Peer Review of *Estimates of the Fraction of the Fleet with High Evaporative Emissions based on the Ken Caryl Station (Denver, Colorado) Field Study*

Prepared for

Assessment and Standards Division

Office of Transportation and Air Quality

U.S. Environmental Protection Agency

Prepared by

Systems Research and Application Corporation

652 Peter Jefferson Parkway, Suite 300

Charlottesville, VA 22911

EPA Contract Number: EP-C-11-007

March 2012

Peer Review of *Estimates of the Fraction of the Fleet with High Evaporative Emissions based on the Ken Caryl Station (Denver, Colorado) Field Study*

Table of Contents

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

FROM: Brian Menard, SRA International

DATE: March 2, 2012

SUBJECT: Peer Review of *Estimates of the Fraction of the Fleet with High Evaporative Emissions based on the Ken Caryl Station (Denver, Colorado) Field Study (High Evaporative Emissions Field Study)*, prepared by Eastern Research Group, Inc.

1. Background

Gasoline vehicles have evaporative emissions control systems that control excessive evaporative emissions. Gasoline vapors can also be evaporated liquid gasoline, if liquid leaks are present. When these systems or the vehicle's gasoline delivery system malfunction, excessive evaporative emissions can be emitted. Few estimates of the frequency of vehicles in just such a state in the fleet exist, though vapor leaks can have an impact on the inventory of vehicle emissions.

As part of the effort to quantify evaporative emissions from the fleet of gasoline-powered on-road vehicles in the developing MOVES mobile sources inventory model, EPA would like to know the distribution of the mal-functioning, or leaking evaporative emissions control systems across all vehicles in the fleet. Evaporative emissions occur in light-duty vehicles when volatile components of gasoline are emitted or when raw gasoline leaks from the fuel system and the evaporative emissions control system. To meet the evaporative emissions modeling needs of the MOVES model, EPA and its stakeholders have conducted studies.

The Coordinating Research Council (CRC) - Real World Group through its E-77 and E-77-2 permeation evaporative emission testing programs has confirmed that leaks, both liquid and vapor, can be a significant part of any fleet hydrocarbon inventory. The program implanted leaks of the minimum detectable diameter of the OBD systems, 0.020". Orders of magnitude higher emissions were seen than a properly operating vehicle, indicating a major impact for inventory, and establishing the need to define the rate of occurrence of "leakers" in the in-use fleet. The missing piece of information is how often the leaking vehicles are occurring. Subsequent laboratory testing in the E-77-2c program implanted similar size leaks, not only at the gas cap but in other locations which were indicated as high occurrence in the initial field testing work. EPA's initial estimate was that "High Evaps" make up on the order of 1% of the gasoline-fueled vehicles in the fleet but there has been evidence that this was lower than what is occurring in the real world. This report uses Colorado evaporative emissions field data collected at I/M stations to estimate the fractions of various levels of high evaporative emission vehicles in the mix of vehicles that patronized the Denver Ken Caryl I/M station during the summer of 2009. Ultimately, EPA would like to know the distribution of the mass of evaporative emissions across all vehicles in the fleet.

The study performed at the Ken Caryl IM station in Denver, Colorado, *Estimates of the Fraction of the Fleet with High Evaporative Emissions based on the Ken Caryl Station (Denver, Colorado) Field Study (High Evaporative Emissions Field Study),* built upon the prior CRC/EPA testing experience. Vehicles entering the Ken Caryl station driveway were screened by an RSD unit using an evaporative index described as EI23. A stratified sample of model year 1961 and newer vehicles were offered participation in intensive evaporative emissions testing, which consisted of the portable sealed housing for evaporative determination (PSHED) hot-soak test, the visual, olfactory, and electronic HC detector examination of the vehicle (MCM test) and additional RSD measurements. Overall, the study reinforced an earlier connection seen between RSD and portable SHED values for real-world light-duty gasoline vehicles with testing of a wider range of model years and RSD vehicle speeds.

The objective of the *High Evaporative Emissions Field Study* is to estimate the fraction of vehicles in the Denver fleet with high evaporative emissions, based on PSHED measurements obtained during summer of 2009, and ultimately project these rates onto the Federal fleet. This estimate can be generated by appropriately weighting measurements by their sampling fractions, assigned on the basis of remote sensing measurements obtained when vehicles entered the Ken Caryl Station during the study period. The CRC E-77 and E-77-2 studies and the Lipan (Colorado) I/M Station studies all preceded the Ken Caryl study, which provides the background and data for this report.

From the vehicle selection and testing at Ken Caryl, two data sets are used to perform this analysis. The first is the set of 175 vehicles that were participants in the study and therefore received RSD measurements and portable SHED measurements. The second is the set of all 5830 vehicles that entered the station driveway during the study and represent the fleet of vehicles that patronize Ken Caryl. Most of these vehicles were not participants in the study and these therefore have only RSD measurements but no portable SHED measurements. The portable SHED values of the 175 participants were re-weighted using the RSD index to estimate the distribution of portable SHED values of the 5830 vehicles that entered Ken Caryl during the study period. The results give an estimate of the fraction of "high" portable SHED vehicles for different definitions of a high portable SHED result.

The RSD and portable SHED results on the 175-vehicle stratified sample of vehicles entering Ken Caryl were used to establish a relationship between the EI23 evaporative emissions index and hot-soak emissions as measured by the portable SHED test. This relationship was then applied to the 5830-vehicle random set, which is made up of most vehicles that entered the I/M station driveway during the study period. Standard re-weighting techniques are used to estimate the fraction of the Ken Caryl fleet that is expected to have portable SHED results greater than various definitions of a high portable SHED value, "cutpoint". The de-stratification technique is also applied to the Ken Caryl fleet as a function of model year group. A Monte Carlo simulation provides a means of estimating the influence of various uncertainties in the Ken Caryl data on the uncertainty of the calculated high portable SHED result fraction. An estimate of the uncertainty is critical to understanding the quality of the results of a calculated high portable SHED value fraction. This, in turn, provides important guidance to EPA for using the results of the calculations for MOVES.

EPA sought an expert peer review of the *High Evaporative Emissions Field Study*, including reviewers' opinion on the appropriateness of the statistical techniques described in the report and their appropriateness in the context of any data accuracy/quality issues. 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 *High Evaporative Emissions Field Study*. 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 the *High Evaporative Emissions Field Study*. 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 *High Evaporative Emissions Field Study* 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 *High Evaporative Emissions Field Study* was reviewed by Dr. H. Christopher Frey (North Carolina State University), Dr. Eric Fujita, (Desert Research Institute), and Mr. Keith Knoll (Czero). 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 *High Evaporative Emissions Field Study*. They brought a range of statistical and scientific skills to this process, as is reflected in their varying focuses in commenting on the report. The reviewers were in general agreement as to the importance of the field study and the significance of its results. Notwithstanding this, some of the reviewers were more critical than others in their comments about the quality and organization of the written report. Two reviewers provided suggestions for editing and reorganizing the report, with one providing substantial edits and suggesting a thorough rewriting and technical editing of the report. The comments in this compilation have been categorized as specific technical, general, and editorial.

3.1 Specific Technical Comments

Frey: [1] There are some fundamental questions related to this work that should be part of the objectives and that should be addressed in the technical results and conclusions:

1. Is PSHED a good surrogate for SHED?
2. Can an RSD, if appropriately interpreted, be a good surrogate for a PSHED measurement?

The first question presumes that SHED is the reference method to which all other methods should be compared. What, however, is really measured in a SHED measurement? There are many evaporative processes. Some, such as refueling, are not addressed by SHED. Which processes are addressed?

In what ways are PSHED measurements similar to those of SHED measurements, and in what ways do they differ? Is PSHED effectively just as good as SHED?

What kinds of evaporative processes can be measured using RSD? There is an unstated hypothesis in this report that RSD measurements can provide information on evaporative emissions in a manner comparable to that of PSHED, if only the RSD measurement is appropriate interpreted. What is the basis for this hypothesis? What evaporative processes affect the quantity of HC that is detected by remote sensing? If there was no error in the measurement, would strong concordance be expected between RSD and PSHED? If so, why? A clearer statement of hypothesis and the theoretical underpinning for it would be helpful when interpreting results.

[2] Over the years, EPA has been criticized for making public policy and developing modeling tools to support public policy that are based on proprietary data and methods. The use of proprietary methods precludes a full understanding and review of the underlying science. A case in point are the “Method A” and “Method B” exhaust plume analysis methods associated with the ESP remote sensing instrumentation. Since the distinction between Method A and Method B appears to be an important technical consideration in this study, the lack of disclosure of what these methods are is unacceptable.

[3] The purpose of the report is to estimate, not develop, fractions of various levels of high evaporative emissions. However, nowhere is any justification or rationale given as to why this report is focusing on the Denver fleet. Since Denver is at high altitude, and barometric pressure is a factor in evaporation, it is not clear that data from Denver would be representative of other parts of the U.S.

[4] What is the purpose of “stratification.”? Why is achieving stratification a goal in itself? E.g., page 4-3, “to achieve stratification, a higher fraction of vehicles…” The reader can eventually figure this out, but why can’t the authors communicate this more clearly? The purpose seems to be to evaluate a screening procedure for identifying vehicles with high evaporative emissions rates, but what about goals for false positives or false negatives?

[5] Is it literally the case that six RSDs were used? i.e., six remote sensing devices at six locations? Or were the two highway “RSDs” based on repeated passes by the same RSD? The

authors need to stop using the term “RSD” to refer to a measurement. RSD = Remote Sensing Device and refers to an instrument. A measurement made using an RSD could be described as a remote sensing measurement. What is an RSD beam block? This is shop jargon (I know what it means, but most readers won’t).

[6] What is the ‘standard I/M inspection’ – for those of us not from Denver, please explain what this is. Also, explain the “Modified California Method” – both of these should be documented in the new methods chapter that needs to be written. Who does the olfactory examination? What is an ‘electronic HC sniffer”? Is this relevant to the report? If not, then delete mention of these.

[7] Page 4-4: Method A was used on ESP 4000 and 4600 instruments, and Method B was used on ESP3000 series instruments. Yet, results for both Methods A and B are reported in Table 4-2. Were two RSD instruments used at each RSD site? Or were both Methods A and B applied to the same data measured from just one RSD instrument at each site? At the end of the paragraph is it mentioned that ‘code’ was ‘added’ to the 4000 and 4600 series instruments – it would have helped if this was mentioned up front, and if there was a prior section that more clearly disclosed the study design in terms of what instruments were deployed at what locations and what the vehicle path was through each RSD site. It would help if this text were reorganized so that there was an intro paragraph, one paragraph on Method A, one paragraph on Method B, and then a paragraph that compares Methods A and B. Are the CO, NO, and CO2 results shown in Table 4-2 based on Method B? The distinction between Methods A and B with respect to how they deal with exhaust versus evaporative concentrations of HC is not clear. To merely state that “ESP believes” that one method is responsive to exhaust and another is not is quite tenuous.

[8] Page 4-4 (bottom): regression toward the mean…. This is stated as if it is an underlying principle in a rather didactic manner, but the actual concept is poorly explained here. A measurement is biased if it is systematically high or systematically low. If the error is randomly distributed with a mean of zero, then the measurement is subject to random error, not bias. The random error can lead to false positives or false negatives if used in the context of a binary decision (e.g., vehicle is a high emitter). This context is not clearly articulated. False positives or false negatives are not necessarily a result of bias, but rather a result of imprecision (random error). The discussion here of bias is thus without sufficient context and therefore is unclear.

[9] What role does ambient temperature have in contributing to variability in estimated evaporative emissions based on RSD measurements? Since the “Temperature” in Table 4-2 (ambient temperature at the time of each RSD measurement?) differs from the PSHED “Seal Temperature”, what role might this have in confounding the results?

[10] Table 4-2: what is the meaning of negative values for HC Method A (ppmC 3) and how are these interpreted? Table 4-2 values of CO_2 percent appear to be what one would expect in the tailpipe, but this cannot be what was actually measured in the exhaust plume. How is the air-to-fuel ratio inferred, or is it assumed to be stoichiometric? Some discussion is needed. The text barely alludes to this. More detail is needed in a methods chapter. Is RSD temperature the ambient temperature at the date and time of the measurement?

[11] The quantity in Figure 4-1 labeled as "RSD EI23" needs to be clearly defined. Is this based on any numbers given in Table 4-2? Which specific column of Table 4-2 is "RSD EI23"? Which specific column of Table 4-2 is "PSHED Mass (g/Qhr)"? Presumably, "Measured PSHED HC at 15 Minute Soak (grams)" in Table 4-2 is the same as "PSHED Mass (g/Qhr)". However, use consistent terminology in both places to avoid ambiguity. The EI23 values need to be added to Table 4-2.

[12] Page 4-22: what role does ambient temperature have in the estimation of EI23? The RSD measurements are made at ambient temperature. Evaporative emissions are proportional to ambient temperature (something that needs to be introduced and discussed in a background or methodology section of this report). Is the EI23 metric less responsive to evaporative emissions at lower ambient temperature? Speed is not the only factor that affects inference of evaporative emissions.

[13] Page 4-23: Why is model year important? Earlier, a note was made that model year was not part of the EI23 binning method.

[14] If there are multiple EI23 bin values available for some vehicles, these data should be analyzed separately to determine the robustness with which a vehicle is assigned to an EI23 bin. Ambiguity in assignment to an EI23 bin would be a significant factor to consider in evaluating the usefulness of this method.

[15] Table 4-5. The table is actually of EI23 bins and model year groups, not screening remote sensing measurements. Thus, the caption is not consistent with the content of the table.

[16] Page 4-25: The terms sample and population in the Appendix B need some careful re-thinking or at least more clear definition. Here, the term 'population' is implied to describe the total sample of 5,830 vehicles (which is actually a sample from a larger fleet). That is okay, but at least be clear as to the meaning of the term 'population' as used in Appendix B. W_h is the fraction of the population of vehicles that fall into each EI23 bin. It is not clear as to the definition of "n" in Appendix B – is this the total number of vehicles in the 'population'? (i.e. n=5830?). L=7 (could be stated clearly). The term σ_h is not clearly defined in appendix B in terms of other variables. Is this the standard error of the fraction of elevated measurements in each strata? Appendix B does not actually show how one estimates the estimated fraction of the population that is above the threshold. How was the value 0.127 estimated? This appears to the product $p_h W_h$ summed over all h. Based on the numbers given in Table 4-6, over 75% of the estimated 'elevated PSHEDs' (a sloppy term) are from Bins 1-4, which account for over 96% of the 'population.'

[17] Table 4-8. It is not very clear as to what variable is implied by "High-PSHED Fraction…" is this based on p_h and W_h defined in some different way compared to Table 4-6?

[18] The assumption of the EI23 bins is that they are bins of EI23 values. Since no assumption is made regarding model year, it is not really correct to imply that if there is a dependency on a model year that somehow the use of EI23 is inherently inappropriate. It could be that the fraction of vehicles with high PSHEDs measurements is correlated with EI23 and with model year, but that does not imply that EI23 would not be a useful indicator. Whether EI23 is a useful indicator can be determined with or without consideration of model year. In fact, if

EI23 has a trend with respect to model year that is consistent with the trend with respect to PSHED measurements, then there might be increased confidence in the utility of EI23 as an indicator.

[19] Section 4.5: the discussion here suffers from a conceptual problem related to not clearly defining what is meant by “uncertainty.” The term uncertainty is used inappropriately as if it refers only to imprecision, and the notion of bias is discussed as if it distinct from “uncertainty.” Uncertainty refers to lack of knowledge regarding the true value of a quantity, and includes both random and systematic sources of error. Random error is imprecision. Systematic error is bias and also known as lack of accuracy. Thus, bias is a component of uncertainty, not distinct from it.

[20] Uncertainties associated with small sample size are typically quantified based on random sampling error. The discussion of the role of ‘chance alone’ is inappropriate as written. Perhaps the intended statement is that if a different random sample of vehicles had been selected, the number of vehicles with PSHED measurements greater than 2 g/Qhr might have been different from the 2 that were observed in the available sample. Because the fraction of vehicles with PSHED measurements greater than 2 g/Qhr is based on a sample, there is ‘sampling error’ in the estimate. If the sample is assumed to be random, then the error of the estimate can be estimated based on sampling distributions of the statistics (a statistic is a quantity estimated from a sample). The errors shown in Table 4-11 are of unclear basis. For example, the ‘size of error for ‘high PSHED Definition’ of 2 is given as 0.025. There should be more detail on how this number was estimated, based on the data given in Table 4.6.

[21] PSHED measurement error should be more clearly discussed. The text refers to ‘two parts’ but really only one ‘measurement error’ is actually addressed. Measurement error typically refers to the imprecision and bias of the measurement method itself. Propane retention and recovery tests are an incomplete indicator of the imprecision and bias of the PSHED method, because actual evaporative emissions are not pure propane. Variability in hot soak emissions is a measurement error only in the context of attempting to assess the repeatability of measurements of the same vehicle under the same conditions. However, it is not clear that such an experiment has actually been done. If there are underlying differences in the state or condition of the vehicle, then the variability in the measurements is not because of the measurement method itself but because of the state of the vehicle being measured. The concept of repeatability of the measurement should be discussed in a separate paragraph or subsection. If the repeatability is only -50% to +200%, then there is significant question as to the usefulness of any kind of PSHED test when compared to a ‘brightline’ threshold that is a point value.

[22] The discussion of detection limit and how it was inferred is difficult to follow. First, it would help to define what is meant by detection limit. It is not clear how a detection limit can be inferred by making a measurement on a vehicle or any sample for which it is not known as to whether the HC concentration is actually zero. Why not use a ‘zero’ calibration gas that contains 0 ppm of HC? A baseline before a vehicle enters the PSHED does not guarantee that actual concentration was 0 ppm of HC. However, it does provide a background level. However, the text does not discuss what is background or the role of background in making measurements.

[23] Page 4-32: the analysis of duplicate EI23 measurements is quite important, and the text refers to Appendix A. Appendix A is very poorly written and very unclear. It is not apparent that there are any data regarding the duplicate EI23 values in the main body of this report or in the appendix. The data and findings from these data should be disclosed.

[24] The rational for the bias in the EI23 values and the implication that it would 'tend to elevate the high-PSHED fraction' needs to be more clearly articulated.

[25] Page 4-33: the apparent confusion regarding detection limit and background level is evident in the second paragraph on this page. One does not subtract a detection limit from a measured value to impute an unbiased estimate. This would be done only for a background level. However, if the background is negligible compared to the measurement, this will have little effect on the results.

[26] The discussion of a possible Monte Carlo simulation is so vague that it hardly merits being in this report. Unless the authors can clearly define terms and propose a meaningful algorithm, the recommendation for future Monte Carlo simulation could be stated briefly, with further development left to those competent to conduct such an analysis.

Fujita: [1] While the EI23 evaporative index would be useful for identifying gross evaporative HC emitters, its ability to estimate fractions of high evaporative emissions within various levels of evaporative emission other than the top end of the distribution seems limited.

[2]Conversion of EI23 measurements to Bins provides what appears to be clearer summary of the distribution of EI23 values by PSHED-equivalent running loss levels. As I understand this procedure, this classification assigns the estimated evaporative indices into bins with width that each corresponds to one standard deviation of the variability of a single EI23 measurement (after accounting for the effects of the exhaust HC emissions on EI23). The EI23 Bins are then associated with probabilities of exceeding various threshold PSHED hot-soak emission levels. This approach allows the association to be made without regard to the quality of the correlation between EI23 and PSHED hot-soak levels, which we know is poor. EI23 values in at least the first three EI23 Bins (with PSHED thresholds of greater than 1, 2 and 5 g/Qhr) are probably below the method limit of detection and are really random noise. If so, there is about equal chance that any of the EI23 values in the first three Bins has a corresponding PSHED above the threshold. Therefore, it is not unexpected that fractions of elevated PSHED in Table 4-6 are about the same for Bins 1 (6.7%), 2 (7.6%) and 3 (9.6%). These fractions are likely not valid given the measurement sensitivity. If 20g/Qhr is a reasonable level where the corresponding EI23 values become reliable, then the distribution shown in Table 4-4 for this High PSHED definition is valid for all EI23 Bins. The fractions are progressive less reliable for the lower EI23 Bins at lower thresholds values.

I believe the net result is an overestimation of the fractions of elevated PSHEDS in the lower Bins. Products of these fractions with the proportionally larger numbers of vehicles in these bins for the Random fleet will result in larger fractions of elevated PSHEDs in the larger fleet of vehicles. For example, results of the de-stratification calculations in Table 4-6 shows that 12.7% of the 5830 vehicles in the random sample are estimated to have corresponding high-PSHEDs defined as greater than 2 g/Qhr. If the first three Bins are counted as zero, then this fraction drops to 5.5%. Also dropping Bins 4 and both 4 and 5 reduces the fraction to 2.9% and

1.6%, respectively. The more appropriate fraction is likely between 1.6 to 5.5% rather than 12.7%.

[3] It should also be noted that the distributions are presented without quantitative estimate of uncertainty and bias that are inherent in the study approach. In addition to the poor limits of detection of RSD evaporative index, the following sources of uncertainty and bias were not assessed in the report.

- The distributions are based on static SHED 15-minute hot-soaks and do not include diurnal evaporative emissions and may not fully account for all running emissions.
- The residual hydrocarbon signal in the RSD measurements in excess of the regression line of HC with CO_2 results is a crude measure of the diluted mixture of evaporative emissions from fuel permeation, vaporize fuel leaks, and fuel system venting during vehicle operation. Unlike exhaust pollutant, there are no tracers for evaporative HC emissions to account for dispersion rate of emissions.
- Replicate LSHED and PSHED tests have large variability. Section 4.5 does not address the significance of the large variability of replicate SHED tests to distribution of fractions of "high evaps" at various definitions.

