Chris Lindhjem, ENVIRON International
Subject: Review of "The DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES, DRAFT / DELIBERATIVE," October 13, 2011

INTRODUCTION

The report, "The DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES" presents an approach to estimating multi-diurnal vapor venting while a vehicle is parked over several days. This report documents the assumptions, data sources, calculations and limitations used to estimate on-road vehicle evaporative emissions due to multi-day diurnal cycles using the DELTA (Diurnal Emissions Leaving To Atmosphere) model. This new model is associated with updates to the EPA MOVES model in conjunction with the proposed Tier 3 rulemaking.

The approach described uses a model of a single ideal vehicle as a starting point. In addition, there is a description of how DELTA can model emissions of an entire fleet. This includes building a fleet average of the tank vapor generated and tank vapor vented (TVG – TVV) relationship, finding and using a fleet average canister size and tank volume, and producing a fleet average TVG – TVV curve for use in the MOVES model. The report then describes how the single vehicle model is used to describe weighted fleet average behavior.

OVERALL REVIEW

There are several changes that should be made to the DELTA model to better reflect the data, scientific theory, and fleet average behavior. The model appears to oversimplify the single vehicle modeling and does not incorporate all the potential conditions in the estimation of the weighted fleet average vapor venting emissions.

By not incorporating the relationship between vapor generation and canister capture efficiency, the DELTA model does not demonstrate its ability to model the data. The calculation of the effect of backpurge appears to ignore the behavior exhibited by the individual vehicle data provided.

By not incorporating the distributions of all in-use conditions, the weighted fleet average would not reflect the overall relationship between vapor generation and vapor venting emissions. Worst case conditions could provide emission rates at low temperature heat builds, while optimal situations would reduce vapor venting under higher temperature situations.

Incorporating all potential in-use situations could markedly change the relationship between ambient conditions and fleet average vapor venting emission predictions currently modeled by DELTA.

Single Vehicle Modeling

The method described for a single vehicle has two main issues that would affect the single vehicle model presented. These issues involve the apparent assumption that canister capture efficiency is a step function between full capture prior to breakthrough and no capture efficiency after breakthrough. This assumption influences how backpurge affects the canister condition and vapor venting. The breakthrough condition should also be defined as when the initial vapor venting occurs, not necessarily when the vapor venting reaches 2% of loaded weight in order to estimate lower emission events.

The first assumption that the canister will not collect vapor once the breakthrough condition is reached does not follow the basic understanding of how activated carbon captures vapor. For a number of reasons (e.g., pore size distributions, surface area coverage, and range of compounds in the vapor), the capture efficiency for a given partial pressure of vapor should slowly decline as shown in Figure 1 of this review. The effect of incorporating the post-breakthrough efficiency would be to lower the vapor venting until the canister is fully loaded.