[4] Ambient temperature was not included as a variable in the study design and PSHED and replicate RSD measurements were all made within a short time at about the same temperature. The test sets within each EI23 Bin were conducted at ambient temperature spanning a range of up to about 30^{o}C. Evaporative emissions are known to increase with ambient temperature with doubling of permeation for 10^{o}C rise in temperature. This likely would not be issue if ambient temperature was a random variable in the study and test sets within each bin had similar random distribution of temperature. Was this checked? The potential bias due to differences in temperature would be minimal for the high emitter bins, but may be more important for the other bins.

[5] Most vehicles in Bins 6 and 7 had high exhaust HC emissions, which can contribute to the estimated evaporative emissions. The report asserts that this positive interference is mitigated by the binning procedure. From the relevant discussion in Appendix A, it is difficult to determine the significant of the positive interference or the effective of the binning procedure.

[6] P. 1-2, line 5. Are there plans for follow-on uncertainty analysis that can be described here?

[7] P. 2-2, second full paragraph: Describe briefly the evidence, with appropriate references, that previous estimate of "high evaps" were lower that what is occurring in the real world.

[8] P. 3-14, last sentence: Meaning is unclear. Why would large variability of PSHED hot-soaks itself result in overestimation of fraction of vehicles with high hot-soak emissions?

[9] P. 4-25, Table 4-6: What is the basis for S_h in the calculation of standard error of the fraction of elevated PSHEDs? What are the sources of the values used in calculating the standard deviation?

[10] P. 4-30, Table 4-10. Unless there is good reason for using natural log, give estimated error for column 2 in units of g/Qhr.

[11] P. A-1, item i): Residual rather than N?

Knoll: [1] [Section 3] It would be useful to provide some further explanation regarding HE-3555 evaporative emissions behavior. Why did these emissions continue to increase with time? Was the evaporative purge system on the vehicle evaluated for proper functionality? Was any testing done to identify root cause?

[2] The first bullet point under Summary of LSHED and PSHED states that vehicles with low hot-soak values have PSHED and LSHED results that "are very similar". I think this statement is misleading and may not be correct. The similar scatter shown by the data across three orders of magnitude on a log-log plot suggests that variation at low values was indeed less than at high values. But it is not clear that the data could be considered nearly the same. This assertion requires further justification from the data analysis.

[3] The last paragraph in . . . section [3] providing relevance to the on-road fleet requires clarification, further explanation and a review of the underlying assumptions. I believe the author is saying that because there is high scatter and a small number of samples available, the upper bound on extrapolating this data to the on-road fleet is necessarily high; higher than it would be if there were either a larger number of sample or a smaller variation in the data. If this is his message, it needs to be stated more clearly and with a more definitive confidence level. Also, is a normal distribution being assumed? If so, state it and explain why such an assumption is valid. If not, then what distribution is assumed and why?

[4] Paragraph 2 of Section 4: The last sentence of this paragraph suggests that two influence factors complicate extrapolation of the Ken Caryl dataset to the Denver-wide fleet. What exactly those two reasons are, however, is not clear from the paragraph text. My interpretation is summarized in the following bullets. Text of the paragraph should more clearly support the thesis statement given at the end of the paragraph.

- The sample of vehicles that visit I/M stations likely has higher emissions than the fleet at-large. The Denver-wide "clean screening" program exempts about 40% of registered vehicles based on low RSD readings. Consequently, the 60% of vehicles that go to I/M stations are the higher emitting fraction of the total Denver fleet. Using this sample population for emissions projection to the Denver-side fleet will likely skew the overall population estimate. However, there is no reason to believe that high tailpipe emissions vehicles are necessarily correlated with high evaporative emissions vehicles. So the real effect of this bias is not clear.
- The Ken Caryl I/M station is located in a higher income part of Denver. Consequently, the population of vehicles visiting this I/M station is likely to comprise newer and therefor cleaner vehicles than the Denver fleet as a whole. As far as I can tell, this bias has no mitigating factors.

[5] Accurate application of the Monte Carlo simulation method assumes a random distribution and a large number of samples. This paragraph should include a statement regarding the limitations of this method for analyzing the current dataset. The author does provide later in

this report adequate justification that the sample population truly is random. This was well thought-out and well reported. Including some statement in this paragraph, however, would be helpful. I do not believe the author addressed the limitation of population size. This limitation should be mentioned here. Some comment regarding the potential impacts of this limitation should also be stated.

[6] In Section 4.4, Table 4-6: It is not clear how the fourth and fifth columns are calculated from columns 2 and 3. This should be explained.

[7] [S]ection [5] of the report

- goes on to discuss additional data that is now available for further investigation. Limitations of the additional data are also identified. For example, the PSHED data from Summer 2010 are identified as not being selected using a stratified random design. As such, these data are not suitable to the Denver-wide fleet.
- leaves the estimation of the high-PSHED fraction of the Denver-wide fleet incomplete. No estimation is provided because the data are identified as inadequate.
- provides no basis for extrapolating the results obtained to an estimate of the nationwide fleet as is needed by EPA. For EPA to apply this dataset to the nationwide fleet (via MOVES), additional justification would be necessary.

3.2 General Comments

Each of the reviewers provided general comments on the *High Evaporative Emissions Field Study*. 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.

Frey: [1] What is the main contribution of this report? What are the key limitations? What additional work is needed? If the purpose is to estimate the fraction of vehicles with evaporative emissions exceeding a threshold, the method described in this report using EI23 Bins and a 'stratification' approach may be reasonable; however, the uncertainty in the estimates made using this method are unknown. Such uncertainties should be estimated as the next step. Without quantification of uncertainty, the utility of this approach is unclear.

[2] Some key issues that should be addressed in the conclusions:

- Is PSHED a useful surrogate for SHED?
- Can RSD measurements, if appropriately interpreted, provide an indicator of evaporative emissions?
- Is EI23 a useful indicator?
- Are the trends in the results for high evaporative emissions fractions in the vehicle fleet consistent with model year? What results developed here provide some confidence that EI23 is operationally useful?
- What are limitations of EI23? What other indicators should be explored?
- What uncertainties have been quantified? What uncertainties have not yet been quantified?

- Need for further evaluation of uncertainties prior to making a decision on acceptance of this approach?
- Application of this or other approaches to fleets that are more representative of the U.S. fleet.
- Others?

Fujita: [1] The experimental approach and methods are adequately documented in the report and accompanying background document. Presentation of the results, including tables and figures, are generally clear except as noted . . .

[2] P. 4-24, 1st paragraph, last sentence: Are the quantifications of uncertainties and bias part of a follow-up report? When is this expected?

Knoll: [1] The analysis relating RSD measurements to SHED results appears valid and well thought out. Uncertainties were investigated and sensitivity analyses were conducted. Use of RSD appears to provide considerable promise for determining high evaporative emissions vehicles from the in-use fleet.

[2] The limited set of vehicles (175 total) that received both RSD and PSHED measurements was used to develop a correlation between RSD readings and measured evaporative emissions. This correlation was applied to the larger set of vehicles (5830 total) that visited the Ken Caryl I/M station during the summer of 2009. In this way, an estimate was made of the percent of vehicles visiting Ken Caryl over the study period that had high evaporative emissions. This projection was well justified based on results presented in the report. Speculation was also made regarding projecting these results to the Denver-wide fleet. Limitations associated with such a broad projection were given. Specifically it was noted that the existing dataset from the Ken Caryl I/M station was limited in relevance to the Denver-wide fleet for two reasons: 1) Colorado exempts about 40% of all registered vehicles from I/M inspection based on RSD measurements and 2) the Ken Caryl I/M stations is located in an affluent section of the Denver metro area. The first caveat means that the study sample (5830 vehicles) is likely to contain a disproportionate percentage of vehicles with high emissions – either evaporative or tailpipe. As such, the study sample is likely to be biased towards those vehicles with high evaporative emissions and is therefore ***not*** a random representation of the Denver fleet. The second caveat means that the study sample is likely to be composed of newer, properly functioning vehicles. Again, this introduces a bias in the database preventing it from being a random representation of the Denver fleet. Speculation was also made regarding projecting these limited results to the nationwide fleet. Limitations associated with this larger projection were not discussed.

3.3 Editorial Comments

Each of the reviewers in varying degrees assessed the narrative of the report and suggested improvements for accuracy, clarity, and consistency. One of the reviewers undertook a thorough critique of the report in this regard, providing significant editorial suggestions and stressing the need for a thorough re-organization, rewrite, and technical. To this end, all of the reviewers highlighted typographical and formatting errors, incorrect word choice, and omissions, including missing references.

3.3.1 Drafting and Technical Edit of the Report

Frey: [1] The review of this report was significantly hampered by the very poor quality of the report organization and writing.

A key question when writing any report is: Who is the intended audience for this report? The intended audience should include all stakeholders of the MOVES model, since this effort appears to be aimed at providing a technical basis for quantification of the fraction of the on-road fleet that has high evaporative emissions rates. However, as written, the report is aimed at fellow technicians who are familiar with the undefined shop jargon used by the authors. This report contains repeated sloppy use of jargon that may be meaningful to the report authors, but that make the report difficult to read by anyone else. Table 1 is a list of terms that are introduced in the text without definition, without adequate definition, or that should be introduced, defined, and used in the text. The list of terms in Table 1 should be used to construct a glossary for this report. When a term is first used in the text, it should be defined in the text.

Table 1. Terms Introduced in Draft Report Without Definition or Explanation: these terms should be defined/explained when first mentioned. A glossary of these terms with definitions should also be created.

Terms that Need to be Defined	Comment
Aging enhanced evaporative emissions vehicles	? given lack of definition of ‘aging,’ and ‘enhanced,’ the meaning of this is unclear to the readers.
Aging enhanced vehicles	Undefined. Explain this.
Approximate algorithm	No idea what this means. Needs to be explained.
As-received condition	Should explain what this means.
Beam block	This is shop jargon. The intended meaning seems to be exhaust plume measurement. Needs to be defined/explained when first used.
Bench purged	Presumably, this implies that the canister was removed from the vehicle and purged (how) on a lab bench. Needs more explanation for clarity.
Bias (systematic error, inaccuracy)	See comments
Bin de-stratification	De-stratification with respect to what? How?
De-stratify (and de-stratifications)	This term is used without definition. Not clear what this is.
Detection limit	Mentioned on p 4-31 but not defined.

(cont.)

Terms that Need to be Defined	Comment
EI23	Mentioned numerous times without any explanation
EI23 Bins	Define when first mentioned. Introduce in a new methodology chapter prior to using this term in results chapters
Electronic HC sniffer	Is this relevant to the content of the report? If not, delete. If so, then explain.
ESP	? Seems to be the name of a company. ESP, Inc.?
Evaporative emissions canister	Is this a canister that produces evaporative emissions? Need to explain to the reader what this is. A corresponding conceptual diagram of the source of evaporative emissions and methods for prevention and control of evaporative emissions would help in explaining what this (and other relevant vehicle systems or components) is.
g/Qhr	Is not defined until page 4-4, although it is used in earlier parts of the report.
Gross liquid "leakers"	Is there a quantitative definition of this, or at least a working definition? Explain.
HC	As good practice any abbreviation should be defined when first used.
high evaps	This is shop jargon. A formal technical report should have thoughtfully developed and carefully defined terminology.
High running loss emissions	What constitutes "high"? by what criterion or criteria?
High-PSHED, and "high-PSHED fraction"	This term is shop jargon. The intended meaning appears to be "vehicles with high evaporative emissions as measured using the Portable SHED
Hot 505	This is undefined. Presumably, this is a hot stabilized dyno test cycle. If so, then give the graph of speed versus time and provide some explanation.
Hot soak	define

(cont.)

Terms that Need to be Defined	Comment
IM	Yes, most readers will know what this is, but as good practice any abbreviation should be defined when first used.
Implanted leak	Undefined. Explain this. Give an example.
Index/PSHED	This term is unclear
Intrusive pressure test	What is this?
Ken Caryl	Introduced as if the name of a person, this should be consistently termed "Ken Caryl IM Station" or something similarly descriptive (e.g., Caryl Station).
leakers	Is there a quantitative definition of this, or at least a working definition? Explain.
Low evap	More shop jargon. A formal technical report should have thoughtfully developed and carefully defined terminology.
Low running loss emissions	What constitutes "low"? by what criterion or criteria?
Method A	Define. Introduce in methods chapter.
Method B	Define. Introduce in methods chapter.
Modified California Method	Define. If not relevant to this report, delete.
MOVES	MOVES is mentioned but never introduced or explained.
Near-zero vehicle	Undefined. Explain this
Noise, noisy	Used on page 4-31 without definition
OBD code to flag	I know what the authors are trying to say, but many readers will have no idea. First, explain OBD and what is an OBD code. Explain what is meant by 'flag'.
OBD evaporative codes	What are these? Needs to be explained
Odometer Resolution	What is the meaning of the codes given in Table 4-1?
ORVR	?
Precision (imprecision)	See comments

(cont.)

Terms that Need to be Defined	Comment
Pre-enhanced vehicles	Undefined. Explain this.
Pretesting	Page 4-2
PSHED	PSHED is defined on page 1-1 as "portable SHED", but "SHED" is not defined.
RSD	The term RSD is used on page 1-1 without definition.
RSD Method B	This method should be introduced and explained in a methodology section of the report.
Running loss emissions	Define/explain
Seal Barometric Pressure	Table 4-2: this term is undefined. There needs to be a footnote to explain what this is.
Seal Temperature (F)	Table 4-2: this term is undefined. There needs to be a footnote to explain what this is.
Selection RSD	Mentioned on page 4-3. An "RSD" is a measurement device, but the term "RSD" is used inappropriately to refer to a measurement of a specific vehicle. The intended meaning of "Selection RSD" is "screening remote sensing measurement." The screening measurement is used to determine whether the vehicle will be recruited for addition RSD measurements and PSHED measurements.
SHED	Amazingly, SHED is not defined the first time it is mentioned, on page 1-1.
Slow vapor leaks	What is a "slow" leak? Does this refer to a low emissions leak? Of vapor? Of evaporating liquid? Needs to be defined and explained.
Standard de-stratification techniques	? undefined.
Standard I/M inspection	Explain. Or, if not relevant, delete.
Stratified sample	With respect to what? This term needs to be explained when first used.
Stratified set	Explain in new methods chapter.
Uncertainty	Should be defined – see comments

(cont.)

Terms that Need to be Defined	Comment
VDF	Table 4-2: this term is undefined. There needs to be a footnote to explain what this is.
VECI Engine Family	Table 4-1. needs to be defined in a footnote.
VECI Evap Family	Table 4-1. needs to be defined in a footnote.

[2] The report needs substantial copy editing by a competent technical writer. For example, the report contains frequent use of the first person, which is inappropriate in formal technical writing. In numerous places, statements of belief are made (e.g., "we believe"). The reader does not care what the authors 'believe.' The reader cares about what is known and what is not known, and reasonable interpretations based on evidence. The report contains numerous metaphors, which are inappropriate for formal technical writing. For example, several times the authors describe what an instrument 'sees.' Aside from these problems there are numerous instances of unclear yet repetitive statements. If a student had handed me this draft report, I would have read a few pages and then handed it back as unacceptable.

As an example of poor writing, consider the last paragraph on page 4-2.

What are 'pretesting data'? 'All of that pretesting data was' could simply be "These data were." "receive RSDs" - this doesn't make sense. How does a vehicle receive a remote sensing device? The intended meaning seems to be "were measured using remote sensing." Having read the appendix, I cannot figure out the basis for the statement "Analysis of the EI23 index… " "to allow the EI23 to be less dependent on an exhaust emissions, we developed EI23 Bin" is awkward – should be "To reduce dependence on exhaust emissions, EI23 Bins were developed." Do not use first person. And so on. Aside from the poor wording, the key technical concepts are unclear. What are the dependences and how have they been inferred? It is frustrating to the reader to be told to go elsewhere for definition of EI23 and EI23 Bin but to be provided with details based on knowing what these concepts are, such as "EI23 Bin has integer values of 1 through 7…" These concepts and terms should be defined, developed, explained, etc., in a methods chapter prior to producing results based on these. The paragraph introduces, perhaps for the first time, the term "running loss emissions," without definition. If EI23 Bin is central to the methods and interpretation, it is simply unacceptable to push it to an appendix and to give such short and uninformative treatment to it in the main body of the report.

[3] Page 1-1. The first sentence refers to 'further developing' something that has not yet been defined in this report. Please, hire a technical editor and have them go through this report very carefully. The first line is poorly written, and the report that follows is also very poorly written.

[4] Page 1-2 "the real investigation in this study happens in…" this kind of colloquial writing has no place in a formal technical report by what is supposed to be one of the top environmental engineering consulting firms in the country to the Federal agency charged with

quantifying and regulating air quality. This report needs to be taken more seriously by the authors.

[5] Background Chapter: this chapter is plagued with undefined jargon, lack of clarity of concepts, and is poorly organized. It is very qualitative and vague and provides little to no insight on the topics being addressed.

[6] “These two RSDs were measured on the same RSD instrument as the Selection RSDs.” This sentence is extremely sloppy, using the term “RSD” where the concept of a ‘remote sensing measurement’ should be used instead.

[7] How does a vehicle “receive” an “RSD”? I have done measurements with an RSD, and I have never seen a vehicle receive an RSD.

[8] Table 4-2: terms PSHED and RSD in caption should be spelled out. All nomenclature in column headers need to be properly defined – e.g., use footnotes. Is RSD temperature the ambient temperature at the date and time of the measurement?

[9] Figure 4-1 needs better formatting. Should use a much larger font size for the numbers on the axes, and consider using scientific notation rather than decimals if showing a log scale. In the caption, spell out PSHED. What is “RSD EI23”?

[10] Table 4-3 is hardly a table and is not formatted well. Add a row for percentages of total to help in the interpretation. Please change the terminology – e.g., ‘Measurement RSDs” (should be Remote Sensing Measurements).

[11] Table 4-4 the term “high PSHEDs” is unacceptable. The intended meaning appears to be “high PSHED measurement” “High-PSHED Definition” should be “High PSHED Measurement threshold” or criterion.

[12] What is ‘de-stratifications’?

[13] “these Selection RSDs can be used to de-stratify the stratified set and provide an estimate of the high-PSHED fraction of the fleet…” given the lack of clear definition of these terms, and the sloppy use of terminology, this sentence is unclear.

[14] ‘is not an unbiased’ – why not say ‘is a potentially biased’… positive statements are always more clear than negative statements.

[15] Page 4-23: “For the RSD to be useful…” should be ‘for the remote sensing measurement to be useful…” why is model year important? Earlier, a note was made that model year was not part of the EI23 binning method.

[16] Table 4-5. [T]he term “Selection RSD” needs to be changed… e.g., “screening remote sensing measurement”? But the table is actually of EI23 bins and model year groups, not screening remote sensing measurements. Thus, the caption is not consistent with the content of the table.

[17] Page 4-24 "we will get started…" might be okay for a presentation but this is not how a technical report should be worded. Try reading aloud the first sentence of the last paragraph on page 4-24. It needs to be rewritten. Aside from being a run-on sentence, it is awkward, contains repetitive points and yet is not very clear.

[18] Page 4-25: N_h is defined in Appendix B but is given a lower case symbol (n_h). To avoid confusion and ambiguity, use consistent mathematical nomenclature. "Fraction of elevated PSHEDs" is given the symbol p_h, which is defined in Appendix B as the "probability"… this is inconsistent. Either it is a frequency or it is a probability- choose one and use the concept consistently. The standard error of fraction of elevated PHEDs is given in Table 4-6 based on a definition involving s_h and N_h, but this definition is not given in Appendix B (it should be).

[19] Page 4-27. The last sentence of the first paragraph is unclear. Rewrite. Create a flow diagram or show an algorithm to make this more clear.

[20] "It is important to understand that" should be deleted. "It… that" statements are passive and contain no information.

[21] "jumps around" – this kind of informal writing needs to be expunged from this report.

Fujita: [1] P. 4-1, 2nd paragraph, line 13: Rather than "accuracy", "representativeness" may be more appropriate in this context.

[2] P. 4-3, 1st paragraph, last two sentences: States that influence of variability of hot-soak emissions will be discussed later in the section. This discussion appears to be missing.

[3] P. 4-3, 2nd full paragraph: References to "not simulated exhaust" and "natural exhaust" in the last two sentences are confusing.

[4] P.4-11, Table 4-2. VDF is not defined anywhere in the report.

Knoll: The last sentence in Section 4.4 appears to be the beginning of an incomplete paragraph. I expected further explanation or evaluation of how the EI23 bins are independent of model year groups. Did some additional text get inadvertently dropped from this section?

3.3.2 Organization of the Report

Frey: [1] Aside from the poor writing, the organization of this report should be reconsidered. Methods and results appear to be mixed together. A good technical report will have a chapter devoted to methods, organized in a manner consistent with the order in which the methods are used later in the report. Furthermore, this report tends to have too much of 'here's what we did' without first introducing the purpose, key concepts, or basis/foundation.

[2] A technical report should have the following elements:

- Introduction
  - states the challenge, problem, issue being addressed,
  - establishes the need for new work
  - **clearly** states the objectives of the work (note: objectives are not a list of tasks – they relate to the purpose of the work)
- Background: Survey of relevant prior work, if needed. Also, a brief review of the types of evaporative emissions and factors to which they are sensitive is needed. For example, evaporative emissions are sensitive to ambient temperature.
- Methods
  - For each major component of the analysis, state the following:
    - Overall purpose
    - Basic concept
    - Empirical or theoretical basis established in prior work (with citations)
  - Provide sufficient information regarding the methods so that someone else could reproduce the work – include definitions of key terms, variables, equations, algorithms, and so on
  - Examples of content for this chapter (illustrative)
    - Schematic of the vehicle path through the various RSDs and PSHED
    - Methods A and B for estimating plume concentrations from remote sensing measurements
    - EI23 definition and definition of EI23 bins
    - Approach to 'stratification'
- Results
  - Results could be organized into more than one chapter if the subject matter is too much for one chapter
  - Results should include a clearly summary of all input data and assumptions
  - Results obtained should be from application of methods described in the methods chapter.
  - Results should be appropriately interpreted
- Conclusions
  - What are the key findings that are related to the objectives stated in Chapter 1?
  - What are the key conclusions that are related to the objectives stated in Chapter 1?
  - What are the key recommendations that are related to the objectives stated in Chapter 1?