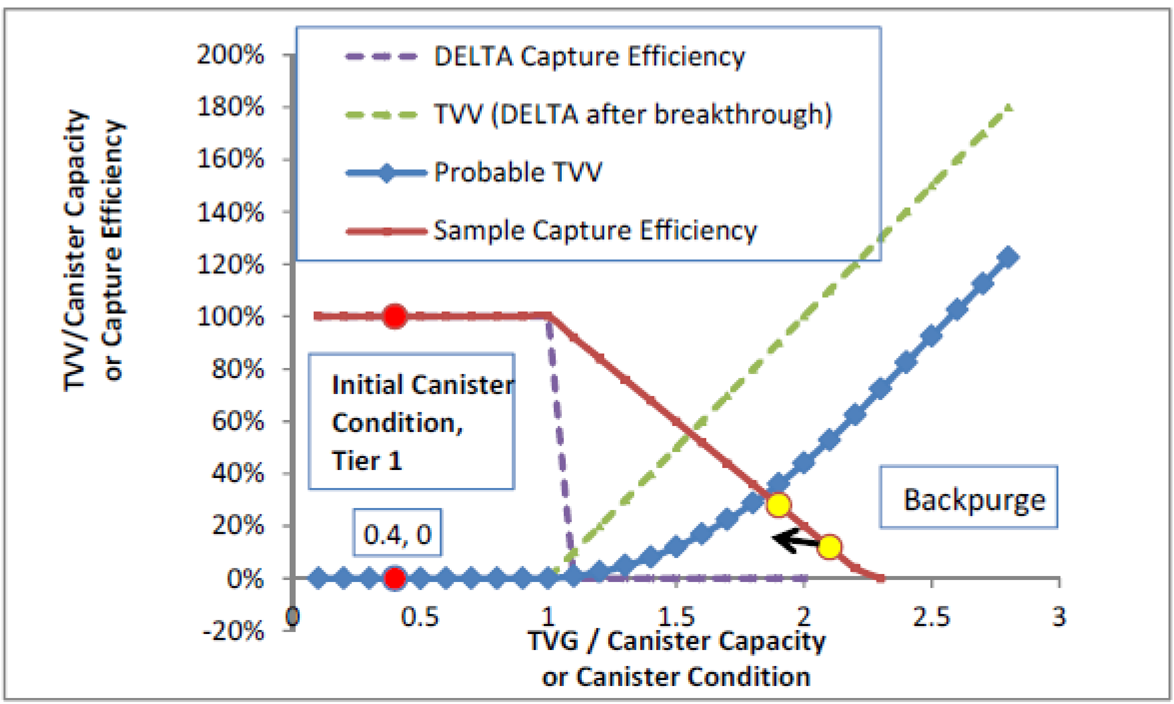

Figure 1. Post-Breakthrough Capture Efficiency for Single Vehicles.

The second assumption that backpurge will bring the canister to a pre-breakthrough condition appears to contradict the individual vehicle results presented in support of the method. Figures 14-17 of the paper demonstrate that vapor venting occurs from the beginning of the next day's vapor generation once the canister has been loaded past breakthrough. That vapor venting emissions would occur early in the next day's heat build indicates that the effect of backpurge is to lower the canister loading based on the day's peak temperature loaded condition, and not from the breakthrough point. The method shown in the report's Figure 6 then does not describe the post-breakthrough backpurge effect; if it had, then the vapor venting would be zero for the beginning vapor generation of each day. Rather, the effect of backpurge might better be modeled to reduce the canister loading in proportion to the ambient vapor drawn through the canister as the tank cools, as shown schematically in Figure 1 above. When the post-backpurged and post-breakthrough canister begins the next day's heat build, the efficiency would be less than 100% and exhibit some immediate vapor venting such as is shown in Figures 14-17.

The report's Figures 14-17 also demonstrate that the single vehicle vapor venting as a function of vapor venting follows an increasing rate as the vapor generation increases. The vapor venting rate would presumably continue to increase until the canister capture efficiency reduces to zero, and from then on the vapor venting rate should equal the vapor generation. This relationship is better described by the suggested post-breakthrough capture efficiency relationship in Figure 1 above and schematically described in the equations below.

Canister condition = Vapor generation x average capture efficiency

Vapor venting = vapor generation x (1 – average capture efficiency)

Where capture efficiency = 100% before breakthrough and f(canister condition) after

Canister condition (beginning of each heat build) = Peak Daily Load - Backpurge

The important finding of the report, demonstrated in Tables 4 and 5, that canister capacity is less than optimal, should be followed up to determine if the canister capacity has actually diminished from deterioration, or that the initial canister loading was responsible for the less than full canister capacity. One method to determine this might be to draw sufficient ambient air through in-use canisters until the weight does not change, record the weight reduced from the additional purge air, and use a loading method such as the one described in the report using butane to determine the in-use full capacity.

The determination of the deterioration and initial loading of canisters has a potential implication for the modeling such that either the canister capacity must be adjusted or the initial loading should be set to a value above zero. The weighted fleet average should account for the range of in-use initial canister loads. Figure 1 above shows how the initial canister load might be incorporated in calculation of the vapor venting emissions by setting an initial canister condition above a zero load.

The canister capacity as measured by the loading of butane may underestimate the canister capacity because, especially for lower RVP fuels, heavier (lower vapor pressure) compounds than butane would be found in the vapor generated. The model even assumes that the vapor has a higher average molecular weight (MW) of 66 than butane (which has a MW of approximately 58), for example. The canister capacity should also be determined for the peak diurnal temperatures to reflect the maximum load each day to account for any heat effects on the canister capacity.

There has been evidence that the tank temperature probably lags the ambient temperatures in most cases (when air circulation is low such as when the vehicle is in an enclosed space), so the modeled tank vapor generation should account for less than peak vapor generation.

Weighted Fleet Average

The refinements suggested here when incorporated may lead to higher or lower emissions than the current approach, depending upon the conditions for which distributions are included for characteristics and in-use conditions. By using distributions of vehicle characteristics, emissions are likely to be nonzero for even low temperature difference heat builds because worst case conditions would be included in the averages. However, determining a fleet average using wide distributions would better reflect the overall fleet behavior by incorporating all situations.

The report notes that determining a weighted fleet average emission rate needs to incorporate tank volume and individual vehicle canister properties (the report might refer to only canister capacity but should also account for the distribution of initial canister loads as well).