[3] Background Chapter: this chapter is plagued with undefined jargon, lack of clarity of concepts, and is poorly organized. It is very qualitative and vague and provides little to no insight on the topics being addressed. Examples of content missing from this report include a brief review of the types of evaporative emissions, factors to which such emissions are sensitive, the SHED measurement approach, how PSHED works, what is remote sensing, and how can remote sensing be used to infer information about evaporative emissions. What does the RSD actually measure that is representative of evaporative emissions, and is this similar to what is measured in PSHED? Why is there an expectation that there should be agreement between evaporative emissions inferred from RSD measurements versus those inferred from PSHEDS? Are they measuring the same processes under similar conditions? How might they differ?

[4] The background chapter should be followed by a new chapter 3 that provides an overview of the methods used in this report, including a schematic of the Ken Caryl IM station, the specific instruments deployed, the analysis methods used, etc. Material that is now in Appendix A and B should be rewritten into the methods chapter.

[5] The current Chapter 3 should be rewritten as "Assessment of Concordance Between Portable and Fixed Location Evaporative Emissions Measurements." This chapter needs technical editing. The basic information is useful and interesting. The technical analysis should include quantification of the statistical significance of each parameter in the regression equation, the standard error of the estimate, the distribution of the residuals, a normality check for the residuals, the coefficient of determination, and other basic information that would commonly be reported as diagnostic goodness-of-fit indicators when developing a regression model. To what extent are results such as in Figures 3-4 and 3-5 actually providing an indication of repeatability of the test – are the conditions really the same in each test? If the repeatability is really this poor, what are the implications for selecting a threshold for what constitutes a 'high evap' vehicle? It is more common to report 95% probability ranges, not 68% probability ranges.

[6] Chapter 4: A schematic of the Ken Caryl station is needed to illustrate what is meant by the "driveway RSD unit" and "Measurement RSDs"

[7] A table prior to Table 4-5 would be more useful… i.e. distribution of vehicles by model year groups and EI23 bins for the selected (stratified?) vehicles.

[8] The first paragraph in Section 4.4 is unclear and is hampered by repeated use of terms that are not well-defined. Methods for stratification and de-stratification should be in a prior methods chapter.

[9] Page 4-25: The Appendix B should be part of a methods chapter given earlier in this report (could be Chapter 3).

[10] Chapter 5: The purpose of Chapter 5 is unclear. Is this meant to be a conclusions chapter? A summary chapter? A results chapter?

- The lead paragraph here is probably the most coherent statement of the objective of this report. Such a statement is needed in the introduction.

- The second paragraph is not useful because it is based on evidence not provided in earlier parts of the report.

- The third paragraph is awkward and overly didactic. One can make the point, for example, that the use of EI23 as an indicator of evaporative emissions was explored in this work, and state the findings, conclusions, and recommendations accruing from this work. Subsequently, a recommendation can be made that the existing data could be analyzed using other indicators for the purpose of evaluating whether other indicators might be better than EI23. Whether 'any evap index' can be used depends on what variables are critical to an 'evap index' and whether they were all measured during the study at the Ken Caryl IM station. Since the report lacks even a basic overview of factors that lead to evaporative emissions, it is not clear as to whether all useful factors have been quantified to support development of 'any' evap index.

- The paragraph at the bottom of page 5-1 is sufficiently cryptic as to be useless to anyone but those involved in the data collection or project management effort. It is not very clear as to what point is being made here.

- Page 5-2 "to measure the RSDs" – this makes no sense. RSDs are devices that make measurement. Why would one make a measurement on the RSD itself?

- The intent of the paragraph on "RSDs of the Denver fleet" is unclear. Perhaps this is a recommendation to calculate EI23 for a wider set of vehicles and use the Ken Caryl IM station data for fraction of high emitters to estimate a fraction of high emitters for the larger fleet. If that is the case, the intent is unclear.

- Last paragraph on page 5-2 – seems to be introducing a lot of new information but in an unclear manner such that the point(s) here are unclear.

Fujita: [1] It would be helpful in Section 2 (Background) to state how the results of this study and similar future studies will be used in the MOVES model. Should be specific enough to identify the relevant algorithms and inputs.

[2] The report does not include a summary of other testing – modified California Method (olfactory, visual and electronic HC sniffer examination of various vehicle components). If this information is summarized elsewhere, it should be references and a brief summary of the finding should be included within this report.

[3] P.4-4, 1st full paragraph, last two sentences: The reason for selecting Method B is difficult to understand without prior knowledge that EI23 is based on residuals of the linear regression. This is only explained in Appendix A. It should be mentioned briefly in the Section 4.2 for clarity.

[4] P. A-2: Add a description of the origin of the constants used in equations shown at the bottom of the page. Explain how this reduces dependence of EI23 on exhaust HC concentrations.

Knoll: [1] Elsewhere in the literature, estimates are made providing comparison of PSHED results with EPA's Tier 2 requirements for evaporative emissions.[1] It would be helpful to include that here for context.

[2] On page 3-12, the statistical analysis leading to the conclusions that "repeated SHED hot-soak measurements for a vehicle would fall between 40% (=1/2.51) and 251% of the vehicle's average (characteristic) hot-soak value 68% of the time" should include a relevant source citation.

[1] 1 "Evaluation of Evaporative Leaks using RSD and Inventory Implications," D. Hawkins, C. Hart, C. Fulper, J. Warila, D. Brzezinski, et al., Presented at the 19th Annual International Emission Inventory Conference, San Antonio, TX, Sept 27-30, 2010.

4. References

Eastern Research Group, Inc. *Estimates of the Fraction of the Fleet with High Evaporative Emissions based on the Ken Caryl Station (Denver, Colorado) Field Study; Report Version 6. 2011*.

Eastern Research Group, Inc. *Investigation of Techniques for High Evaporative Emissions Vehicle Detection: Denver Summer 2008 Pilot Study at Lipan Street Station; Report Version 4*. 2009.

Appendix A: Resumes of Peer Reviewers

H. Christopher Frey

http://www4.ncsu.edu/~frey/
frey@ncsu.edu
(919) 515-1155

Education

Ph.D., Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, May 1991.

Master of Engineering, Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA, May 1987.

B.S., Mechanical Engineering, University of Virginia, Charlottesville, VA, May 1985.

Professional Experience

Aug 04 – present	Professor, Department of Civil, Construction, and Environmental Engineering, *North Carolina State University*, Raleigh, NC
Aug 06 – Aug 07	Sabbatical: Exposure Modeling Advisor, National Exposure Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC.
Jul 99 – Jul 04	Associate Professor, Department of Civil Engineering, *North Carolina State University*, Raleigh, NC
Jan 94 - Jun 99	Assistant Professor, Department of Civil Engineering, *North Carolina State University*, Raleigh, NC
Jun 91 - Dec 93	Research Associate (Research Faculty), Center for Energy and Environmental Studies, and Department of Engineering and Public Policy, Carnegie Institute of Technology, *Carnegie Mellon University*, Pittsburgh, PA
1993 (Fall)	Adjunct Assistant Professor, Graduate School of Public and International Affairs, *University of Pittsburgh*, Pittsburgh, PA
1992 (Summer)	Environmental Science and Engineering Fellow, Office of Research and Development, *U.S. Environmental Protection Agency*, Washington, DC. Sponsored by American Association for the Advancement of Science (AAAS).
Jul 88 - May 91	Research Assistant, Department of Engineering and Public Policy, Carnegie Institute of Technology, *Carnegie Mellon University*, Pittsburgh, PA

Jun 87 - Jul 88	Engineer, Combustion and Chemical Engineering Department, *Radian Corporation*, Research Triangle Park, NC
Aug 85 - May 87	Research Assistant, Department of Mechanical Engineering, Carnegie Institute of Technology, *Carnegie Mellon University*, Pittsburgh, PA
1981 - 1986	Summer jobs: • Mechanical Engineer, *General Electric*, Valley Forge, PA, 1986 • Mechanical Engineer, *Voice of America*, U.S. Information Agency, Washington, DC, Summer 1985 • Research Apprentice/Engineering Aid, *U.S. Naval Research Laboratory*, Washington, DC, Summers of 1981 and 1984 • Engineering Technician/Engineering Aid, *U.S. Army Materials, Fuels, and Lubricants Laboratory*, Fort Belvoir, VA, Summers of 1982 and 1983

Special Appointments

2010 – 2013	Chair, Lead Review Panel, U.S. EPA Clean Air Scientific Advisory Committee
Oct 09 – Sept 12	Member, Board on Environmental Studies and Toxicology (BEST), National Research Council.
Oct 08 – Sept 11	Member, Clean Air Scientific Advisory Committee (CASAC), U.S. Environmental Protection Agency (appointed by EPA Administrator as one of the seven members of the statutory CASAC).
Oct 08 – Sept 09	Member, Committee on Review of EPA's Toxicological Assessment of Tetrachloroethylene, National Research Council.
Nov 08 – present	Member, U.S. EPA Science Advisory Board (SAB) Expert Elicitation Advisory Panel, November 2008 – present.
Nov 07 - present	Member, Particulate Matter (PM) Review Panel, Clean Air Scientific Advisory Committee (CASAC), U.S. Environmental Protection Agency.
Apr 07 – present	Federal Advisory Committee Act (FACA) MOVES Review Workgroup (review of U.S. EPA’s MOVES mobile source emission factor and inventory model)
Jan 07 – present	Author, Multi-Pollutant Air Quality Management Assessment, NARSTO
Apr 05 – Nov 07	Member, Working Group on Uncertainty in Exposure Assessment, International Programme on Chemical Safety (IPCS), World Health Organization (WHO).
Dec 04 – Dec 07	President-Elect, President, Past-President of the Society for Risk Analysis.
May 04 – Jun 06	Expert and Lead Author, 2006 Guidelines on National Greenhouse Gas Emission Inventories, Intergovernmental Panel on Climate Change (IPCC).
Apr 04 – Aug 06	Member, FIFRA Scientific Advisory Panel, U.S. Environmental Protection Agency.

Mar 04 – Jul 06 Member, National Research Council Committee on the Effects of Changes in New Source Review Programs for Stationary Sources of Air Pollutants.

Scholarly and Professional Honors

1. *Undergraduate Honors: Rodman Scholar*, University of Virginia, 1981-1985 (top 6% of entering engineering students); *National Society of Professional Engineers Scholarship*: 1981-1982; *Elks Lodge Scholarship*: 1981-1982; *Intermediate Honors for High Distinction*, University of Virginia, 1983; *Raven Society*, University of Virginia honor society - elected 1984; *M.E. George Scholarship*, University of Virginia, 1984-1985. Selected based on character, leadership, and scholarship for residence on the Lawn of the University of Virginia, 1984-1985 (47 of 2,500 fourth year undergraduates selected). The Lawn is part of the original University "Grounds" designed by Thomas Jefferson, and residence on the Lawn is considered a high honor.
2. *Scientific, Engineering, and Leadership Honorary Society Memberships Pi Tau Sigma*, the national mechanical engineering honor society. Elected Oc. 1983. *Omicron Delta Kappa*, the national leadership honor society. Elected April 1984. *Tau Beta Pi*, the national engineering honor society. Elected October 1984. *Sigma Xi*, the scientific research society. Elected April 1986.
3. *Environmental Science and Engineering Fellow*, American Association for the Advancement of Science and the U.S. Environmental Protection Agency, Summer 1992. Also received *1992 Robert C. Bernard Environmental Science and Engineering Scholarship*, American Association for the Advancement of Science, Fall 1992, for best project produced under the fellowship.
4. Faculty Early Career Development (CAREER) Award, National Science Foundation (received June 1997).
5. Invited participant, National Academy of Engineering, Fifth Annual Symposium on Frontiers of Engineering, Irvine, CA, October 13-16, 1999. Participation was limited to 100 outstanding engineers age 30 to 45 from academia, government, and industry who are invited to attend after a competitive nomination process.
6. Chauncey Starr Award, Society for Risk Analysis, December 1999. The Chauncey Starr Award is awarded to a risk analyst under 40 in recognition of "exceptional contributions to the field of Risk Analysis."
7. Kimley-Horn Faculty Award, Department of Civil Engineering, Spring 2002.
8. Elected as to a three year term as President-Elect, President, and Past-President of the Society for Risk Analysis, 2004-2007.
9. 2004-2006 National Research Council member of Committee on Changes in New Source Review air pollution regulations.
10. Invited to serve on National Academy of Engineering organizing committee for the 2005 German-American Frontiers of Engineering conference.

11. 2004-2006 invited as U.S. delegation member and lead author to Intergovernmental Panel on Climate Change international meeting and activity on revising greenhouse gas emissions guidance.
12. 2004-2005 invited to serve as steering committee member and a lead author on tri- lateral (Canada-US-Mexico) NARSTO assessment of emission inventories.
13. 2004-2006 one of seven appointed members of the U.S. Environmental Protection Agency FIFRA Scientific Advisory Panel.
14. 2006 invited to serve as a lead author tri-lateral (Canada-US-Mexico) NARSTO assessment of methods for analyzing and managing multi-pollutant environmental problems.
15. December 2006. Fellow, Society for Risk Analysis.
16. Recognized by the Intergovernmental Panel on Climate Change (IPCC) for "contributing to the award of the Nobel Peace Prize for 2007 to the IPCC."
17. Clean Air Scientific Advisory Committee (CASAC), Member, Appointed by the Administrator of the U.S. Environmental Protection Agency to a 3-year term October 2008 – September 2011.
18. March 2008. Fellow, Air & Waste Management Association.
19. 2008 NCSU Alumni Association Outstanding Research Award, May 8, 2008.
20. 2008 Mobile Clean Air and Renewable Energy Award – Individual, May 6, 2008.
21. 2009 Earthwise Faculty Award, Office of Sustainability, North Carolina State University, April 2009.

Professional Society Memberships

<u>Professional Society Memberships:</u>

American Society of Civil Engineers (ASCE), 1994-2009
Air & Waste Management Association (AWMA), 1985-present
Society for Risk Analysis (SRA), 1994-present (President, 2006)

Leadership Positions in Professional Societies

Organization	Description	Dates
Society for Risk Analysis	Member	1994 - present
	Chair, Awards Committee	12/08-12/09
	Chair, Nominations Committee	12/07-12/08
	Member, Committee of SRA Past Presidents on Regulatory Reform	March 2009
	Immediate Past-President, member of SRA Council and Executive Committee, and Chair of Publications Committee	12/06-12/07
	President, chair of SRA Council, Chair of the Executive Committee	12/05-12/06
	President-Elect, member of SRA Council and Executive Committee, Chair of Annual Meeting Committee	12/04-12/05
	Councilor: at-large elected member of governing board of SRA	12/96-12/99
	Education Committee, member	1998-1999
	Electronic Media Committee, member and Council Liason (oversaw creation of SRA web site, www.sra.org)	1996-1999
Research Triangle Chapter, Society for Risk Analysis	President-Elect (one year term)	1995
	President (one year term)	**1996**
	Past-President (one year term)	1997
	Webmaster	1998
Air & Waste Management Association	**Member**	**1992 - present**
	Vice Chair, ET-1, Transportation: On and Off Road Mobile Sources	**2008 - present**
	Chair, EE-1 Health Effects and Exposure Committee	2002-2003
	Vice Chair, EE-1	2001-2002
	Secretary, EE-1	2000-2001
	Member, EE-5 Risk Assessment and Management Committee	2000 - present
NCSU Student Chapter of Air & Waste Mgmt. Assoc.	**Founding Faculty Advisor**	**1995 - present**
American Society of Civil Engineers	Member	1994 - 2010
	Member, Sessions Committee, Energy Division	1995 – 1998
	Member, Publications Committee for ASCE Journal of Energy Engineering	1995 - 2000

PEER-REVIEWED ARCHIVAL JOURNAL PAPERS

1. Rubin, E.S., J.S. Salmento, and H.C. Frey, "Cost-Effective Emission Controls for Coal-Fired Power Plants," *Chemical Engineering Communications*, 74:155-167 (1988).

2. Frey, H.C., and E.S. Rubin, "Probabilistic Evaluation of Advanced SO_2/NO_x Control Technology," *Journal of the Air and Waste Management Association*, 41(12):1585-1593 (December 1991).

3. Frey, H.C., and E.S. Rubin, "Evaluation Method for Advanced Acid Rain Compliance Technology," *Journal of Energy Engineering*, 118(1):38-55 (April 1992).

4. Frey, H.C., and E.S. Rubin, "Evaluation of Advanced Coal Gasification Combined-Cycle Systems Under Uncertainty," *Industrial and Engineering Chemistry Research*, 31(5):1299-1307 (May 1992).

5. Diwekar, U.M., H.C. Frey, and E.S. Rubin, "Synthesizing Optimal Flowsheets: Applications to IGCC System Environmental Control," *Industrial and Engineering Chemistry Research*, 31(8):1927-1936 (August 1992).

6. Frey, H.C., and E.S. Rubin, "Integration of Coal Utilization and Environmental Control in Integrated Gasification Combined Cycle Systems," *Environmental Science and Technology*, 26(10):1982-1990 (October 1992).

7. Frey, H.C., E.S. Rubin, and U.M. Diwekar, "Modeling Uncertainties in Advanced Technologies: Application to a Coal Gasification System with Hot Gas Cleanup," *Energy* 19(4):449-463 (1994).

8. Shih, J.S., and H.C. Frey, "Coal Blending Optimization Under Uncertainty," *European Journal of Operations Research*, 83(3):452-465 (1995).

9. Frey, H.C., and D.S. Rhodes, "Characterizing, Simulating, and Analyzing Variability and Uncertainty: An Illustration of Methods Using an Air Toxics Emissions Example," *Human and Ecological Risk Assessment: an International Journal*, 2(4):762-797 (December 1996).

10. Diwekar, U.M., E.S. Rubin, and H.C. Frey, "Optimal Design of Advanced Power Systems Under Uncertainty," *Energy Conversion and Management*, 38(15):1725-1735 (1997).

11. Rubin, E.S., J.R. Kalagnanam, H.C. Frey, and M.B. Berkenpas, "Integrated Environmental Control Concepts for Coal-Fired Power Plants," *Journal of the Air and Waste Management Association*, 47(11):1180-1188 (November 1997).

12. Frey, H.C., and Z. Iwanski, "Probabilistic Methodology for Risk Assessment of New Energy Technologies and Application to Gasification Repowering for an Oil Refinery in Poland," *Energy Conversion and Management*, 39 (16/18):267-274 (1997).

13. Agarwal, P., and H.C. Frey, "Modeling and Evaluation of the Externally Fired Combined Cycle Using ASPEN," *Journal of Energy Engineering*, 123(3):69-87 (December 1997).

14. Frey, H.C., and D.S. Rhodes, "Characterization and Simulation of Uncertain Frequency Distributions: Effects of Distribution Choice, Variability, Uncertainty, and Parameter Dependence," *Human and Ecological Risk Assessment: an International Journal*, 4(2):423-468 (April 1998).

15. Frey, H.C., and D.E. Burmaster, "Methods for Characterizing Variability and Uncertainty: Comparison of Bootstrap Simulation and Likelihood-Based Approaches," *Risk Analysis,* 19(1):109-130 (February 1999).

16. Hanna, S.R., Z. Lu, H.C. Frey, N. Wheeler, J. Vukovich, S. Arunachalam, M. Fernau, and D.A. Hansen, "Uncertainties in Predicted Ozone Concentrations due to Input Uncertainties for the UAM-V Photochemical Grid Model Applied to the July 1995 OTAG Domain," *Atmospheric Environment*, 35(5):891-903 (2001).

17. Frey, H.C., and S. Bammi, "Quantification of Variability and Uncertainty in Lawn and Garden Equipment NO_x and Total Hydrocarbon Emission Factors," *Journal of the Air & Waste Management Association*, 52(4):435-448 (April 2002).

18. Frey, H.C., and S.R. Patil, "Identification and Review of Sensitivity Analysis Methods," *Risk Analysis*, 22(3):553-578 (June 2002).

19. Frey, H.C., and J. Zheng, "Quantification of Variability and Uncertainty in Utility NO_x Emission Inventories," *Journal of Air & Waste Manage. Association,* 52(9):1083-1095 (September 2002).

20. Frey, H.C., and J. Zheng, "Probabilistic Analysis of Driving Cycle-Based Highway Vehicle Emission Factors," *Environmental Science and Technology,* 36(23):5184-5191 (December 2002).

21. Frey, H.C., and S. Bammi, "Probabilistic Nonroad Mobile Source Emission Factors," *ASCE Journal of Environmental Engineering*, 129(2):162-168 (February 2003).

22. Frey, H.C., A. Unal, N.M. Rouphail, and J.D. Colyar, "On-Road Measurement of Vehicle Tailpipe Emissions Using a Portable Instrument," *Journal. of Air & Waste Manage. Assoc.*, 53(8):992-1002 (August 2003).

23. Abdel-Aziz, A., and H.C. Frey, "Quantification of Hourly Variability in NO_x Emissions for Baseload Coal-Fired Power Plants," *Journal of the Air & Waste Management Association*, 53(11):1401-1411 (November 2003).

24. Abdel-Aziz, A., and H.C. Frey, "Development of Hourly Probabilistic Utility NOx Emission Inventories Using Time Series Techniques: Part I-Univariate Approach," *Atmospheric Environment,* 37:5379-5389 (2003).