But there are several other factors that should be incorporated into the weighted average. One is that the distribution of fill volume fractions should be incorporated into the vapor generation and backpurged calculations. (The 40% fill volume used in the E77 program is not necessarily the in-use fleet average anyway, but rather it follows the official testing protocol.) Whether in DELTA or in MOVES, the frequency of multiple diurnals needs to be incorporated to calculate fleet averaged emissions. The use of all potential distributions of vehicle characteristics (canister capacity and initial day canister load) and fill volume fractions would reduce the chance that there would be a threshold vapor generation below which vapor venting emissions would be zero as described in Figures 21, 23, 24 and 25.

In addition, the researchers should determine if the canister capacity (full capacity compared to no load, regardless of the initial day loading) correlates with tank volume, and add tank volume to Tables 1-3 to describe the comparison. The proper canister capacity to tank volume may be important because the vapor generation (a function of tank and fill volume fraction as well as temperature and RVP) and canister capacity may be balanced and a function of the evaporative emission standards. The use of an average canister capacity, tank volume, and fill volume fraction ignores too many variables that affect emissions for in-use fleets.

EDITORIAL SUGGESTIONS

There may be typos or grammar, but what are described here are suggested additions to fully clarify what has been presented.

One characteristic that has not been discussed is the fuel weathering that occurs. While the DELTA model can be used regardless of weathering, it should be noted that MOVES would need to incorporate fuel weathering in the estimation of in-use RVP (lower than fresh dispensed fuel RVP) or the range in-use in-tanks RVP. In addition, any other inputs (tank temperature, frequency of multi-diurnals, or other input factors) that MOVES may determine as inputs to the multi-diurnal emission calculation should be discussed.

Figure 13

Statement: Canister weight is plotted against vapor generation.

Comment: Should the 'canister weight' be relabeled as vapor vented? This figure is difficult to follow because the vapor generation decreases at the end of each day's heat build, so should the vapor generation decreasing be plotted at all? This figure is also used to demonstrate how the data is transformed from canister weight to vapor venting in Figures 14-17, but it does not follow directly that canister weight can be converted to vapor venting.

Figure 14

Statement: Vapor generation reduces between one day and the next.

Comment: The vapor generation increases except (it appears) between one day and the next where it decreases. Should the vapor generation continue to increase, or is there an assumption that backpurge reduces the vapor generation during the cooling phase of the test? It appears that this occurs in the Appendix B code in the expression below where the TVG is subtracted by a datapoint[2]. Without the raw data, it is not possible to fully review the results to discern where vapor generation is shown to reduce from one day to the next.

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else:

  if test_Dict[key][i+1][1] >= highPointTVV and datapoint[8] - output_Dict[key][-1][7]
        > 120: highPointTVG = highPointTVG - datapoint[2]
```

Figures 15-17

Statement: Comparisons between the fleet average prediction and the individual vehicle results.

Comment: The figures need to show calculated fleet averages for the individual vehicle results presented, so that the data and DELTA prediction can be compared on an equivalent weighted fleet average basis. I suspect that the data driven fleet average may show a different shape of the curve representing the relationship between vapor vented and vapor generation than the DELTA predicted fleet average, regardless of the effect of canister capacity (or the effect of initial canister loads).

Figures 18 and 19

Statement: The figures are labeled as test vehicles from the E77 program.

Comment: Given the smooth regular curves, the figures are more probably DELTA estimates based on the canister conditions from the E77 program. The labels should clearly describe these as theoretical emission rates for various vehicle conditions and not actual data.

Sam Reddy's Comments on EPA DELTA Model

EPA Delta model is a good start in the right direction because it is based on evap canister working capacity, diurnal vapor generation, and canister back-purge. The modeling started on a right track but it was thrown off track because of the data used for the analysis and correlation. My comments are listed below:

1. Assumption of 35% back-purge after each diurnal is not correct: real world back purge is less than 10% after first diurnal, then it slowly increases every subsequent day by about 10% and reaches 70% and then remains constant (70% of diurnal vapor back-purged after 8 or more consecutive diurnals). The model must take into account variable back-purge to avoid under estimation of emissions initially and over estimation of emissions later in multiple diurnals.
2. I am afraid that unsuitable diurnal test data from CRC E-77-2c was used to analyze and correlate the model. The data is unrealistic/unreasonable because it consisted of CARB diurnal tests (65-105F) with RVP9 and RVP10 fuels containing ethanol (correct CARB diurnal fuel is RVP7). The RVP9 and RVP10 test fuels may have been suitable for permeation studies but not for CARB diurnal tests. No evap system is designed to handle CARB diurnal vapor generation with RVP9 or RVP10 fuel and no evap system functions properly. The CARB diurnal vapor generation doubles with RVP9 fuel and leads to numerous problems/errors (e.g., fuel boiling and reduced canister purging because of high running loss vapor generation, canister rapid loading and premature breakthrough, etc.). CARB diurnal vapor generation increase by 260% with RVP10 fuel compared to RVP7 fuel. Let us look at Vehicle #207 in Table 5 (Delta model report) with actual canister working capacity of 153 g; your estimated Breakthrough Point (estimated canister working capacity) in different tests ranged from 49 g to 194 g. How can the estimated capacity of the same canister vary by 400% (49 g in one test and 194 g in another test)? This happened because of the use of extreme/unreal diurnal test data for the analysis.
3. The breakthrough trap canister in CRC E-77-2c tests, makes the diurnal testing unrealistic; the test does simulate real world diurnal process (back purging of main canister is affected by the trap canister).
4. Another minor problem with CRC E-77-2c data is, the breakthrough trap canister was not big enough to capture all the breakthrough in some of the tests with RVP10 fuel.
5. Some canister breakthrough emission data looks strange; Figure 15 shows canister breakthrough emission more than diurnal vapor generation – how is that possible?
6. Based on incorrect estimation of canister working capacity (e.g., 49 g estimated canister working capacity of Vehicle #207 in test #7150), it was concluded that the canisters were deteriorating and loosing working capacity. If we really believe that canisters are deteriorating, we have to verify with experimental data (measure butane working

capacities of in use canisters). Also, the estimated working capacity of the same canister in another test was 194 g.