25. Abdel-Aziz, A., and H.C. Frey, "Development of Hourly Probabilistic Utility NOx Emission Inventories Using Time Series Techniques: Part II-Multivariate Approach," *Atmospheric Environment,* 37:5391-5401 (2003).

26. Frey, H.C., and S. Li, “Quantification of Variability and Uncertainty in AP-42 Emission Factors: Case Studies for Natural Gas-Fueled Engines,” *Journal of the Air & Waste Management Association*, 53(12):1436-1447 (December 2003).

27. Unal, A., N.M. Rouphail, and H.C. Frey, “Effect of Arterial Signalization and Level of Service on Measured Vehicle Emissions,” *Transportation Research Record, Journal of the Transportation Research Board*, No. 1842, pp. 47-56 (2003).

28. Unal, A., H.C. Frey, and N.M. Rouphail, “Quantification of Highway Vehicle Emissions Hot Spots Based Upon On-Board Measurements,” *Journal of the Air & Waste Management Association*, 54(2):130-140 (February 2004).

29. Abdel-Aziz, A., and H.C. Frey, “Propagation of Uncertainty in Hourly Utility NOx Emissions Through a Photochemical Grid Air Quality Model: A Case Study for the Charlotte, NC Modeling Domain,” *Environmental Science and Technology*, 38(7):2153-2160 (2004).

30. Patil, S.R., and H.C. Frey, “Comparison of Sensitivity Analysis Methods Based Upon Applications to a Food Safety Risk Model,” *Risk Analysis*, 23(3):573-585 (June 2004).

31. Zheng, J., and H.C. Frey, “Quantification of Variability and Uncertainty Using Mixture Distributions: Evaluation of Sample Size, Mixing Weights and Separation between Components,” *Risk Analysis*, 24(3):553-571 (June 2004).

32. Zhao, Y., and H.C. Frey, “Quantification of Variability and Uncertainty for Censored Data Sets and Application to Air Toxic Emission Factors,” *Risk Analysis*, 24(3):1019-1034 (2004).

33. Frey, H.C., and Y. Zhao, “Quantification of Variability and Uncertainty for Air Toxic Emission Inventories With Censored Emission Factor Data,” *Environmental Science and Technology*, 38(22):6094-6100.

34. Chen, J., and H.C. Frey, “Optimization Under Variability and Uncertainty: A Case Study for NO_x Emissions Control for a Gasification System,” *Environmental Science and Technology*, 38(24):6741-6747 (2004).

35. Zhao, Y., and H.C. Frey, “Development of Probabilistic Emission Inventory for Air Toxic Emissions for Jacksonville, Florida,” *Journal of the Air & Waste Management Association*, 54(11):1405-1421 (2004).

36. Mokhtari, A., and H.C. Frey, “Recommended Practice Regarding Selection of Sensitivity Analysis Methods Applied to Microbial Food Safety Process Risk Models,” *Human and Ecological Risk Assessment*, 11(3):591-605 (2005).

37. Zheng, J., and H.C. Frey, “Quantitative Analysis of Variability and Uncertainty with Known Measurement Error: Methodology and Case Study,” *Risk Analysis*, 25(3):663-676 (2005).

38. Mokhtari, A., and H.C. Frey, “Sensitivity Analysis of a Two-Dimensional Probabilistic Risk Assessment Model Using Analysis of Variance,” *Risk Analysis*, 25(6):1511-1529 (2005).

39. Frey, H.C., and Y. Zhu, "Improved System Integration for Integrated Gasification Combined Cycle (IGCC) Systems," *Environmental Science and Technology*, 40(5):1693-1699 (March 2006).

40. Mokhtari, A., H.C. Frey, and L.-A. Jaykus, "Application of Classification and Regression Trees (CART) for Sensitivity Analysis of the Escherichia coli O157:H7 Food Safety Process Risk Model," *Journal of Food Protection*. 69(3): 609–618 (March 2006).

41. Zhang, K., and H.C. Frey, "Road Grade Estimation for On-Road Vehicle Emissions Modeling Using LIDAR Data," *Journal of the Air & Waste Management Association*, 56(6):777-788 (2006).

42. Silva, C.M, T.L. Farias, H.C. Frey, and N.M. Rouphail, "Evaluation of Numerical Models for Simulation of Real-World Hot-Stabilized Fuel Consumption and Emissions of Gasoline Light- Duty Vehicles." *Transportation Research Part D*, 11(5):377-385 (2006).

43. Miller, C.A., G. Hidy, J. Hales, C.E. Kolb, A.S. Werner, B. Haneke, D. Parrish, C. Frey, L. Rojas-Blanco, M. DesLauriers, B. Pennell, and J.D. Mobley, "Air Emissions Inventories in North America: A Critical Assessment," *Journal of the Air & Waste Management Association*, 56(8):1115-1129 (2006).

44. Mokhtari, A., H.C. Frey, and J. Zheng, "Evaluation and recommendation of sensitivity analysis methods for application to Stochastic Human Exposure and Dose Simulation (SHEDS) models," *Journal of Exposure Assessment and Environmental Epidemiology*, (2006) Available electronically. Paper version is in press.

45. Mokhtari, A., and H.C. Frey, "Evaluation of Sampling-Based Methods for Sensitivity Analysis: Case Study for the *E. coli* Food Safety Process Risk Model," *Human and Ecological Risk Assessment*, 12(6):1128-1152 (Dec 2006).

46. Zhao, Y. and H.C. Frey, "Uncertainty for Data with Non-Detects: Air Toxic Emissions from Combustion," *Human and Ecological Risk Assessment*, 12(6):1171-1191 (Dec 2006).

47. Zhu, Y., and H.C. Frey, "Uncertainty Analysis of Integrated Gasification Combined Cycle (IGCC) Systems Based on Frame 7H versus 7F Gas Turbines," *Journal of the Air & Waste Management Association*, 56(12):1649-1661 (Dec 2006).

48. Frey, H.C., and K. Kim, "Comparison of Real-World Fuel Use and Emissions for Dump Trucks Fueled with B20 Biodiesel Versus Petroleum Diesel," *Transportation Research Record*, 1987:110-117 (2006).

49. Frey, H.C., N.M. Rouphail, and H. Zhai, "Speed- and Facility-Specific Emission Estimates for On-Road Light-Duty Vehicles based on Real-World Speed Profiles," *Transportation Research Record*, 1987:128-137 (2006).

50. Vicari A.S., A. Mohktari, R.A. Morales, L.A. Jaykus, H.C. Frey, B.D. Slenning and P. Cowen, "Second-Order Modeling of Variability and Uncertainty in Microbial Hazard Characterization," *Journal of Food Protection*, 70(2):363-372 (February 2007).

51. Frey, H.C., N.M. Rouphail, H. Zhai, T.L. Farias, and G.A. Gonçalves, "Modeling and Comparing Real-World Fuel Consumption for Diesel- and Hydrogen-Fueled Transit Buses and Implication for Emissions," *Transportation Research – Part D*. 12:281-291 (2007).

52. Zhu, Y., and H.C. Frey, "Simplified Performance Model of Gas Turbine Combined Cycle Systems," *ASCE Journal of Energy Engineering*, 133(2):82-90 (June 2007).

53. Zhang, K., and H.C. Frey, "Evaluation of Response Time of a Portable System for In-Use Vehicle Tailpipe Emissions Measurements," *Environmental Science and Technology*, 42(1), 221–227 (2008).

54. Frey, H.C., K. Zhang, and N.M. Rouphail, "Fuel Use and Emissions Comparisons for Alternative Routes, Time of Day, Road Grade, and Vehicles Based on In-Use Measurements," *Environmental Science and Technology*, 42(7):2483–2489 (2008).

55. Abolhasani, S., H.C. Frey, K. Kim, S. Pang, W. Rasdorf, P. Lewis, "Real-World In-Use Activity, Fuel Use, and Emissions for Nonroad Construction Vehicles: A Case Study for Excavators," *Journal of the Air & Waste Management Association*, 58(8):1033-1046 (2008).

56. Kim, K., H.C. Frey, W. Rasdorf, S. Pang, P. Lewis, "Characterization of Real-World Activity, Fuel Use, and Emissions for Selected Motor Graders Fueled with Petroleum Diesel and B20 Biodiesel," *Journal of the Air & Waste Management Association*, 58(10):1274-1287 (2008).

57. Zhai, H., H.C. Frey, and N.M. Rouphail, "A Vehicle-Specific Power Approach to Speed- and Facility-Specific Emissions Estimates for Diesel Transit Buses," *Environmental Science and Technology*, ASAP Article, 10.1021/es800208d, Web Release Date: September 25, 2008 (http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/asap/abs/es800208d.html) (2008).

58. Frey, H.C., W.J. Rasdorf, K. Kim, S.H. Pang, P. Lewis, "Comparison of Real-World Emissions of Backhoes, Front-End Loaders and Motor Graders for B20 Biodiesel vs. Petroleum Diesel for Selected Engine Tiers," *Transportation Research Record*, 2058:33-42 (2008).

59. Frey, H.C., N.M. Rouphail, and H. Zhai, "Link-Based Emission Factors for Heavy-Duty Diesel Trucks Based on Real-World Data," *Transportation Research Record*, 2058:23-32 (2008).

60. Frey, H.C., P.Y. Kuo, and C. Villa, "Methodology for Characterization of Long-Haul Truck Idling Activity under Real-World Conditions," *Transportation Research – Part D*, 13D(8):516-523 (2008).

61. Coelho, M., H.C. Frey, N.M. Rouphail, H. Zhai, and L. Pelkmans, "Assessing Methods for Comparing Emissions from Gasoline and Diesel Light-Duty Vehicles Based on Microscale Measurements," *Transportation Research – Part D*, 14D(2):91-99 (March 2009).

62. Ozkaynak, H., H.C. Frey, J. Burke, and R.W. Pinder, "Analysis of coupled model uncertainties in source to dose modeling of human exposures to ambient air pollution: a $PM_{2.5}$ case-study," *Atmospheric Environment*, 43(9): 1641-1649 (March 2009).

63. Lewis, P., W. Rasdorf, H.C. Frey, S.H. Pang, and K. Kim, "Requirements and Incentives for Reducing Construction Vehicle Emissions and Comparison of Nonroad Diesel Engine Emissions Data Sources," *ASCE Journal of Construction Engineering and Management*, 135(5):341-351 (May 2009).

64. Bogen, K., A. Cullen, H.C. Frey, and P. Price, "Probabilistic Exposure Analysis for Chemical Risk Characterization," *Toxicological Sciences*, 109(1):4-17 (May 2009). Available on-line at http://toxsci.oxfordjournals.org/cgi/reprint/kfp036?ijkey=sIBW9Sm3pvbPQnm&keytype=ref

65. Frey, H.C., and P.Y. Kuo, "Real-World Energy Use and Emission Rates for Idling Long-Haul Truck Engines and Selected Idle Reduction Technologies," *Journal of the Air & Waste Management Association*, 59(7):857-864 (July 2009).

66. Zhai, H., H.C. Frey, N.M. Rouphail, G. Goncalves, and T. Farias, "Comparison of Flexible Fuel Vehicle and Life Cycle Fuel Consumption and Emissions of Selected Pollutants and Greenhouse Gases for Ethanol 85 Versus Gasoline," *Journal of the Air & Waste Management Association*, 59(8):912- 924 (August 2009).

67. Pang, S.H., H.C. Frey, and W.J. Rasdorf, "Life Cycle Inventory Energy Consumption and Emissions for Biodiesel versus Petroleum Diesel Fueled Construction Vehicles," *Environmental Science and Technology*, 43(16):6398-6405 (August 15, 2009).

68. Frey, H.C., P.Y. Kuo, and C. Villa, "Effects of Idle Reduction Technologies on Real World Fuel Use and Exhaust Emissions of Idling Long-Haul Trucks," *Environmental Science and Technology*, 43(17):6875–6881 (DOI: 10.1021/es900186e, published online July 30, 2009). Available at: http://pubs.acs.org/doi/full/10.1021/es900186e.

69. Frey, H.C., H. Zhai, and N.M. Rouphail, "Regional On-Road Vehicle Running Emissions Modeling and Evaluation for Conventional and Alternative Vehicle Technologies," *Environmental Science and Technology*, 43(21):8449–8455 (doi: 10.1021/es900535s, published online Sept 22, 2009). Available at: http://pubs.acs.org/doi/full/10.1021/es900535s.

70. Choi, H.W. and H.C. Frey, "Estimating Light Duty Gasoline Vehicle Emission Factors at High Transient and Constant Speeds for Short Road Segments," *Transportation Research – Part D*. 14(8):610–614 (2009). Available at: http://dx.doi.org/10.1016/j.trd.2009.09.001

71. Frey, H.C., and K. Kim, "In-Use Measurement of Activity, Fuel Use, and Emissions of Cement Mixer Trucks Operated on Petroleum Diesel and B20 Biodiesel," *Transportation Research – Part D*. 14(8):585-592 (2009). Available at: http://dx.doi.org/10.1016/j.trd.2009.08.004

72. Lewis, P., H.C. Frey, and W. Rasdorf, "Development and Use of Emissions Inventories for Construction Vehicles," *Transportation Research Record*, 2123:46-53 (2009).

73. Rasdorf, W., H.C. Frey, P. Lewis, K. Kim, S. Pang, and S. Abolhasani, "Field Procedures for Real- World Measurements of Emissions from Diesel Construction Vehicles," *ASCE Journal of Infrastructure Systems*, 16(3):216-225 (Sept 2010).

74. Choi, H.W., and H.C. Frey, "Estimating Diesel Vehicle Emission Factors at Constant and High Speeds for Short Road Segments," *Transportation Research Record*, No. 2158:19-27 (2010).

75. Frey, H.C., W. Rasdorf, P. Lewis, "Results of a Comprehensive Study of Fuel Use and Emissions of Nonroad Diesel Construction Equipment," *Transportation Research Record*, No. 2158:69-76 (2010).

76. Liu, X., H.C. Frey, and Y. Cao, "Estimation of In-Vehicle Concentration and Human Exposure for $PM_{2.5}$ Based on Near Roadway Ambient Air Quality and Variability in Vehicle Operation," *Transportation Research Record*, No. 2158:105-112 (2010).

77. Frey, H.C., K. Zhang, and N.M. Rouphail, "Vehicle-Specific Emissions Modeling Based Upon On- Road Measurements," *Environmental Science and Technology*, 44(9):3594-3600 (2010).

78. Choi, H.W., and H.C. Frey, "Method for In-Use Measurement and Evaluation of the Activity, Fuel Use, Electricity Use, and Emissions of a Plug-in Hybrid Diesel-Electric School Bus," *Environmental Science and Technology*, 44(9):3601-3607 (2010).

79. Cao, Y., and H.C. Frey, "Assessment of Inter-Individual and Geographic Variability in Human Exposure to Fine Particulate Matter in Environmental Tobacco Smoke," *Risk Analysis*, 31(4):578-591 (2011).

80. Liu, X., and H.C. Frey, "Modeling Of In-Vehicle Human Exposure to Ambient Fine Particulate Matter," *Atmospheric Environment*, 45(27):4745-4752 (2011). http://dx.doi.org/10.1016/j.atmosenv.2011.04.019.

81. Zhai, H., H.C. Frey, and N.M. Rouphail, "Development of A Modal Emissions Model for A Hybrid Electric Vehicle," *Transportation Research – Part D*. 16(6):444-450 (August 2011).

82. Cao, Y., and H.C. Frey, "Geographic differences in inter-individual variability of human exposure to fine particulate matter," *Atmospheric Environment*, 45(32):5684-5691 (http://dx.doi.org/10.1016/j.atmosenv.2011.07.034).

<u>In Press/Accepted for Publication</u>

83. Lewis, P., M. Leming, H.C. Frey, and W. Rasdorf, "Assessing the Effects of Operational Efficiency on Pollutant Emissions of Nonroad Diesel Construction Equipment," *Transportation Research Record*, accepted February 2011 (in press).

84. Cao, Y., and H.C. Frey, "Modeling of Human Exposure to In-Vehicle $PM_{2.5}$ from Environmental Tobacco Smoke," *Human and Ecological Risk Assessment*, submitted 7/14/10. Revised and resubmitted 3/9/11. Accepted 3/10/11 (in press).

85. Rasdorf, W.R., P. Lewis, S.K. Marshall, I. Arocho, H.C. Frey, "Evaluation of Fuel Use and Emissions Over the Duration of a Construction Building Project," *ASCE Journal of Infrastructure Systems*, submitted March 3, 2011, accepted July 18, 2011.

86. Graver, B.M, and H.C. Frey, "In-Use Measurement of the Activity, Energy Use, and Emissions of a Plug-in Hybrid Electric Vehicle," *Environmental Science and Technology*, accepted 9/7/11.

87. Marshall, S.K., W. Rasdorf, P. Lewis, H.C. Frey, "A Methodology for Estimating Emissions Inventories for Commercial Building Projects," *ASCE Journal of Architectural Engineering*, submitted 2/3/2011, Accepted 10/1/2011.

BOOKS

1. Cullen, A.C., and H.C. Frey. *The Use of Probabilistic Techniques in Exposure Assessment: A Handbook for Dealing with Variability and Uncertainty in Models and Inputs*. Plenum: New York, 1999. 335 pages.

EDITED BOOKS AND PROCEEDINGS

1. *Advances in Studies on Risk Analysis and Crisis Response*, C. Huang, C. Frey, and J. Feng, eds., Atlantis Press: Paris, France. ISBN 978-90-78677-03-1. 2007.

BOOK CHAPTERS AND ENCYCLOPEDIA ARTICLES

1. Frey, H.C., and E.S. Rubin, "Uncertainty Evaluation in Capital Cost Projection," in *Encyclopedia of Chemical Processing and Design*, Vol. 59, J.J. McKetta, ed., Marcel Dekker: New York, 1997, pp. 480-494.
2. Frey, H.C., "Quantitative Analysis of Variability and Uncertainty in Energy and Environmental Systems," Chapter 23 in *Uncertainty Modeling and Analysis in Civil Engineering*, B. M. Ayyub, ed., CRC Press: Boca Raton, FL, 1998, pp. 381-423.
3. Frey, H.C., and R. Bharvirkar, "Quantification of Variability and Uncertainty: A Case Study of Power Plant Hazardous Air Pollutant Emissions," Chapter 10 in *Human and Ecological Risk Analysis*, D. Paustenbach, Ed., John Wiley and Sons: New York, 2002. pp 587-617.
4. Zhu, Yunhua, and H.C. Frey, "Integrated Gasification Combined Cycle (IGCC) Systems," Chapter 3 in *Advanced Power Plant Materials, Design and Technology*, D. Roddy, ed., Woodhead Publishing, in press (submitted 7/27/09).
5. Hubbell, B., and H.C. Frey, "Risk Based Assessment and Management Framework," Chapter 3 in *Technical Challenges of Multipollutant Air Quality Management*; Hidy, G.M., Brook, J., Demerjian, K., Molina, L., Pennell, W., Scheffe, R., Eds.; Springer: New York, in press (as of March 2010).
6. Zhu, Yunhua, and H.C. Frey, "Integrated Gasification Combined Cycle (IGCC) systems," Chapter 3 in *Combined Cycle Systems for Near-Zero Emission Power Generation*, A.D. Rao, editor, Woodhead Publishing Limited, Cambridge, England, UK (submitted 6/30/11).

7. Frey, H.C., and Y. Zhu, "Techno-Economic Analysis," Chapter 10 in *Combined Cycle Systems for Near-Zero Emission Power Generation*, A.D. Rao, editor, Woodhead Publishing Limited, Cambridge, England, UK (submitted 10/11/11).

BOOK REVIEWS

1. Merz, J.F., and H.C. Frey, "Book Review: Regulating Toxic Substances," *Risk, Health, Safety, and Environment*, 5:75-80 (Winter 1994).

EDITORIALS

1. Frey, H.C. and E. S. Rubin, "Evaluate Uncertainties In Advanced Process Technologies," *Chemical Engineering Progress*, 88(5):63-70 (May 1992)

2. Frey, H.C., "Guest Editorial: Introduction to Special Section on Sensitivity Analysis and Summary of NCSU/USDA Workshop on Sensitivity Analysis," *Risk Analysis*, 22(3):539-545 (June 2002).

3. Frey, H.C., and M.J. Small, "Uncertainty in Emission Factors and Emission Inventories," *Journal of Industrial Ecology*, 7(1):9-11 (2003).

4. Özkaynak, H., H.C. Frey, and B. Hubbell, "Characterizing Variability and Uncertainty in Exposure Assessment Improves Links to Environmental Decision-Making," *EM Magazine* (Air & Waste Management Association), July 2008, pp. 18-22.

<u>Conference Proceedings (Peer Reviewed):</u>

1. Rubin, E.S., J.S. Salmento, and H.C. Frey, "Evaluating Combined SO_2/NO_X Processes," *Proceedings: Fourth Symposium on Integrated Environmental Control*, Report No. GS-6519, Electric Power Research Institute, Palo Alto, California, September 1989, pp. 6-1 to 6-15.

2. Frey, H.C., E.S. Rubin, and U.M. Diwekar, "An Evaluation Method for Integrated Gasification Combined Cycle (IGCC) Power Systems," Paper No. 90-103.6, *Proceedings of the 83rd Annual Meeting* (held June 24-29 in Pittsburgh, PA), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1990.

3. Rubin, E.S., H.C. Frey, and U.M. Diwekar, "Probabilistic Modeling of the Performance and Economics of IGCC Systems," *Integrating Environmental Controls and Energy Production*, Report No. EC-Vol. 2, American Society of Mechanical Engineers, New York, New York, 1991, p. 59-66.

4. Frey, H.C., and E.S. Rubin, "Evaluating Advanced Technologies for Acid Rain Compliance," *Energy in the 90's*, B.F. Hobbs, ed., American Society of Civil Engineers, New York, 1991, p. 172-178.

5. Frey, H.C., and E.S. Rubin, "High Efficiency Integrated Environmental Control for Coal-Based Power Generation," Paper No. 92-108.02, *Proceedings of the 85th Annual Meeting* (held June 21-26 in Kansas City, MO), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1992.

6. Frey, H.C., “Performance Model of the Fluidized Bed Copper Oxide Process for SO_2/NO_x Control,” Paper No. 93-WA-79.01, *Proceedings of the 86th Annual Meeting* (held June 13-18 in Denver, CO), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1993.
7. Frey, H.C., "Separating Variability and Uncertainty in Exposure Assessment: Motivation and Methods," Paper No. 93-RA-116A.02, *Proceedings of the 86th Annual Meeting,* (held June 13-18 in Denver, CO), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1993.
8. Rubin, E.S., M.B. Berkenpas, H.C. Frey, and B. Toole-O'Neil, "Modeling the Uncertainty in Hazardous Air Pollutant Emissions," *Proceedings of the Second International Conference on Managing Hazardous Air Pollutants*, Electric Power Research Institute, Palo Alto, CA, July 1993.
9. Frey, H.C., “Probabilistic Performance, Environmental, and Economic Evaluation of an Advanced Coal Gasification System,” Paper No. 94-TA260.05P, *Proceedings of the 87th Annual Meeting* (held June 19-24 in Cincinnati, OH), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1994.
10. Frey, H.C., “Quantitative Analysis of Uncertainty and Variability in Exposure and Risk Assessment: Some Guidance on Why and How,” Paper No. 94-TP55.03, *Proceedings of the 87th Annual Meeting* (held June 19-24 in Cincinnati, OH), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1994.
11. Diwekar, U.M., E.S. Rubin, and H.C. Frey, “Optimal Design and Synthesis of Advanced Power Systems under Uncertainty,” *Proceedings of the Coal-Fired Power Systems 94— Advances in IGCC and PFBC Review Meeting, Volume 1*, U.S. Department of Energy, Morgantown, West Virginia, June 21-23, 1994, pp. 499-512.
12. Frey, H.C., U.M. Diwekar, and E.S. Rubin, “Probabilistic Modeling of High Efficiency Environmental Control for Advanced Coal Gasification Power Generation,” *Proceedings, 5th Pollution Prevention Topical Conference*, American Institute of Chemical Engineers, New York, 1994.
13. Haimes, Y.Y., T. Barry, and J.H. Lambert (Eds), “When and How Can You Specify a Probability Distribution When You Don't Know Much?,” *Risk Analysis,* 14(5):661-706 (October 1994). Steering Committee Member and Workshop Participant/Contributor (see pp. 703-706).
14. Frey, H.C., and A.C. Cullen, “Distribution Development for Probabilistic Exposure Assessment,” Paper No. 95-42.02, *Proceedings of the 88th Annual Meeting* (held June 18-23 in San Antonio, TX), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1995.
15. Agarwal, P., and H.C. Frey, “Performance Model of the Externally-Fired Combined Cycle (EFCC) System,” Paper No. 95-7.02, *Proceedings of the 88th Annual Meeting* (held June 18-23 in San Antonio, TX), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1995.

16. Frey, H.C., M.D. Kini, S.R. Ranjithan, and S.Y. Fu, "Uncertainty, Bias, and Variability in Emission Factors for Light Duty Gasoline Vehicles," Paper No. 96-108B.03, *Proceedings of the 89th Annual Meeting* (held June 23-28 in Nashville, TN), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1996.

17. Frey, H.C., and P. Agarwal, "Probabilistic Analysis and Optimization of Clean Coal Technologies," Paper No. 96-119.02, *Proceedings of the 89th Annual Meeting* (held June 23-28 in Nashville, TN), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1996.

18. Tran, L.K., and H.C. Frey, "Methods for Evaluating the Costs of Utility NO_X Control Technologies," Paper No. 96-139.06, *Proceedings of the 89th Annual Meeting* (held June 23-28 in Nashville, TN), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1996.

19. Frey, H.C., "Comparison of Classroom and Video-Based Instruction: A Case Study for a Graduate-Level Air Pollution Control Course," Paper No. 96-125.03, *Proceedings of the 89th Annual Meeting* (held June 23-28 in Nashville, TN), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1996.

20. Rubin, E.S., U.M. Diwekar, and H.C. Frey, "Optimizing Advanced Power Systems Design Under Uncertainty," *Proceedings of the Advanced Coal-Fired Power Systems Review Meeting*, U.S. Department of Energy, Morgantown, West Virginia, July 16-18, 1996 (CD- ROM).

21. Frey, H.C., "Bootstrap Methods for Quantitative Analysis of Variability and Uncertainty in Exposure and Risk Assessment," Paper No. 97-RA100B.03, *Proceedings of the 90th Annual Meeting* (held June 18-13 in Toronto, Canada), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1997 (CD-ROM).

22. Frey, H.C., and D.A. Eichenberger, "Quantification of Uncertainty in Remote Sensing-Based School Bus CO and Hydrocarbon Emission Factors," Paper No. 97-RP143.07, *Proceedings of the 90th Annual Meeting* (held June 18-13 in Toronto, Canada), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1997 (CD-ROM).

23. Frey, H.C., and Z. Iwanski, "Probabilistic Methodology for Risk Assessment of New Energy Technologies and Application to Gasification Repowering for an Oil Refinery in Poland," *FLOWERS '97: Florence World Energy Symposium*, SGEditorial: Padova, Italy, 1997, pp. 267-274.

24. Frey, H.C., and R. Bharvirkar, "Desktop Modeling of the Performance, Emissions, and Cost of Gasification Systems," Paper No. 98-RAA.02P, *Proceedings of the 91st Annual Meeting* (held June 14-18 in San Diego, CA), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1998 (CD-ROM).

25. Frey, H.C., "Methods for Quantitative Analysis of Variability and Uncertainty in Hazardous Air Pollutant Emissions," Paper No. 98-RP105B.01, *Proceedings of the 91st Annual Meeting* (held June 14-18 in San Diego, CA), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1998 (CD-ROM).

26. Akunuri, N.V., and H.C. Frey, “Modeling the Performance, Emissions, and Cost of an Entrained-Flow Gasification Combined Cycle System Using ASPEN,” Paper No. 99-379, *Proceedings of the 92nd Annual Meeting* (held June 20-24 in St. Louis, MO), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1999 (CD-ROM).

27. Unal, A., R.H. Dalton, H.C. Frey, and N.M. Rouphail, “Simultaneous Measurement of On-Road Vehicle Emissions and Traffic Flow Using Remote Sensing and an Area-Wide Detector,” Paper No. 99-712, *Proceedings of the 92nd Annual Meeting* (held June 20-24 in St. Louis, MO), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1999 (CD-ROM).

28. Frey, H.C., R. Bharvirkar, and J. Zheng, “Quantification of Variability and Uncertainty in Emission Factors,” Paper No. 99-267, *Proceedings of the 92nd Annual Meeting* (held June 20-24 in St. Louis, MO), Air and Waste Management Association, Pittsburgh, Pennsylvania, June 1999 (CD-ROM).

29. Zheng, J., A. Unal, and H.C. Frey, "Variability and Uncertainty Analysis of CO Exposure to Vehicle Passengers During Cold-Start, Proceedings of 93rd Annual Meeting of the Air & Waste Management Association, Salt Lake City, Utah, June 18-22, 2000.

30. Rouphail, N.M, H.C. Frey, A. Unal, and J.D. Colyar, "Vehicle Emissions and Traffic Measures: Exploratory Analysis of Field Data at Signalized Intersections," Proceedings of 2001 Annual Meeting of the Transportation Research Board, Washington, DC, January 6-12, 2001.

31. Frey, H.C., and J. Zheng, " Quantification of Variability and Uncertainty in Emission Inventories: A Prototype Software Tool with Application to Utility NO_x Emissions," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2001.

32. Coehlo, M., and H.C. Frey, "Evaluation of Alternative Future Energy Scenarios for Brazil Using an Energy Mix Model," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2001.

33. Zheng, J., and H.C. Frey, "Quantitative Analysis of Variability and Uncertainty in Emission Estimation: An Illustration of Methods Using Mixture Distributions," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2001.

34. Bammi, S., and H.C. Frey, " Quantification Of Variability and Uncertainty In Lawn And Garden Equipment NO_x and Total Hydrocarbon Emission Factors," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2001.

35. Frey, H.C., N.M. Rouphail, A. Unal, and J. Colyar, "Measurement of On-Road Tailpipe CO, NO, and Hydrocarbon Emissions Using a Portable Instrument," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2001.

36. Frey, H.C., and S. Li, "Quantification of Variability and Uncertainty in Stationary Natural Gas-fueled Internal Combustion Engine NO_x and Total Organic Compounds Emission Factor," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2001.

37. Li, S., and H.C. Frey, "Methods and Example for Development of a Probabilistic Per-Capita Emission Factor for VOC Emissions from Consumer/Commercial Product Use", *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2002.

38. Abdel-Aziz, A., and H.C. Frey, "Quantification of Variability and Uncertainty in Hourly NOx Emissions from Coal-Fired Power Plants," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2002.

39. Unal, A., and H.C. Frey, "Hot Spot Analysis of Real-World Vehicle Emissions Based Upon a Portable On-Board Measurement System," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2002.

40. Zheng, J., and H.C. Frey, "Development of a Software Module for Statistical Analysis of Variability and Uncertainty," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2002.

41. Unal, A., N.M. Rouphail, and H.C. Frey, "Effect of Arterial Signalization and Level of Service on Measured Vehicle Emissions," TRB Paper No. 03-2884, Proceedings, 82nd Annual Meeting of the Transportation Research Board, Washington, DC, January 12-16, 2003.

42. Zhao, Y., and H.C. Frey, "Quantification of Uncertainty and Variability for Air Toxic Emission Factor Data Sets Containing Non-Detects," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2003.

43. Abdel-Aziz, A. and H.C. Frey, "Quantification of Hourly Variability in Hourly Activity and NO_x Emissions for Baseload Coal-Fired Power Plants," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2003.

44. Frey, H.C., A. Unal, J. Chen, and S. Li, "Modeling Mobile Source Emissions Based Upon In- Use and Second-by-Second Data: Development of Conceptual Approaches for EPA's New MOVES Model," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2003.

45. Zheng, J., and H.C. Frey, "Windows-Based Software Implementation and Uncertainty Analysis of the EPA SHEDS/Pesticides Model," *Proceedings, Annual Meeting of the Air & Waste Management Association*, Pittsburgh, PA, June 2003.

46. Zhao, Y., and H.C. Frey, "Development of Probabilistic Emission Inventory of Air Toxics for Jacksonville, FL," *Proceedings, Annual Meeting of the Air & Waste Management Association*, June 22-25, 2004, Indianapolis, IN, published by Air & Waste Management Association, Pittsburgh, PA, June 2004.

47. Hanna, A., J. Vukovich, S. Arunachalam, D. Loughlin, H.C. Frey, J. Touma, J. Irwin, and V. Isakov, "Assessment of Uncertainty in Benzene Concentration Estimates in the Houston, TX, Area," *Proceedings, Annual Meeting of the Air & Waste Management Association*, June 22-25, 2004, Indianapolis, IN, published by Air & Waste Management Association, Pittsburgh, PA, June 2004.

48. Hanna, S.R., D. Heinold, R. Paine, H.C. Frey, D. Baker, R. Karp, and H. Feldman, "A Monte Carlo Study of the Uncertainties in Predictions by ISC3ST and AERMOD of Annual Average Benzene and 1,3-Butadiene Concentrations around the Houston Ship Channel," *Proceedings, Annual Meeting of the Air & Waste Management Association*, June 22-25, 2004Indianapolis, IN, published by Air & Waste Management Association, Pittsburgh, PA, June 2004.

49. Frey, H.C., and K. Kim, "In-Use Emissions of Heavy-Duty Diesel Dump Trucks on Petroleum Diesel and B20 Biodiesel Fuels," *Proceedings, Annual Meeting of the Air & Waste Management Association*, June 20-23, 2005, Minneapolis, MN.

50. Zhang, K., and H.C. Frey, "Road Grade Estimation for On-Road Vehicle Emissions Modeling Using LIDAR Data," *Proceedings, Annual Meeting of the Air & Waste Management Association*, June 20-23, 2005, Minneapolis, MN.

51. Phillips, L.A., and H.C. Frey, "Analysis of Current Risk Perception of Indoor Air Quality," *Proceedings, Annual Meeting of the Air & Waste Management Association*, June 20-23, 2005, Minneapolis, MN.

52. Frey, H.C., and K. Kim, "Comparison of Real-World Fuel Use and Emissions for Dump Trucks Fueled with B20 Biodiesel Versus Petroleum Diesel," Paper 06-1078, 2006 Annual Meeting of the Transportation Research Board, Washington, DC, January 2006.

53. Frey, H.C., N.M. Rouphail, and H. Zhai, "Speed- and Facility-Specific Emission Estimates for On-Road Light-Duty Vehicles based on Real-World Speed Profiles," Paper 06-1096, 2006 Annual Meeting of the Transportation Research Board, Washington, DC, January 2006.

54. Kim, K., S. Abolhasani, S.H. Pang, and H.C. Frey, "Real-world Data Collection Procedure for Non-road Construction Equipment: Problems, Solutions, and Data Quality Assurance," Paper No. 548, Proceedings, Annual Meeting of the Air & Waste Management Association, New Orleans, LA, June 20-23, 2006.

55. Zhai, H., H.C. Frey, and N.M. Rouphail, "Speed- and Facility-Specific Emissions Estimates for Transit Buses based on Measured Speed Profiles," Paper No. 195, Proceedings, Annual Meeting of the Air & Waste Management Association, New Orleans, LA, June 20-23, 2006

56. Frey, H.C., "Incorporating Risk and Uncertainty into the Assessment of Impacts of Global Climate Change on Transportation Systems," Proceedings, 2nd Workshop on Impacts of Global Climate Change On Hydraulics and Hydrology and Transportation, Center for Transportation and the Environment, NC State, held in Washington, DC, March 29, 2006.

57. Rouphail, N.M., H.C. Frey, and H. Zhai, "Measuring the Effect of Level of Service on Vehicle Emissions," Fifth International Symposium on Highway Capacity and Quality of Service, Transportation Research Board, Yokohama, Japan, July 25-29, 2006.

58. Rouphail, N.M, and H.C. Frey, "Advances in Measuring and Modeling Traffic Impacts on Vehicle Emissions: An Overview," Proceedings, Seventh International Congress on Advances in Civil Engineering, Yildiz Technical University, Istanbul, Turkey, October 11-13, 2006.

59. Zhai, H., H.C. Frey, N.M. Rouphail, G.A. Gonçalves, and T.L. Farias, "Fuel Consumption and Emissions Comparisons between Ethanol 85 and Gasoline Fuels for Flexible Fuel Vehicles," Paper No. 2007-AWMA-444, Proceedings, 100th Annual Meeting of the Air & Waste Management Association, Pittsburgh, PA, June 26-28, 2007.

60. Frey, H.C., and K. Zhang, "Spatial and Temporal Analysis of Real-World Empirical Fuel Use and Emissions," Paper No. 2007-AWMA-285, Proceedings, 100th Annual Meeting of the Air & Waste Management Association, Pittsburgh, PA, June 26-28, 2007.

61. Frey, H.C., and P.Y. Kuo, "Potential Best Practices for Reducing Greenhouse Gas (GHG) Emissions in Freight Transportation," Paper No. 2007-AWMA-443, Proceedings, 100th Annual Meeting of the Air & Waste Management Association, Pittsburgh, PA, June 26-28, 2007.

62. Frey, H.C., W. Rasdorf, S.-H. Pang, K. Kim, S. Abolhasani, and P. Lewis, "Methodology for Activity, Fuel Use, and Emissions Data Collection and Analysis for Nonroad Construction Equipment," Paper No. 2007-AWMA-447, Proceedings, 100th Annual Meeting of the Air & Waste Management Association, Pittsburgh, PA, June 26-28, 2007.

63. Zhai, H., H.C. Frey, and N.M. Rouphail, "Impact of Alternative Vehicle Technologies on Vehicle Emissions," Transportation Land Use, Planning, and Air Quality 2007, Orlando, FL, July 9-11, 2007.

64. Zheng, J., and H.C. Frey, "Treatment of Censored Data and Dependency Among Sampling Distributions in Probabilistic Human Health Exposure Assessment," in *Advances in Studies on Risk Analysis and Crisis Response*, C. Huang, C. Frey, and J. Feng, eds., Atlantis Press: Paris, France, 2007, pp. 802-808. (Proceedings of 1st International Conference on Risk Assessment and Crisis Response, Shanghai, China, September 25-26, 2007).

65. Frey, H.C., W.J. Rasdorf, K. Kim, S.H. Pang, P. Lewis, "Comparison of Real-World Emissions of Backhoes, Front-End Loaders and Motor Graders for B20 Biodiesel vs. Petroleum Diesel for Selected Engine Tiers," Proceedings, 87th Annual Meeting of the Transportation Research Board, January 13-17, 2008.

66. Frey, H.C., P.Y. Kuo, and C. Villa, "Methodology for Characterization of Long-Haul Truck Idling Activity under Real-World Conditions," Proceedings, 87th Annual Meeting of the Transportation Research Board, January 13-17, 2008.

67. Frey, H.C., N.M. Rouphail, and H. Zhai, "Link-Based Emission Factors for Heavy-Duty Diesel Trucks Based on Real-World Data," Proceedings, 87th Annual Meeting of the Transportation Research Board, January 13-17, 2008.

68. Frey, H.C., W. Rasdorf, S.-H. Pang, K. Kim, S. Abolhasani, and P. Lewis, "Vehicle-Specific Emissions Modeling For Non-Road Construction Vehicles Based Upon Real-World Measurements," Paper No. 569, Proceedings, 101st Annual Meeting of the Air & Waste Management Association, Portland, OR, June 24-27, 2008.

69. Frey, H.C., Kim, S. Pang, W. Rasdorf, P. Lewis, "Characterization of Real-World Activity, Fuel Use and Emissions for Selected Motor Graders Fueled with Petroleum Diesel and B20 Biodiesel," Paper No. 607, Proceedings, 101st Annual Meeting of the Air & Waste Management Association, Portland, OR, June 24-27, 2008.

70. Frey, H.C., P.Y. Kuo, and C. Villa, "Measurement and Modeling of Fuel Use and Exhaust Emissions from Idling Long-Haul Freight Truck and Auxiliary Power Unit Engines," Paper No. 616, Proceedings, 101st Annual Meeting of the Air & Waste Management Association, Portland, OR, June 24-27, 2008.

71. Frey, H.C., and H.W. Choi, "Estimating Light Duty Gasoline Vehicle Emission Factors at High Transient and Constant Speeds for Short Road Segments to Support Near-Roadway Air Quality Studies ," Paper No. 625, Proceedings, 101st Annual Meeting of the Air & Waste Management Association, Portland, OR, June 24-27, 2008.

72. Frey, H.C., H. Zhai, N. Rouphail, G. Gonçalves, T. Farias, "Fuel Consumption and Tailpipe Emissions Comparisons between Ethanol 85 and Gasoline Fuels for Flexible Fuel Vehicles," Paper No. 637, Proceedings, 101st Annual Meeting of the Air & Waste Management Association, Portland, OR, June 24-27, 2008.

73. Lewis, P., H.C. Frey, W.J. Rasdorf, "Development and Use of Emissions Inventories for Construction Vehicles," *Proceedings, 88th Annual Meeting of the Transportation Research Board*, to be held January 2009.

74. Frey, H.C., H. Zhai, and N.M. Rouphail, "Regional On-Road Vehicle Running Emissions Modeling and Evaluation for Conventional and Alternative Vehicle Technologies, *Proceedings, 88th Annual Meeting of the Transportation Research Board*, to be held January 2009.

75. Deshpande, B., H.C. Frey, Y. Cao, and Z. Liu, "Modeling of the Penetration of Ambient $PM_{2.5}$ to Indoor Residential Microenvironment," Paper 2009-A-86-AWMA, *Proceedings, 102nd Annual Conference and Exhibition*, Air & Waste Management Association, Detroit, Michigan, June 16-19, 2009.

76. Frey, H.C., and B. Hubbell, "A Risk-based Assessment And Management Framework For Multipollutant Air Quality," Paper 2009-A-235-AWMA, *Proceedings, 102nd Annual Conference and Exhibition*, Air & Waste Management Association, Detroit, Michigan, June 16-19, 2009.

77. Liu, Z., H.C. Frey, Y. Cao, and B. Deshpande, "Modeling of In-vehicle $PM_{2.5}$ Exposure Using the Stochastic Human Exposure and Dose Simulation Model," Paper 2009-A-238-

AWMA, *Proceedings, 102nd Annual Conference and Exhibition*, Air & Waste Management Association, Detroit, Michigan, June 16-19, 2009.

78. Cao, Y., H.C. Frey, Z. Liu, and B. Deshpande, "Evaluation of the Modeling of Exposure to Environmental Tobacco Smoke (ETS) in the SHEDS-PM Model," Paper 2009-A-239-AWMA, *Proceedings*, *102nd Annual Conference and Exhibition*, Air & Waste Management Association, Detroit, Michigan, June 16-19, 2009.

79. Frey, H.C., H.W. Choi, E. Pritchard, and J. Lawrence, "In-Use Measurement of the Activity, Energy Use, and Emissions of a Plug-in Hybrid Electric Vehicle," Paper 2009-A-242-AWMA, *Proceedings, 102nd Annual Conference and Exhibition,* Air & Waste Management Association, Detroit, Michigan, June 16-19, 2009.