7. To avoid over estimation of emissions, the canister butane working capacities should be converted into canister gasoline vapor working capacities by multiplying with a factor F (e.g., F=1.2 or 1.3). Gasoline vapor consists of somewhat heavier molecules than butane; therefore, higher adsorption capacity for gasoline vapor.
8. As discussed below and illustrated in the following figure, multiple day diurnal emissions from a fuel tank follow a nice relationship consisting three straight lines, which might help to refine DELTA model.

If you use better data (real world and realistic/reasonable diurnals) and correct back purge numbers, the modeling will get back on the right track and it will become much simpler, more accurate and useful. The multiple diurnal EPA data published in EPA420-R-08-014, Chapter 5, is a good starting point. Even though it was not an automotive fuel tank, but it makes no difference and it captured all the essential information that you need for modeling multiple day real world diurnal breakthrough emissions. CRC E-77-2c data may be more detailed and thorough but it is artificial, unrealistic, and unreal; therefore, it is not suitable for the real world evap model development and/or verification.

I did some quick calculations using the data from EPA420-R-08-014, Chapter 5, as shown below.

30 gal tank 40% fill RVP9; EPA 72-96F diurnal; assuming total tank volume of 33 gal; from the diurnal equation, the vapor generation will be (2.12 g/gal vap sp)x(33-12) = 44.5 g

Measured diurnal vapor generation = 45 g (in the figure); good agreement with the diurnal equation.

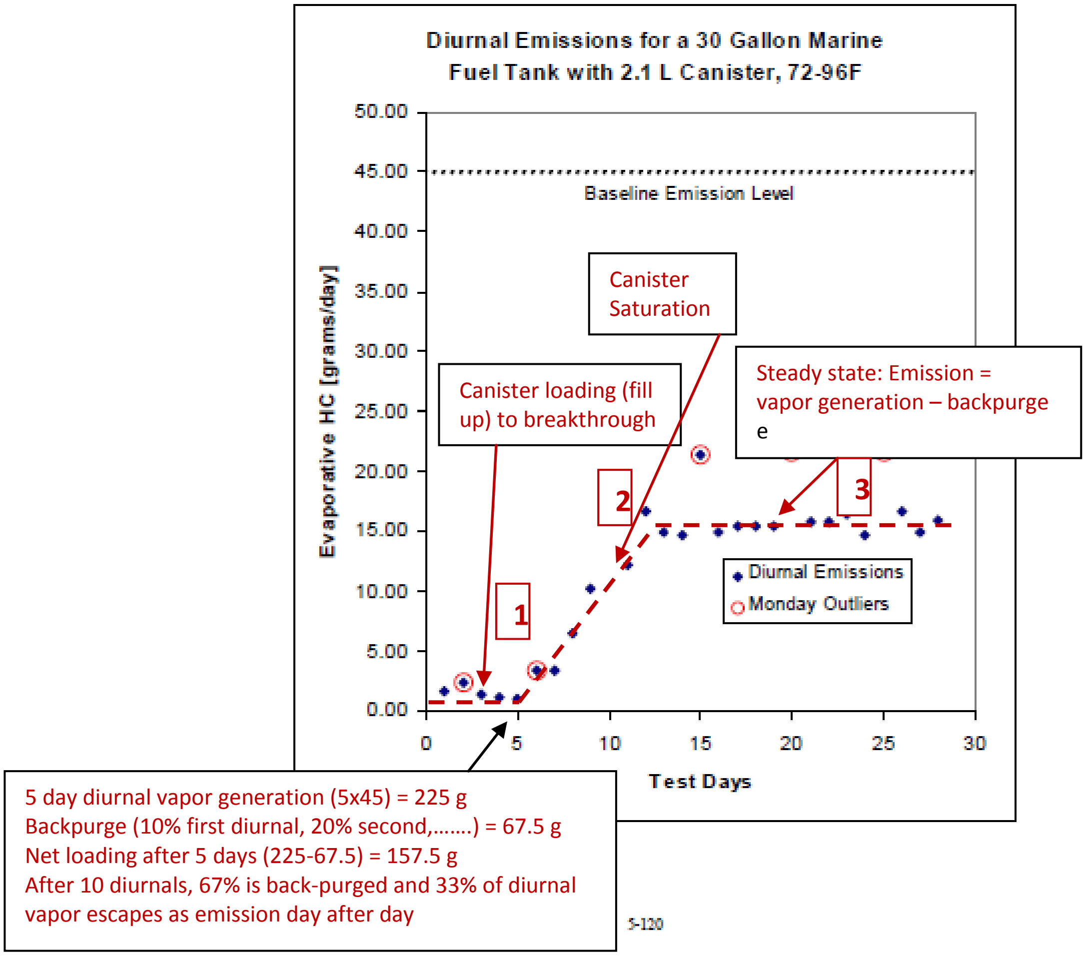
2.1L 11BWC carbon canister; published butane working capacity is 120 g; gasoline vapor working capacity 1.3x(butane working capacity) = 156 g

It is expected that canister breakthrough occurs after 156 g vapor loading; the results in the figure show, the canister breakthrough did occur after 157.5 g loading (as shown in the figure, total vapor generation minus total back-purge in 5 diurnals).

Therefore, this data is suitable for DELTA model.

Final Regulatory Impact Analysis

APPENDIX 5C: Diurnal Emission Results: Canister and Passive-Purge



The following approach might make it easier to develop a diurnal emission model. Divide the TVV vs. TVG or Diurnal Emissions (g/day) E vs. No of Diurnals N, into three parts as shown in the figure.

Part 1: Canister loading to breakthrough; Total vapor generation < canister capacity

Day 1 diurnal vapor generation (Wade-Reddy equation) = M grams

Day 2 diurnal vapor generation = Net diurnal vapor generation = 0.9M (after accounting for backpurge)

Day 3 diurnal vapor generation = Net diurnal vapor generation = 0.8M

Or a linear back purge factor F = 1.1 – 0.1N where N is number of diurnals

N^{th} day Net diurnal vapor generation = (1.1 - 0.1N)M

Total net diurnal vapor generation in N days = 0.5N(M + (1.1 - 0.1N)M) = MN(1.05 - 0.05N)

Note that without back purge, total vapor generation is MN; (1.05 - 0.05N) is a correction for back purge.

Canister breakthrough will occur when total net diurnal vapor generation MN(1.05 - 0.05N) is greater than or equal to canister capacity C.

MN(1.05 - 0.05N) = C   knowing M and C for a given vehicle, solve for N (breakthrough day)

Let us apply this equation to the above example: M=45 and C=156

$45N(1.05 - 0.05N) = 156$

$N^2 - 21N + 69.4 = 0$ solving quadratic equation gives N=4.1

Which means, no canister breakthrough for 4 diurnals (4 days); breakthrough starts on 5th day

Part 2: Similar analysis using F=(1.1 - 0.1N)M for N < 8; F=0.3 for N>8

Part 3: Steady state

Net Diurnal Vapor Generation/day = Diurnal emissions/day = FM where F=0.3 constant for N>8

Which means only 30% of diurnal vapor generation (estimated by the diurnal equation) escapes as emission into the atmosphere after 8 multiple diurnals. And it's less than 30% if the multiple diurnals are less than 8.

This is all assuming that they are real world diurnals (e.g., EPA diurnal RVP9 72-96F or CARB diurnal RVP7 65-105F). If we use extreme diurnals (high RVP fuels and high temperatures), everything falls apart.

I will be glad to discuss the comments in person if it is helpful to the EPA team.