80. Frey, H.C., H.W. Choi, and K. Kim, "Measurement of the Energy Use and Emissions of Passenger Rail Locomotives Using a Portable Emission Measurement System," Paper 2009-A-243-AWMA, *Proceedings*, *102nd Annual Conference and Exhibition*, Air & Waste Management Association, Detroit, Michigan, June 16-19, 2009.

81. Graver, B., and H.C. Frey, "Estimation of Air Carrier Emissions at Raleigh-Durham International Airport," Paper 2009-A-486-AWMA, *Proceedings, 102nd Annual Conference and Exhibition,* Air & Waste Management Association, Detroit, Michigan, June 16-19, 2009.

82. Choi, H.W., and H.C. Frey, "Estimating Diesel Vehicle Emission Factors at Constant and High Speeds for Short Road Segments," Paper 10-0382, *Proceedings, 89th Annual Meeting of the Transportation Research Board*, January 2009. (Submitted 7/13/09, in review).

83. Graver, B., and H.C. Frey, "Estimation of Per Seat and Per Passenger Air Carrier Emissions at Raleigh-Durham International Airport," Paper TRB 10-1417, *Proceedings, 89th Annual Meeting of the Transportation Research Board*, January 2010 (submitted 7/29/09, in review).

84. Frey, H.C., W. Rasdorf, P. Lewis, "Results of a Comprehensive Study of Fuel Use and Emissions of Nonroad Diesel Construction Equipment," Paper TRB 10-2763, *Proceedings, 89th Annual Meeting of the Transportation Research Board*, January 2010 (submitted 7/31/09, in review).

85. Coelho, M.C., J. Andrade, D. Soares, H.C. Frey, and N.M. Rouphail, "A Vehicle Energy Use and Safety Information Support System," Paper TRB 10-3034, *Proceedings, 89th Annual Meeting of the Transportation Research Board*, January 2010 (submitted 8/1/09, in review).

86. Liu, X., H.C. Frey, and Y. Cao, "Estimation of In-Vehicle Concentration and Human Exposure for PM2.5 Based on Near Roadway Ambient Air Quality and Variability in Vehicle Operation," Paper TRB 10-3564, *Proceedings, 89th Annual Meeting of the Transportation Research Board*, January 2010 (submitted 8/1/09, revised and resubmitted October 2009).

87. Liu, X., Y. Cao, and H.C. Frey, "Quantifying Human Exposure to Fine Particulate Matter Inside a Vehicle," Paper 2010-A-975-AWMA, Proceedings, *103rd Annual Conference and Exhibition*, Air & Waste Management Association, Calgary, Canada, June 2010.

88. Frey, H.C., H.W. Choi, B.M. Graver, and G.S. Sandhu, "Comparative Assessment of Passenger Railroad Locomotives Using Portable Emission Measurement Systems," Paper 2010-A-970-AWMA, *Proceedings, 103rd Annual Conference and Exhibition*, Air & Waste Management Association, Calgary, Canada, June 2010.

89. B.M. Graver, and H.C. Frey, Quantifying the Microscale Activity, Energy Use, and Emissions of a Plug-In Hybrid Electric Vehicle Based on In-Use Data," Paper 2010-A-946-AWMA, *Proceedings, 103rd Annual Conference and Exhibition*, Air & Waste Management Association, Calgary, Canada, June 2010.

90. Lewis, P., M. Leming, H.C. Frey, and W. Rasdorf, "Assessing the Effects of Operational Efficiency on Pollutant Emissions of Nonroad Diesel Construction Equipment," TRB 11-3186, *Proceedings, 90th Annual Meeting of the Transportation Research Board*, January 2011(submitted 8/1/10, accepted for presentation).

91. Zhai, H., H.C. Frey, and N.M. Rouphail, "Development of A Modal Emissions Model for A Hybrid Electric Vehicle," TRB 11-1190, Annual Meeting of the Transportation Research Board, January 2011(submitted 8/1/10, accepted for presentation).

92. Frey, H.C., G. Sandhu, Y. Sun, T. Lee, H. Swidan, B. Liu, and S. Babaee, "Incorporating Vehicle Portable Emissions Measurement Systems Into the Classroom," 2011-A-146-AWMA, Proceedings, 104th Annual Meeting of the Air & Waste Management Association, Orlando, FL, June 21-24, 2011.

93. Jiao, W., and H.C. Frey, "Inter-individual, Geographic, and Seasonal Variability in Human Exposure to Fine Particulate Matter," 2011-A-176-AWMA, Proceedings, 104th Annual Meeting of the Air & Waste Management Association, Orlando, FL, June 21-24, 2011.

94. Sun, Y., and H.C. Frey, "Comparison of Real-world Activity, Fuel Use, and Emissions for Selected Light Duty Gasoline Vehicles Based on Driving Cycles," 2011-A-306-AWMA, Proceedings, 104th Annual Meeting of the Air & Waste Management Association, Orlando, FL, June 21-24, 2011.

95. Lee, T., and H.C. Frey, "Variability in Gram Per Gallon Vehicle Emission Factors With Engine Load and Among Driving Cycles," 2011-A-328-AWMA, Proceedings, 104th Annual Meeting of the Air & Waste Management Association, Orlando, FL, June 21-24, 2011.

96. Liu, X., and H.C. Frey, "Apportionment of Human Exposure to Fine Particulate Matter Among Indoor and Outdoor Emission Sources and Processes," 2011-A-365-AWMA, Proceedings, 104th Annual Meeting of the Air & Waste Management Association, Orlando, FL, June 21-24, 2011.

97. Graver, B.M., and H.C. Frey, "Fuel Use and Emission Rates for F59PH Locomotive Engines Tested on an Engine Dynamometer," 2011-A-586-AWMA, Proceedings, 104th Annual Meeting of the Air & Waste Management Association, Orlando, FL, June 21-24, 2011.

98. Graver, B.M., and H.C. Frey, "Modeling of Hybrid and Plug-In Hybrid Electric Vehicle Energy Use and Emissions Based on In-Use Measurement," 2011-A-590-AWMA, Proceedings, 104th Annual Meeting of the Air & Waste Management Association, Orlando, FL, June 21-24, 2011.

99. Liu, B., and H.C. Frey, "Comparison of Driving Schedule Project Level MOVES Emission Factors to Empirical Data," 2011-A-645-AWMA, Proceedings, 104th Annual Meeting of the Air & Waste Management Association, Orlando, FL, June 21-24, 2011.

100. Frey, H.C., and S. Pierce, "Comparison of the Performance, Emissions, and Cost of Fossil-Fuel Combustion and Gasification Based "Zero Emissions" Power Plant Designs," 2011-A-646-AWMA, Proceedings, 104th Annual Meeting of the Air & Waste Management Association, Orlando, FL, June 21-24, 2011.

101. Frey, H.C., H.W. Choi, and K. Kim, "Measurement of Emissions of Passenger Rail Locomotives Using a Portable Emissions Measurement System," 12-0739, Proceedings, Annual Meeting, Transportation Research Board, Washington, DC, January 2011.

102. Sandhu, G.S., and H.C. Frey, "Real-World Measurement and Evaluation of Heavy Duty Truck Duty Cycles, Fuels, and Emission Control Technologies," 12-4674, Proceedings, Annual Meeting, Transportation Research Board, Washington, DC, January 2011.

103. Lewis, P., W. Rasdorf, M. Leming, and H.C. Frey, "Effects of Engine Idling on NAAQS Criteria Pollutant Emissions from Nonroad Diesel Construction Equipment," 12-0219, Proceedings, Annual Meeting, Transportation Research Board, Washington, DC, January 2011.

Conference Proceedings (other):

1. Frey, H.C., E.S. Rubin, and J.S. Salmento, "Evaluation of the Fluidized Bed Copper Oxide Process Using A Probabilistic Engineering Model," *Proceedings of the Sixth Annual International Pittsburgh Coal Conference*, University of Pittsburgh, Pittsburgh, Pennsylvania, 1989, pp. 356-365.

2. Diwekar, U.M., E.S. Rubin, and H.C. Frey, "Stochastic Modeling of Integrated Coal Gasification Combined Cycle Systems Using ASPEN," *Proceedings of the Sixth Annual International Pittsburgh Coal Conference*, University of Pittsburgh, Pittsburgh, Pennsylvania, 1989, pp. 837-846.

3. Rubin, E.S., J.S. Salmento, and H.C. Frey, "Development and Application of the Integrated Environmental Control Model," *Proceedings, Sixth Annual Coal Preparation, Utilization, and Environmental Control Contractors Conference*, Pittsburgh Energy Technology Center, U.S. Department of Energy, Pittsburgh, Pennsylvania, August 1990, pp. 375-382.

4. Frey, H.C., E.S. Rubin, and U.M. Diwekar, "Modeling Uncertainties in IGCC System Performance and Cost," *Proceedings of the Seventh Annual International Pittsburgh Coal Conference,* University of Pittsburgh, Pittsburgh, Pennsylvania, 1990, pp. 805-814.

5. Diwekar, U.M., H.C. Frey, and E.S. Rubin, æStochastic Modeling of Chemical Processes," Paper 216e presented at the American Institute of Chemical Engineers 1990 Annual Meeting, Chicago, Illinois, November 11-16, 1990.

6. Rubin, E.S., H.C. Frey, and U.M. Diwekar, "Characterizing Uncertainties in IGCC System Performance and Cost," *Proceedings of the Eleventh Annual Gasification and Gas Stream Cleanup Systems Contractors Review Meeting, Volume 1*, DOE/METC-91/6123 (DE92001101), U.S. Department of Energy, Morgantown, West Virginia, August 1991, pp. 66-75.

7. Frey, H.C., and E.S. Rubin, "Modeling IGCC Performance, Emissions, and Cost Using Probabilistic Engineering Models," *Proceedings of the Eighth Annual International Pittsburgh Coal Conference*, University of Pittsburgh, Pittsburgh, Pennsylvania, October, 1991.

8. Frey, H.C., E.S. Rubin, and U.M. Diwekar, "Process Modeling of Advanced Technologies Under Uncertainty," Paper No. 58a presented at the American Institute of Chemical Engineers 1992 Spring National Meeting, New Orleans, Louisiana, March 29 - April 2, 1992.

9. Frey, H.C., and E.S. Rubin, "Evaluate Uncertainties in Advanced Process Technologies," *Chemical Engineering Progress*, 88(5):63-70 (May 1992).

10. Rubin, E.S., H.C. Frey, and M.B. Berkenpas, "Development of the Integrated Environmental Control Model," *Proceedings, Eighth Annual Coal Preparation, Utilization, and Environmental Control Contractor's Conference*, Pittsburgh Energy Technology Center, U.S. Department of Energy, Pittsburgh, Pennsylvania, July 27-30, 1992, pp. 619-626.

11. Frey, H.C., "Quantitative Analysis of Uncertainty and Variability in Environmental Policy Making," *1992 Environmental Science and Engineering Fellows Program Reports*, American Association for the Advancement of Science, Washington, DC, 1993, pp. 25-33.

12. Berkenpas, M.B., E.S. Rubin, H.C. Frey, and B. Toole-O'Neil, "Modeling Air Toxics Emissions From Electric Power Plants," *Proceedings of the 1993 AWMA/EPRI/ASME International Symposium on Integrated Energy and Environmental Management*, Air and Waste Management Association, Pittsburgh, PA, March 1993, pp. 275-285.

13. Rubin, E.S., M.B. Berkenpas, and H.C. Frey, "Development of the Integrated Environmental Control Model," *Proceedings, Ninth Annual Coal Preparation, Utilization, and Environmental Control Contractor's Conference*, Pittsburgh Energy Technology Center, U.S. Department of Energy, Pittsburgh, Pennsylvania, July 19-22, 1993, pp. 447-454.

14. Shih, J.S, and H.C. Frey, "Coal Blending Optimization Under Uncertainty," *Proceedings of the Tenth Annual International Pittsburgh Coal Conference*, University of Pittsburgh, Pittsburgh, Pennsylvania, September, 1993, pp. 1110-1115.

15. Frey, H.C., "Economic Model of the Fluidized Bed Copper Oxide Process for SO_2/NO_x Control," *Proceedings of the Tenth Annual International Pittsburgh Coal Conference*, University of Pittsburgh, Pittsburgh, Pennsylvania, September, 1993, pp. 597-602.

16. Frey, H.C., “Engineering-Economic Evaluation of SCR NO_X Control Systems for Coal-Fired Power Plants,” *Proceedings of the American Power Conference, Vol. 57-II*, Illinois Institute of Technology, Chicago, Illinois, April 1995, pp. 1583-1588.

17. Diwekar, U.M, E.S. Rubin, and H.C. Frey, “Optimization of Environmental Control System Design for an IGCC Power Plant,” *Proceedings of the American Power Conference, Vol. 58- I*, Illinois Institute of Technology, Chicago, Illinois, April 1996, pp. 58-63.

18. Frey, H.C., and P. Agarwal, “Probabilistic Analysis and Optimization of New Power Generation Technologies: A Case Study for the Externally-Fired Combined Cycle,” *Proceedings of the American Power Conference*, *Vol. 58-I*, Illinois Institute of Technology, Chicago, Illinois, April 1996, pp. 52-57.

19. Diwekar, U.M., E.S. Rubin and H.C. Frey, “Optimal Design of Advanced Power Systems Under Uncertainty,” *Proceedings of ECOS '96 International Symposium—Efficiency, Costs, Optimization, Simulation, and Environmental Aspects of Energy Systems*, Royal Institute of Technology, Stockholm, Sweden, June 1996.

20. Frey, H.C., and Z. Iwanski, “Probabilistic Modeling of Gasification Repowering for an Oil Refinery in Poland,” *Conference Proceedings, POWER-GEN ‘97 Europe, Volume III* (held June 17-19 in Madrid, Spain), Pennwell: The Netherlands, June 1997, pp. 417-435.

21. Frey, H.C., and Z. Iwanski, “Methods for Characterizing and Managing Technological Risks in Advanced Power Generation Systems: Application to Gasification Repowering in Poland,” in *1997 Gasification Technologies Conference* (held October 5-8 in San Francisco, CA), EV- 107922, Electric Power Research Institute, Palo Alto, California, October 1997.

22. Rhodes, D.S., and H.C. Frey, “Quantification of Variability and Uncertainty in AP-42 Emission Factors Using Bootstrap Simulation,” *Emission Inventory: Planning for the Future* (held October 28-30 in Research Triangle Park, NC), Air and Waste Management Association, Pittsburgh, Pennsylvania, October 1997, pp. 147-161.

23. Frey, H.C., “Variability and Uncertainty in Highway Vehicle Emission Factors,” *Emission Inventory: Planning for the Future* (held October 28-30 in Research Triangle Park, NC), Air and Waste Management Association, Pittsburgh, Pennsylvania, October 1997, pp. 208-219.

24. Frey, H.C., R. Bharvirkar, R. Thompson, and S. Bromberg, “Quantification of Variability and Uncertainty in Emission Factors and Inventories,” Conference on the Emission Inventory, Air and Waste Management Association, Pittsburgh, Pennsylvania, December 1998.

25. Frey, H.C., M.A. Barlaz, M. Pickett, and S. Vaswani, "New Methods for Assessment of Pollution Prevention Technologies: Integration of Probabilistic Process Modeling and Design; Life Cycle Analysis; and Regional Environmental Benefits Assessment," Proceedings of the NSF Design and Manufacturing Research Conference, Vancouver, Canada, January 3-6, 2000.

26. Frey, H.C., N. Rouphail, A. Unal, and J. Colyar, "Emissions and Traffic Control: An Empirical Approach," Presented at CRC On-Road Vehicle Emissions Workshop, San Diego, CA, March 27-29, 2000.

27. Frey, H.C., M.A. Barlaz, M. Pickett, and S. Vaswani, C. Xie, and M. Li, "New Methods for Assessment of Pollution Prevention Technologies: Integration of Probabilistic Process Modeling and Design; Life Cycle Analysis; and Regional Environmental Benefits Assessment," Proceedings of the NSF Design, Manufacturing, and Industrial Innovation Research Conference, Tampa, FL, January 7-10, 2001.

28. Frey, H.C., M.A. Barlaz, M. Li, and C. Xie, "New Methods for Assessment of Pollution Prevention Technologies: Integration of Probabilistic Process Modeling and Design; Life Cycle Analysis; and Regional Environmental Benefits Assessment," Proceedings of the NSF Design, Manufacturing, and Industrial Innovation Research Conference, San Juan, Puerto Rico, January, 2002.

29. Hanna, S.R., J. Wilkinson, A. Russell, J. Vukovich, H.C. Frey, "Estimating Uncertainties of Air Quality Modeling Systems Using Monte Carlo Approaches," *Proceedings, AMS Norfolk Conference,* Norfolk, VA, May 2002.

30. Frey, H.C. and J. Zheng, "Method for Development of Probabilistic Emission Inventories: Example Case Study for Utility NO_X Emissions," *Proceedings, U.S. Environmental Protection Agency Emission Inventory Conference*, Atlanta, GA, April 2002.

31. Frey, H.C. and Y. Zhao, "Quantification of Variability and Uncertainty in Air Toxic Emission Factors When Data Contains Non-Detected Values, " *Proceedings, U.S. Environmental Protection Agency Emission Inventory Conference*, Atlanta, GA, April 2002.

32. Frey, H.C., and S. Bammi, "Quantification of Variability and Uncertainty for Selected Nonroad Mobile Source Emission Factors," *Proceedings, U.S. Environmental Protection Agency Emission Inventory Conference*, Atlanta, GA, April 2002.

33. Frey, H.C., A. Unal, N.M. Rouphail, and J.D. Colyar, "Use of Onboard Tailpipe Emissions Measurements for Development of Mobile Source Emission Factors," *Proceedings, U.S. Environmental Protection Agency Emission Inventory Conference*, Atlanta, GA, April 2002.

34. Frey, H.C., and S. Li, "Methods for Quantifying Variability and Uncertainty in AP-42 Emission Factors: Case Studies for Natural Gas-Fueled Engines," *Proceedings, U.S. Environmental Protection Agency Emission Inventory Conference*, Atlanta, GA, April 2002.

35. Frey, H.C., M.A. Barlaz, and M. Li, "New Methods for Assessment of Pollution Prevention Technologies," Proceedings of the NSF Design, Manufacturing, and Industrial Innovation Research Conference, Birmingham, AL, January, 2003.

36. Frey, H.C., A. Unal, and J. Chen, "Evaluation and Recommendation of a Modal Method for Modeling Vehicle Emissions," *Proceedings, U.S. Environmental Protection Agency Emission Inventory Conference*, San Diego, CA, April 2003.

37. Houyoux, M., D.H. Loughlin, A.P. Holland, H.C. Frey, and A. Abdel-Aziz, "Design, Application, and Recommendations for Including Inventory Uncertainties in Emission Inventory Preparation for Modeling," *Proceedings, U.S. Environmental Protection Agency Emission Inventory Conference*, San Diego, CA, April 2003.

38. Frey, H.C., N.M. Rouphail, and K. Kim, "Operational Evaluation of In-Use Emissions and Fuel Consumption of B20 versus Diesel-Fueled Heavy Duty Vehicles," *Proceedings, On-Road Vehicle Emissions Workshop*, held March 29-31, 2004, San Diego, CA, published by Coordinating Research Council, Atlanta, GA.

39. Frey, H.C., and Y. Zhao, "Development of Probabilistic Emission Inventories of Air Toxics for an Urban Area," *Proceedings, U.S. Environmental Protection Agency Emission Inventory Conference*, Clearwater, FL, June 2004.

40. Frey, H.C., and K. Zhang, "Implications of Measured In-Use Light Duty Gasoline Vehicle Emissions for Emission Inventory Development at High Spatial and Temporal Resolution," Proceedings, International Emission Inventory Conference, U.S. Environmental Protection Agency, Raleigh, NC, May 15-17, 2007.

41. Frey, H.C., and P.Y. Kuo, "Assessment of Potential Reduction in Greenhouse Gas (GHG) Emissions in Freight Transportation," Proceedings, International Emission Inventory Conference, U.S. Environmental Protection Agency, Raleigh, NC, May 15-17, 2007.

42. Frey, H.C., W.J. Rasdorf, S.H. Pang, K. Kim, and P. Lewis, "Methods for Measurement and Analysis of In-Use Emissions of Nonroad Construction Equipment," Proceedings, International Emission Inventory Conference, U.S. Environmental Protection Agency, Raleigh, NC, May 15-17, 2007.

43. Frey, H.C., "Methods for and Examples of Quantification of Uncertainty in Emission Factors and Inventories," Proceedings, International Emission Inventory Conference, U.S. Environmental Protection Agency, Raleigh, NC, May 15-17, 2007.

44. Coehlo, M., D.S. Soares, H.C. Frey, "Energy use and greenhouse gases emissions in vehicles: Contrasting alternative fuels, propulsion systems and market policies in Portugal and USA," Conference on Rethinking Transportation, Louisville, KY, October 2008

45. Rouphail, N.M., H. Zhai, H.C. Frey, and B. Graver, "Impact of Alternative Vehicle Technologies and Land Use Patterns on Long-Term Regional On-Road Vehicle Emissions," 12^{th} World Congress on Transportation Research, Lisbon, Portugal, July 11-15, 2010.

Technical Reports

1. Rubin, E.S., J.S. Salmento, J.G. Barrett, C.N. Bloyd, and H.C. Frey, *Modeling and Assessment of Advanced Processes for Integrated Environmental Control of Coal-Fired Power Plants*, NTIS DE86014713, Prepared by Carnegie-Mellon University for the U.S. Department of Energy, Pittsburgh, Pennsylvania, July 1986.

2. Frey, H.C., *Performance and Economic Model of the Fluidized Bed Copper Oxide Process*, Master's Report, Department of Mechanical Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania, May 1987.

3. May, P.A., and H.C. Frey, *Evaluation of* NO_X *Emission Controls for Load-Following Cogeneration Facilities*, Prepared by Radian Corporation for New Jersey Department of Environmental Protection, New Jersey, July 1987.

4. Radian Corporation, *Technical Support for Proposed Prevention of Significant Deterioration Rule for Nitrogen Oxides*, Volumes 1 and 2., Prepared by Radian Corporation for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, February 1, 1988 (Contributing author). (These documents received both peer review and public review as part of a regulatory rule-making process)

5. Frey, H.C., and C.W. Stackhouse, Jr., "Cost and Cost Effectiveness of Electrostatic Precipitators Applied to Very Low Sulfur Oil-Fired Boilers to Achieve Lower Particulate Matter Emissions," Technical Memorandum from Radian Corporation to W.H. Maxwell, Emissions Standards and Engineering Division, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 9, 1988 (Technical Memoranda are reviewed by EPA)

6. Frey, H.C., J.A. Martinez, and E.F. Aul, "Modifications to Venturi Scrubber Cost Algorithm for Application to Small Coal- and Wood-Fired Boilers," Technical Memorandum from Radian Corporation to W.H. Maxwell, Emissions Standards and Engineering Division, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 11, 1988 (Technical Memoranda are reviewed by EPA)

7. Frey, H.C., and J.T. Waddell, "State Permitting Practices for Particulate Matter Emissions from Small Coal- and Wood-Fired Boilers," Technical Memorandum from Radian Corporation to R.A. Copeland, Emissions Standards and Engineering Division, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 7, 1988. (Technical Memoranda are reviewed by EPA)

8. Abadines, E., *et al*., *Catastrophic Oil Spills on the Great Lakes*, Final Report, Department of Engineering and Public Policy, School of Urban and Public Affairs, and Department of Social and Decision Sciences, Carnegie-Mellon University, Pittsburgh, Pennsylvania, December 1989, 143p. (Reviewed by a panel of outside experts)

9. Piccot, S.D., J.A. Buzun, and H.C. Frey, *Emissions and Cost Estimates for Globally Significant Anthropogenic Combustion Sources of* NO_X, N_2O, CH_4, *CO, and* CO_2, EPA/600/7-90-010, Prepared by Radian Corporation for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1990. (This report was reviewed by EPA)

10. Frey, H.C. and E.S. Rubin, *Stochastic Modeling of Coal Gasification Combined Cycle Systems: Cost Models of Selected Integrated Gasification Combined Cycle (IGCC) Systems*,

Topical Report, DOE/MC/24248-2901, NTIS DE90015345, Prepared by Carnegie-Mellon University for the U.S. Department of Energy, Morgantown, West Virginia, June 1990, 307p. (Reviewed by several personnel at the U.S. Department of Energy)

11. Rubin, E.S., J.S. Salmento, H.C. Frey, A. Abu-Baker, and M. Berkenpas, *Modeling of Integrated Environmental Control Systems for Coal-Fired Power Plants*, Final Report, DOE Contract No. DE- AC22-87PC79864, Prepared by Carnegie-Mellon University for the U.S. Department of Energy, Pittsburgh, Pennsylvania, April 1991, 214p.

12. Frey, H.C., and E.S. Rubin, *Development and Application of a Probabilistic Evaluation Method for Advanced Process Technologies*, Final Report, DOE/MC/24248-3015, NTIS DE91002095, Prepared by Carnegie-Mellon University for the U.S. Department of Energy, Morgantown, West Virginia, April 1991, 364p.

13. Frey, H.C., *Probabilistic Modeling of Innovative Clean Coal Technologies: Implications for Research Planning and Technology Evaluation*, Ph.D. Thesis, Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, Pennsylvania, May 1991.

14. Frey, H.C., *Quantitative Analysis of Uncertainty and Variability in Environmental Policy Making*, Environmental Science and Engineering Fellows Program, American Association for the Advancement of Science, Washington, DC, September 1992.

15. Frey, H.C., and E.S. Rubin, *Development of the Integrated Environmental Control Model: Performance Models of Selective Catalytic Reduction* NO_X *Control Systems*, Quarterly Progress Report, DOE/PC/91346--3, Contract No. DC-AC22-92PC91346, Prepared by Carnegie Mellon University for the U.S. Department of Energy, Pittsburgh, Pennsylvania, July 1993.

16. Frey, H.C., and E.S. Rubin, *Development of the Integrated Environmental Control Model: Cost Models of Selective Catalytic Reduction* NO_X *Control Systems*, Quarterly Progress Report, DOE/PC/91346--5, Contract No. DC-AC22-92PC91346, Prepared by Carnegie Mellon University for the U.S. Department of Energy, Pittsburgh, Pennsylvania, December 1993.

17. Frey, H.C., *Modeling and Assessment of the Fluidized Bed Copper Oxide Process for* SO_2/NO_X *Control*, Prepared by North Carolina State University for U.S. Department of Energy, March 30, 1994.

18. Frey, H.C., *Development and Application of Performance and Cost Models for Gas Turbine-Based Selective Catalytic Reduction* NO_X *Control, Task 1 Topical Report, Volume 1,* Prepared by North Carolina State University for Carnegie Mellon University and U.S. Department of Energy, Morgantown, West Virginia, October 1994.

19. Frey, H.C., R.J. Lempert, G. Farnsworth, D.C. Acheson, P.S. Fischbeck, and E.S. Rubin, *A Method for Federal Energy Research Planning: Integrated Consideration of Technologies, Markets, and Uncertainties,* Prepared by Carnegie Mellon, RAND, and Atlantic Council for

Lawrence Livermore National Laboratory, Livermore, CA. April 1995. (This report was reviewed by a “blue-ribbon” Working Group)

20. Agarwal, P, and H.C. Frey, *Development and Application of Performance and Cost Models for the Externally-Fired Combined Cycle*, Task 1 Topical Report, Volume 2, Prepared by North Carolina State University for Carnegie Mellon University and U.S. Department of Energy, Morgantown, West Virginia, July 1995. (A draft of this report was reviewed by Carnegie Mellon)

21. Frey, H.C., and R.B. Williams, *Performance and Cost Models for the Direct Sulfur Recovery Process*, Task 1 Topical Report, Volume 2, Prepared by North Carolina State University for Carnegie Mellon University and U.S. Department of Energy, Morgantown, West Virginia, September 1995.

22. Frey, H.C., and D.A. Eichenberger, *Remote Sensing of Mobile Source Air Pollutant Emissions: Variability and Uncertainty in On-Road Emissions Estimates of Carbon Monoxide and Hydrocarbons for School and Transit Buses*, FHWY/NC/97-005, Prepared by North Carolina State University for North Carolina Department of Transportation, Raleigh, June 1997. (A draft of this report was reviewed by a project advisory panel comprised primarily of personnel at the NC Department of Transportation and Federal Highway Administration.)

23. Kini, M.D., and H.C. Frey, *Probabilistic Evaluation of Mobile Source Air Pollution: Volume 1, Probabilistic Modeling of Exhaust Emissions from Light Duty Gasoline Vehicles*, Prepared by North Carolina State University for Center for Transportation and the Environment, Raleigh, December 1997. (A draft of this report was reviewed by external peer reviewers at the U.S. Environmental Protection Agency).

24. Bharvirkar, R. and H.C. Frey, *Development of Simplified Performance and Cost Models of Integrated Gasification Combined Cycle Systems*, Prepared by North Carolina State University for Carnegie Mellon University, Pittsburgh, Pennsylvania, July 1998.

25. Frey, H.C., *Estimates of Uncertainty in Air Quality Model Inputs Based Upon Expert Elicitation*, Prepared by North Carolina State University for Hanna Consultants, Kennebunkport, Maine, September 28, 1998. (reviewed by sponsor).

26. Frey, H.C., and D.S. Rhodes, *Quantitative Analysis of Variability and Uncertainty in Environmental Data and Models: Volume 1. Theory and Methodology Based Upon Bootstrap Simulation*, Report No. DOE/ER/30250--Vol. 1, Prepared by North Carolina State University for the U.S. Department of Energy, Germantown, MD, April 1999.

27. Frey, H.C., and L.K. Tran, *Quantitative Analysis of Variability and Uncertainty in Environmental Data and Models: Volume 2. Performance, Emissions, and Cost of Combustion-Based* NO_X *Controls for Wall and Tangential Furnace Coal-Fired Power Plants*, Report No. DOE/ER/30250-- Vol. 2, Prepared by North Carolina State University for the U.S. Department of Energy, Germantown, MD, April 1999.

28. Berkenpas, M.B., H.C. Frey, J.J. Fry, J. Kalagnanam, and E.S. Rubin, "Integrated Environmental Control Model: Technical Documentation," Prepared by Carnegie Mellon University for U.S. Department of Energy, Pittsburgh, PA. May 1999. (available at: ftp://ftp.netl.doe.gov/pub/IECM/iecmpage.htm)

29. Frey, H.C., R. Bharvirkar, and J. Zheng, *Quantitative Analysis of Variability and Uncertainty in Emissions Estimation*, Prepared by North Carolina State University for the U.S. Environmental Protection Agency, Research Triangle Park, NC. July 1999.

30. Rouphail, N.M., H.C. Frey, A. Unal, and R. Dalton, *ITS Integration of Real-Time Emissions and Traffic Management Systems*, IDEA Project No. ITS-44, Prepared by North Carolina State University for the IDEA Program, Transportation Research Board, National Research Council, Washington, DC. May 2000. (available at www4.ncsu.edu/~frey/freytech.html).

31. Frey, H.C., and J. Zheng, User's Guide for Analysis of Uncertainty and Variability in Emissions Estimation (AUVEE), Prepared by North Carolina State University for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 2000.

32. Hanna, S., Z. Lu, H.C. Frey, N. Wheeler, J. Vukovich, S. Arunachalam, M. Fernau, and J. Davis, Uncertainties in Predicted Ozone Concentrations due to Input Uncertainties for UAM-V Photochemical Grid Model Applied to the July 1995 OTAG Domain, Report No. 1000710, Prepared by Harvard School of Public Health, North Carolina State University, and MCNC for EPRI, Palo Alto, CA, and Ameren, St. Louis, MO. November 2000.

33. Frey, H.C., and N. Akunuri, "Probabilistic Modeling and Evaluation of the Performance, Emissions, and Cost of Texaco Gasifier-Based Integrated Gasification Combined Cycle Systems Using ASPEN," Prepared by North Carolina State University for Carnegie Mellon University and U.S. Department of Energy, Pittsburgh, PA, January 2001.

34. Frey, H.C., and J. Zheng, Methods and Example Case Study for Analysis of Variability and Uncertainty in Emissions Estimation (AUVEE), Prepared by North Carolina State University for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 2001.

35. Frey, H.C., N.M. Rouphail, A. Unal, and J.D. Colyar, Emissions Reduction Through Better Traffic Management: An Empirical Evaluation Based Upon On-Road Measurements, FHWY/NC/2002-001, Prepared by North Carolina State University for North Carolina Department of Transportation, December 2001. 323 pp.

36. Frey, H.C., A. Unal, and J. Chen, Recommended Strategy for On-Board Emission Data Analysis and Collection for the New Generation Model, Prepared by North Carolina State University for the Office of Transportation and Air Quality, U.S. Environmental Protection Agency, Ann Arbor, MI. February 2002.

37. Frey, H.C., J. Zheng, Y. Zhao, S. Li, and Y. Zhu, Technical Documentation of the AuvTool Software for Analysis of Variability and Uncertainty, Prepared by North Carolina State University for the Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC. February 2002.

38. Zheng, J., and H.C. Frey, AuvTool User's Guide, Prepared by North Carolina State University for the Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC. February 2002.

39. Frey, H.C., A. Unal, J. Chen, S. Li, and C. Xuan, Methodology for Developing Modal Emission Rates for EPA's Multi-Scale Motor Vehicle and Equipment Emission Estimation System, EPA420-R-02- 027, Prepared by North Carolina State University for the Office of Transportation and Air Quality, U.S. Environmental Protection Agency, Ann Arbor, MI, October 2002. Available at http://www.epa.gov/otaq/ngm.htm#background.

40. Loughlin, D., H.C. Frey, K. Hanisak, and A. Eyth, "Implementation Requirements for the Development of a Sensitivity/Uncertainty Analysis Tool for MIMS," Draft, Prepared by Carolina Environmental Program and North Carolina State University for U.S. Environmental Protection Agency, Research Triangle Park, NC, May 6, 2003.

41. Frey, H.C., "Evaluation of an Approximate Analytical Procedure for Calculating Uncertainty in the Greenhouse Gas Version of the Multi-Scale Motor Vehicle and Equipment Emissions System," Prepared for Office of Transportation and Air Quality, U.S. Environmental Protection Agency, Ann Arbor, MI, May 30, 2003.

42. Frey, H.C., D. Crawford-Brown, J. Zheng, and D. Loughlin, "Hierarchy of Methods to Characterize Uncertainty: State of Science of Methods for Describing and Quantifying Uncertainty," Draft, Prepared for E. H. Pechan and Associates, Inc., Springfield, VA, for submittal to U.S. Environmental Protection Agency, Research Triangle Park, NC, August 12, 2003.

43. Frey, H.C., J. Zheng, D. Loughlin and D. Crawford-Brown,, "Hierarchy of Methods to Characterize Uncertainty: State of Science on Communication of Uncertainty," Draft, Prepared for E. H. Pechan and Associates, Inc., Springfield, VA, for submittal to U.S. Environmental Protection Agency, Research Triangle Park, NC, August 12, 2003

44. Frey, H.C., A. Mokhtari, and T. Danish, "Evaluation of Selected Sensitivity Analysis Methods Based Upon Applications to Two Food Safety Risk Process Models," Prepared by North Carolina State University for Office of Risk Assessment and Cost-Benefit Analysis, U.S. Department of Agriculture, Washington, DC, September 2003. (www.ce.ncsu.edu/risk/)

45. Frey, H.C., and Y. Zhao, "Development of Probabilistic Emission Inventories of Benzene, Formaldehyde And Chromium for the Houston Domain," Prepared by North Carolina State University for U.S. Environmental Protection Agency, Research Triangle Park, NC, September 2003.

46. Frey, H.C., A. Mokhtari, and J. Zheng, “Recommended Practice Regarding Selection, Application, and Interpretation of Sensitivity Analysis Methods Applied to Food Safety Process Risk Models,” Prepared by North Carolina State University for U.S. Department of Agriculture, Washington, DC, January 30, 2004.

47. Frey, H.C., and Y. Zhu, “Documentation of Performance and Cost Models for Simple and Combined Cycle Gas Turbine Systems,” Prepared by North Carolina State University for the U.S. Department of Energy via Carnegie Mellon University, Pittsburgh, PA, October 2004.

48. Frey, H.C., and K. Kim, “Operational Evaluation of Emissions and Fuel Use of B20 Versus Diesel Fueled Dump Trucks,” FHWY/NC/2005-07, Prepared by North Carolina State University for North Carolina Department of Transportation, Raleigh, NC, Sept 30, 2005.

49. Mokhtari, A., and H.C. Frey, “Review and Recommendation of Methods for Sensitivity and Uncertainty Analysis for the Stochastic Human Exposure and Dose Simulation (SHEDS) Models, Volume 1: Review of Available Methods for Conducting Sensitivity and Uncertainty Analysis in Probabilistic Models,” Draft, Prepared by North Carolina State University for Alion Science and Technology, Inc., Durham, NC, June 30, 2005.

50. Mokhtari, A., and H.C. Frey, “Review and Recommendation of Methods for Sensitivity and Uncertainty Analysis for the Stochastic Human Exposure and Dose Simulation (SHEDS) Models, Volume 2: Evaluation and Recommendation of Methodology for Conducting Sensitivity Analysis in Probabilistic Models,” Draft, Prepared by North Carolina State University for Alion Science and Technology, Inc., Durham, NC, June 30, 2005.

51. Rubin, E.S., M.B. Berkenpas, H.C. Frey, C. Chen, S. McCoy, and C.J. Zaremsky, Technical Documentation: Integrated Gasification Combined Cycle Systems (IGCC) with Carbon Capture and Storage (CCS), Prepared by Carnegie Mellon University for the U.S. Department of Energy, Pittsburgh, PA, May, 2007

52. Frey, H.C., and P.Y. Kuo, Best Practices Guidebook for Greenhouse Gas Reductions in Freight Transportation, Prepared by North Carolina State University for U.S. Department of Transportation, Washington, DC, October 2007.

53. Frey, H.C., W.J. Rasdorf, K. Kim, S. Pang, P. Lewis, and S. Abolhasani, “Real-World Duty Cycles and Utilization for Construction Equipment in North Carolina,” HWY-2006-08, Prepared by North Carolina State University for North Carolina Department of Transportation, Raleigh, NC, January 2008.

54. Frey, H.C., and Kangwook Kim, Comparison of Fuel Use and Emissions of B20 Biodiesel Fueled Combination Trucks With Versus Without A Fuel Additive, Prepared by North Carolina State University for North Carolina Department of Transportation, Raleigh, NC, January 7, 2008.

55. Frey, H.C., and Kangwook Kim, Comparison of Biodiesel versus Petroleum Diesel Based On In-Use Measurement of Emissions for Heavy Duty Vehicles: Vancouver Case Study,

Prepared by North Carolina State University for Lafarge North America, Calgary, Alberta, Canada, January 21, 2008.

56. Frey, H.C., and Kangwook Kim, Comparison of Biodiesel versus Petroleum Diesel Based On In-Use Measurement of Emissions for Heavy Duty Vehicles: Atlanta Case Study, Prepared by North Carolina State University for Lafarge North America, Towson, Maryland, January 21, 2008.

57. Frey, H.C., and Kangwook Kim, "Comparison of Propane Mixed Diesel versus Petroleum Diesel Based On In-Use Measurement of Emissions for a Medium-Heavy Duty Diesel Utility Vehicle: Pilot Study," Prepared by North Carolina State University for Blossman Propane Gas and Appliance, Inc., Easley, SC, March 3, 2008.

58. Frey, H.C., and H.W. Choi, Baseline Fuel Use and Emissions Rates for Petroleum Diesel Fueled Combination Trucks, TA-2008-09, Prepared by North Carolina State University for North Carolina Department of Transportation, Raleigh, NC, May 28, 2008.

59. Frey, H.C., and H.W. Choi, Baseline Emission Rates for F59 and GP40 Locomotives Operated on Ultra Low Sulfur Diesel, TA-2008-15, Prepared by North Carolina State University for North Carolina Department of Transportation, Raleigh, NC, July 31, 2008.

60. Graver, B., and H.C. Frey, "Measurement and Evaluation of the Activity, Energy Use, and Emissions of a Plug-in Hybrid Electric Vehicle," Prepared for Advanced Transportation Energy Center, March 2010.

61. Frey, H.C., and B.M. Graver, "Measurement and Evaluation of Fuels and Technologies for Passenger Rail Service in North Carolina," Draft, Research Project No. HWY-2010-12, Prepared by North Carolina State University for North Carolina Department of Transportation, Raleigh, NC, October 31, 2011.

COMMITTEE REPORTS

1. Science Advisory Board, *An SAB Report: Review of the USEPA's Report to Congress on Residual Risk*, Prepared by Residual Risk Subcommittee of the Science Advisory Board for U.S. Environmental Protection Agency, EPA-SAB-EC-98-013, September 1998. (Contributing member of Residual Risk Subcommittee, also contributed pages A-15 to A-51).

2. Eastern Research Group, *Report of the Workshop on Selecting Input Distributions for Probabilistic Assessments*, Prepared by Eastern Research Group for U.S. Environmental Protection Agency, September 1998. Contributed "Chairperson's Summary" (wrote Chapter 2 and reviewed/edited other chapters)

3. National Research Council, "Interim Report of the Committee on Changes in New Source Review Programs for Stationary Sources of Air Pollutants," The National Academies Press, Washington, DC, January 2005 [contributing member of the committee].

4. NARSTO EI Assessment Team, Improving Emission Inventories for Effective Air Quality Management Across North America, A NARSTO Assessment, NARSTO-05-001, http://www.narsto.org/section.src?SID=8, 2005. Co-Chair of the NARSTO Emission Inventory Assessment, Lead Author for Chapter 8: "Methods for Assessment of Uncertainty and Sensitivity in Inventories," and contributing author to Chapter 5: "Strengths and Weaknesses of Current Emission Inventories."

5. Frey, C., J. Penman, L. Hanle, S. Monni, and S. Ogle, "Uncertainties," Chapter 3 in Volume 1, General Guidance and Reporting, *2006 IPCC Guidelines for National Greenhouse Gas Inventories,* National Greenhouse Gas Inventories Programme, Inter-Governmental Panel on Climate Change, Technical Support Unit, Kanagawa, Japan, 2006.

6. Goodwin, J., M. Woodfield, M. Ibnoaf, M. Kozh, H. Yan, C. Frey, R. Montgomery, T. Pulles, D. Ottinger-Schaeffer, and K. Treanton, "Approaches to Data Collection," Chapter 2 in Volume 1, General Guidance and Reporting, *2006 IPCC Guidelines for National Greenhouse Gas Inventories,* National Greenhouse Gas Inventories Programme, Inter-Governmental Panel on Climate Change, Technical Support Unit, Kanagawa, Japan, 2006.

7. National Research Council, New Source Review for Stationary Sources of Air Pollution, Committee on Changes in New Source Review Programs for Stationary Sources of Air Pollution, The National Academies Press, Washington, DC, 2006 [contributing member of the committee].

8. World Health Organisation, *Harmonization Project Document No. 6, Part 1: Guidance Document on Characterizing and Communicating Uncertainty in Exposure Assessment*, International Program on Chemical Safety, World Health Organization, and Co-sponsored by International Labour Organization, and the United Nations Environmental Programme, WHO Geneva, Switzerland, 2008.
(http://www.who.int/ipcs/publications/methods/harmonization/exposure_assessment.pdf)

9. WHO/FAO, Risk Characterization of Microbiological Hazards in Food Guidelines, Microbial Risk Assessment Series No. 17, World Health Organization and Food and Agriculture Organization of the United Nations, 2009. (Contributor).

10. National Research Council, *Review of the Environmental Protection Agency's Draft IRIS Assessment of Tetrachloroethylene,* The National Academies Press, Washington, DC, 2010, ISBN-13: 978-0-309- 15094-1 [contributing member of the committee].
(http://www.nap.edu/catalog.php?record_id=12863).

INVITED RESEARCH PRESENTATIONS (SEMINARS) – MOST RECENT 10 OUT OF 92

1. "Vehicle Energy and Emissions Research at NC State," Advisory Council Meeting, Institute for Transportation Research and Education, North Carolina State University, Raleigh, NC, April 16, 2009.

2. "Evaluating the Performance, Emissions, and Cost Of Power Plants Using the Integrated Environmental Control Model," NC Division of Air Quality, Raleigh, NC, November 2, 2009.

3. "Measurement and Modeling of Real-World Activity, Fuel Use, and Emissions of Onroad Vehicles," North Carolina Association of Municipal Planning Organizations, January 28, 2010.

4. "Method and Example Case Study for Source Apportionment of $PM_{2.5}$ Exposure," Invited seminar with Montse Fuentes at U.S. Environmental Protection Agency, Research Triangle Park, NC, April 28, 2010.

5. "NO_x Emissions: Where Have We Been and Where are We Going?," Denitrification Research Coordination Network (www.denitrification.org), Invited presentation at Workshop on Nitrogen Assessment Science in the USA, Boulder, Colorado, May 18, 2010.

6. "Uncertainty in Emissions Estimates," State Implementation Plan Coordination Workshop, Mid-Atlantic Regional Air Management Association, Baltimore, MD, September 27, 2010.

7. "Framework for Context-Sensitive Spatially- and Temporally-Resolved Onroad Mobile Source Emission Inventories," U.S. Environmental Protection Agency, Research Triangle Park, NC, November 16, 2010 (with N.M. Rouphail, H. Hu, B. Liu, and X. Song).

8. "Life Cycle Inventory Energy Consumption and Emissions of Greenhouse Gases and Other Pollutants for Biofuels Versus Petroleum Fuels," Division of Environment, Hong Kong University of Science and Technology, December 14, 2010.

9. "More than Ten Years Experience in Field Measurements of Onroad and Nonroad Vehicles Using Portable Emissions Measurement Systems," 2010 International Workshop on Mobile Source Emission Testing and Modeling, Xiamen, P.R. China, December 18, 2010.

10. "Measurement of Onroad and Nonroad Vehicles Using Portable Emissions Measurement Systems," PEMS: The Latest Tools and Techniques for In-Use Measurements, University of California at Riverside, March 24, 2011.

11. "Overview of Research Activities in Transportation-Related Emissions and Exposure," Department of Mechanical Engineering, Instituto Superior Tecnico, Lisbon, Portugal, July 25, 2011.

CONFERENCE PRESENTATIONS (OVER 200, LIST AVAILABLE UPON REQUEST)

SPONSORED GRANTS AND CONTRACTS – recent examples out of over 50

1. *Title*: A Spatial-Temporal Modeling Approach for Evaluating the Impact of Environmental Stressors, in Conjunction with Human Activity, on Human Health
   Investigators: M. Fuentes, H. Christopher Frey, S. Ghosh
   Granting Agency: National Institutes of Health
   Dates: January 1, 2008 to December 31, 2011

2. *Title*: Spatial Temporal Analysis of Health Effects Associated with Sources and Speciation of Fine Particulate Matter
   Investigators: M. Fuentes (Statistics), H. Christopher Frey, Y. Zhang (MEAS), M. Bell (Yale U.), F. Dominici (Johns Hopkins)
   Granting Agency: U.S. Environmental Protection Agency STAR Grants Program
   Dates: December 1, 2008 to November 30, 2011

3. *Title*: Development and Evaluation of Methodological Framework for Real- World Vehicle Energy Use and Emissions Estimation at Multiple Temporal and Vehicular Scales
   Investigators: H.C. Frey (PI) and N.M. Rouphail (Co-PI)
   Granting Agency: National Science Foundation
   Dates: May 15, 2008 to May 14, 2012

4. *Title*: Measurement and Evaluation of Fuels and Technologies for Passenger Rail Service in North Carolina
   Investigators: H.C. Frey (PI)
   Granting Agency: North Carolina Department of Transportation
   Dates: August 16, 2009 to August 15, 2011

5. *Title*: Multiple Tiered Methodology for Micro- to Macro-Scale Assessment of Plug- In Hybrid Electric Vehicles (M4-PHEVs)
   Investigators: H.C. Frey (PI) and Joe DeCarolis (Co-PI)
   Granting Agency: National Science Foundation
   Dates: October 1, 2009 to September 30, 2012

6. *Title*: Dynamometer Testing of Railroad Locomotive Engines
   Investigators: H.C. Frey (PI)
   Granting Agency: Federal Railroad Administration via NC Department of Transportation
   Dates: January 20, 2010 to January 19, 2011

7. *Title*: Framework for Context-Sensitive Spatially- and Temporally-Resolved Onroad Mobile Source Emission Inventories
   Investigators: H.C. Frey (PI) and Nagui M. Rouphail (Co-PI)
   Granting Agency: U.S. Environmental Protection Agency
   Dates: May 1, 2010 to April 30, 2013.

8. *Title*: Locomotive Biofuel Study
Investigators: H.C. Frey (PI) and Alex Hobbs (Co-PI)
Granting Agency: Federal Railroad Administration
Dates: August 16, 2011 to August 15, 2013.

MASTERS THESES AND DOCTORAL DISSERTATIONS DIRECTED

1. Pankaj Agarwal, MS, "Modeling and Assessment of the Externally-Fired Combined Cycle System," graduated December 1995 (chair).

2. Mitesh Kini, MS, "Probabilistic Modeling of Exhaust Emissions from Light Duty Gasoline Vehicles," graduated December 1996 (chair).

3. Loan K. Tran, MS, "Performance and Cost Modeling of NO_x Combustion Control Technologies in Pulverized Coal Power Plants," graduated December 1996 (chair).

4. Kamalpreet Singh, MS, "Uncertainty Analysis in Air Quality Modeling," graduated December 1997 (chair).

5. David Rhodes, MS, "Quantitative Analysis of Variability and Uncertainty in Environmental Risk Assessment," graduation August 1997 (chair).

6. Ranjit Bharvirkar, MS, "Quantitative Analysis of Variability and Uncertainty in Emission Factors and Emission Inventories," May 1999 (chair).

7. Alper Unal, MS, "Modeling of Highway Vehicle Emissions Using Remote Sensing Data," May 1999 (chair).

8. Naveen Akunuri, MS, "Process Modeling of Integrated Gasification Combined Cycle Systems Using ASPEN," May 1999 (chair).

9. Russell Dalton, MS, 1999 (co-chair with Nagui M. Rouphail)

10. Sudeep Vaswani, MS, "Development of Models for Calculating the Life Cycle Inventory of Methanol by Liquid Phase and Conventional Production Processes," June 2000 (co-chair with M.A. Barlaz).

11. Matthew Pickett, MS, "Modeling the Performance and Emissions of British Gas/Lurgi-Based Integrated Gasification Combined Cycle Systems," January 2001 (co-chair with M.A. Barlaz)

12. Colyar, James Daniel, MS, "An Empirical Study of the Relationships Between Macroscopic Traffic Parameters and Vehicle Emissions," March 2001 (co-chair with Nagui Rouphail).

13. Coehlo, Maysa, PhD, "Evaluation of Alternative Future Energy Scenarios for Brazil

Using an Energy Mix Model," June 2001 (chair)

14. Bammi, Sachin, MS, "Quantitative Analysis of Variability and Uncertainty in On- Road and Non-Road Mobile Source Emission Factors," July 2001 (chair)

15. Patil, Sumeet R., MS, "Identification, Application, and Comparison of Sensitivity Analysis Methods for Food Safety Risk Assessment Models," August 2001 (chair)

16. Xie, Chi, MS, "Modeling the Performance and Emissions of Integrated Gasification Combined Cycle based Lurgi Ammonia Synthesis System," December 2001 (chair)

17. Zheng, Junyu, PhD Dissertation, "Quantification of Variability and Uncertainty in Emission Estimation: General Methodology and Software Implementation," May 2002 (chair)

18. Li, Minsheng, MS Thesis, "Life Cycle Inventory Development for a Solid Waste/Coal Blend Gasification System for Production of Power and Chemicals," August 2002 (co-chair with M. Barlaz).

19. Unal, Alper, PhD Dissertation, "On-Board Measurement and Analysis of On-Road Vehicle Emissions," August 2002 (chair).

20. Li, Song, PhD Dissertation, "Development and Demonstration of a Methodology for Characterizing and Managing Uncertainty and Variability in Emission Inventories," August 2002 (chair).

21. Abdel-Aziz, Amr, PhD Dissertation, "Incorporating Uncertainties in Emission Inventories Into Air Quality Modeling," December 2002 (chair).

22. Chen, Jianjun, MS Thesis, "Optimization of Gasification Combined Cycle Systems Under Variability and Uncertainty," July 2003 (chair).

23. Danish, Tanwir, MS Thesis, "Evaluation of Selected Sensitivity Analysis Methods Applied to a Food Safety Risk Model," July 2003 (chair).

24. Zhao, Yuchao, PhD Dissertation, "Quantification of Variability and Uncertainty in Emission Factors and Emission Inventories for Urban Air Toxics," August 2003 (chair).

25. Mokhtari, Amirhossein, PhD Dissertation, "Evaluation of Sensitivity Analysis Methods for Application to Microbial Food Safety Process Risk Models," July 2004.

26. Zhu, Yunhua, PhD Dissertation, "Evaluation of Gas Turbine and Gasifier-Based Power Generation Systems," August 2004.

27. Phillips, Lori Ann, MS Thesis, "Public Perception of Indoor Air Quality and Evaluation of Indoor Air Cleaners," May 2006.

28. Abolhasani, Saeed, MS Thesis, "Assessment of On-Board Emissions and Energy Use of Nonroad Construction Vehicles," August 2006.

29. Zhang, Kaishan, PhD Dissertation, "Micro-Scale On-Road Vehicle-Specific Emissions Measurements and Modeling," August 2006.

30. Kim, Kangwook, PhD Dissertation, "Operational Evaluation of In-Use Emissions and Fuel Consumption of B20 Biodiesel versus Petroleum Diesel-Fueled Onroad Heavy-Duty Diesel Dump Trucks and Nnonroad Construction Vehicles," December 2007.

31. Zhai, Haibo, PhD Dissertation, "Regional Onroad Mobile Source Emissions Characterization for Conventional and Alternative Vehicle Technologies," December 2007.

32. Pang, Shih-hao, PhD Dissertation, "Life Cycle Inventory Incorporating Real-World In-Use Measurement Data for Nonroad Construction Vehicles and Equipment," December 2007.

33. Kuo, Po-Yao, PhD Dissertation, "Evaluation of Freight Truck Anti-Idling Strategies for Reduction of Greenhouse Gas Emissions," August 2008.

34. Choi, Hyung-Wook, PhD Dissertation, "Measurement and modeling of the activity, energy, and emissions of conventional and alternative vehicles," August 2009.

35. Cao, Ye., MS Thesis, "Modeling of Human Exposure to Fine Particulate Matter sing a Stochastic Scenario-Based Model, August 2010.

36. Graver, B., MS Thesis, "Measurement, Prediction, and Evaluation of Microscale Energy Use and Emissions for a Plug-In Hybrid Electric Vehicle Based on Real-World Driving Data," August 2010.

37. Sandhu, G., MS Thesis, "Methods For Quality Assurance Of Portable Emissions Measurement System Data and Methods For Field Comparison Of Alternative Fuels," August 2010.

NATIONAL PUBLIC SERVICE – PEER REVIEW AND ADVISORY PANELS

(a) Invited Participant, U.S. Environmental Protection Agency workshop on Monte Carlo simulation in exposure assessment, June 1992.

(b) Peer Reviewer, U.S. Environmental Protection Agency Exploratory Research Grants Program. June 1994.

(c) Peer Reviewer, U.S. Environmental Protection Agency Graduate Fellowship Program. Spring 1995. Three day review meeting was held in Washington, DC in March.

(d) Scientific Peer Review Panelist, U.S. Environmental Protection Agency draft report to Congress on Air Toxics Emissions from Fossil-Fuel-Fired Electric Power Plants. Activity occurred from June to August 1995. The peer review panel consisted of ten nationally recognized experts in air toxics, risk assessment, environmental control, and related fields.

(e) Invited to present at the U.S. Department of Energy's national laboratories' Energy Coordinating Committee subcommittee on research planning. The meeting was held in Dallas, Texas on September 12, 1995. The presentation was on "A Method for Federal Energy Research Planning". The meeting was attended by representatives of Argonne National Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, Pacific Northwest Laboratory, and Sandia National Laboratory.

(f) Oversaw the creation and testing of World Wide Web site for the Society for Risk Analysis, December 1996 - March 1997.

(g) Peer Reviewer, U.S. Environmental Protection Agency, Office of Mobile Sources, 1998.

(h) Peer Reviewer, U.S. Environmental Protection Agency, Risk Assessment Forum, 1998.

(i) Peer Reviewer, U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, 1998.

(j) Proposal Review Panel, "Professional Opportunities for Women in Research and Education," National Science Foundation, Arlington, VA, March 10, 1998

(k) Chair of expert advisory workshop, sponsored by U.S. Environmental Protection Agency, Risk Assessment Forum, held April 21-22, 1998 in New York City.

(l) Member of Residual Risk Subcommittee, appointed by US EPA's Science Advisory Board (SAB) Executive Committee, to review EPA's draft Report to Congress on Residual Risk Assessment. The subcommittee met in RTP on August 3, 1998. The subcommittee's report will be completed in September 1998. Contributed independent review comments, participated in panel discussions, provided post-meeting comments in a written report, reviewed the draft report of the subcommittee prepared by the chair, and provided additional comments interactively with other members of the committee.

(m) Invited to serve on a U.S. Environmental Protection Agency Science Advisory Panel (SAP) that met May 24-25, 1999 in Crystal City, VA, to review a draft EPA report related to pesticides. The SAP is a peer-review activity mandated by the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), similar in nature to the EPA Science Advisory Board.

(n) Invited to serve on a U.S. Environmental Protection Agency Science Advisory Panel (SAP) that met March 1-2, 2000 in Crystal City, VA, to review draft EPA reports related to risk assessment of human exposure to pesticide residues in produce. Contributed substantially to the report of the SAP.

(o) Served as an outside reviewer on a Technical Qualifications Board (TQB) in the National Center for Environmental Assessment of the U.S. Environmental Protection Agency on March 8, 2000 in Research Triangle Park, NC. A TQB is similar to a promotion review committee. The TQB reviewed the technical and scientific qualifications of a particular EPA employee who is a candidate for promotion to a higher grade level within the Federal civil service.

(p) Participant in "North Carolina Air Quality Roundtable: Transportation Conformity." The Roundtable is a group of leaders from Federal, state, and local government, industry, public interest groups, and academia to develop strategies for dealing with transportation and air quality issues. Particpated in four sessions of the Roundtable from August 2001 through March 2002. The roundtable was organized by the Center for Transportation and the Environment.

(q) Participant in March 5, 2002 meeting of the Greater Triangle Regional Council on the topic of air quality and transportation. Held at RDU Airport Authority building. Another meeting is planned for April/May 2002 and I plan to participate if possible.

(r) Peer Review, Food Safety and Inspection Service draft report on "Draft FSIS Risk Assessment for Listeria in Ready-to-Eat Meat and Poultry Products," prepared a 21 page report containing detailed comments on modeling methodology, March 2003.

(s) Appointed to a four year time on the EPA FIFRA SAP (please see items *m* and *n* above). April 2004-August 2006.

(t) Invited member, National Research Council Committee on the Effects of Changes in New Source Review Programs for Stationary Sources of Air Pollutants, March 2004 to Summer 2006.

(u) Review of SBIR proposal for USDA, April 2004.

(v) Member of Technical Panel, Probabilistic Risk Analysis Working Group, Risk Assessment Forum, U.S. Environmental Protection Agency, and Co- Chair of Working Group 1 – Utility of PRA for Decision Making (preparing a white paper), August 2006 to present.

(w) Clean Air Scientific Advisory Committee (CASAC): provides scientific review for the National Ambient Air Quality Standards.

i. Member of statutory CASAC, appointed by the Administrator of the U.S. Environmental Protection Agency to a three – year term (October 2008 to September 2011).

ii. Member, Particulate Matter (PM) Review Panel, September 2007 to July 2010.

1. Review of Draft Integrated Review Plan, Teleconference, November 30, 2007.
2. Review of 1st Draft of the Integrated Science Assessment, and Scope and Methods Plan for the Risk and Exposure Assessment, Public Meeting, April 1-2, 2009, Chapel Hill, NC
3. Review of 2nd Draft of the Integrated Science Assessment, 1st Draft of the Risk and Exposure Assessment, and 1st Draft of the Visibility Assessment, Public Meeting, October 5-7, 2009, Chapel Hill, NC
4. Review of 2nd Draft of the Risk and Exposure Assessment, and 2nd Draft of the Visibility Assessment, 1st Draft of the Policy Assessment, Public Meeting, March 10-11, 2010, Chapel Hill, NC.
5. Review of 2nd Draft of the Policy Assessment, Public Meeting, July 26-27, 2010, Chapel Hill, NC.

iii. Member, Carbon Monoxide (CO) Review Panel,

1. Review 1st Draft of Integrated Science Assessment, and Scope and Methods Plan for the Risk and Exposure Assessment, Public Meeting, May 12-13, 2009, Chapel Hill, NC.
2. Review 2nd Draft Integrated Science Assessment and 1st Draft Risk and Exposure Assessment, Public Meeting, November 16-17, 2009, Chapel Hill, NC
3. Review 2nd Draft Risk and Exposure Assessment, and Draft Policy Assessment, Public Meeting, March 22-23, 2010, Chapel Hill, NC.

iv. Nitrogen Dioxide (NO_2) Review Panel

1. Review of Proposed Rule for the Revision of the NAAQS for NO_2, public teleconference, August 10, 2009.

v. Sulfur Dioxide (SO_2) Review Panel

1. Review of 2nd Draft, Risk and Exposure Assessment, Public Meeting, April 16-17, 2009. Chapel Hill, NC.

vi. SO_x/NO_x Secondary Standard Review Panel

1. Review of Second Draft, Risk and Exposure Assessment, Public Meeting, July 22-23, 2009, Durham, NC.
2. Review of 2nd Draft Policy Assessment, Public Meeting, October 6-7, 2010, Durham, NC.
3. Review of Final Policy Assessment, Public Meeting, February 15-16, 2011, Chapel Hill, NC

vii. Lead Review Panel (Chair of Panel)

1. Review of Integrated Review Plan –May 5, 2011
2. Review of 1st Draft Integrated Science Assessment –July 20-21, 2011, RTP, NC

viii. Ozone Review Panel

1. Review of First Draft Integrated Science Assessment and Scope & Methods Plan for Risk and Exposure Assessment, May 19- 20, 2011, RTP, NC

(x) Invited member of ad hoc peer review panel to review the U.S. Environmental Protection Agency's draft Report on the Environment, Washington, DC, January 11, 2008.

(y) Invited member of ad hoc peer review panel to review nine proposals, National Science Foundation, Washington, DC, January 28, 2008.

(z) Invited member, U.S. Environmental Protection Agency, Advisory Council on Clean Air Compliance Analysis, Review of the Characterization of Uncertainty in the Estimated Benefits of Reduced PM-Mortality using Expert Elicitation, Washington, DC, May 8, 2008. Report completed in July 2008.

(aa) Invited member, National Research Council Committee on Tetrachloroethylene, August 2008 to September 2009.

(bb) Member, U.S. EPA Science Advisory Board (SAB) Expert Elicitation Advisory Panel, November 2008 – June 2009.

(cc) Member, Board on Environmental Studies and Toxicology, National Research Council, October 2009 to September 2012.

(dd) Invited Expert Panelist, US EPA Multipollutant Science and Risk Analysis Workshop, February 22-24, 2011, Chapel Hill, NC (served on four panels).

(ee) Invited Expert, U.S. EPA Advisory Council on Clean Air Compliance review of EPA's draft Report to Congress on black carbon particulate matter, April 18-19, 2011, Washington, DC.

INTERNATIONAL PUBLIC SERVICE

(a) Invited to join the United States delegation to Intergovernmental Panel on Climate Change (IPCC) Expert Panel on Good Practice in Inventory Preparation: Cross-Sectoral Methodologies for Uncertainty Estimation and Inventory Quality, held October 5-7, 1999 in Culham, England (near Oxford). I was an active participant in Working Group 2: Quantifying Uncertainties in Practice and contributed substantially to the draft guidelines on uncertainty analysis of greenhouse gas emission inventories. The expert meeting was attended by approximately 100 experts from approximately 40 countries. My participation in the meeting was sponsored by the U.S. Environmental Protection Agency.

(b) Peer Review, Joint FAO/WHO Guidelines on Exposure Assessment of Microbial Hazards in Food and Water, Fall 2002.

(c) Drafting Group member and Invited Participant, Joint FAO/WHO Workshop on "Guidelines on Risk Characterization of Microbiological Hazards in Food," Helsingor, Denmark, February 24-28, 2003. Drafted sections on quantitative analysis of variability and uncertainty and regarding sensitivity analysis methods in collaboration with other international experts.

(d) Invited participant, international workshop on probabilistic exposure assessment, Belgium, November 2003.

(e) Steering Committee member and lead author, NARSTO Emission Inventory Assessment, 2003-2005. NARSTO is a trilateral Canadian, U.S., and Mexican organization.

(f) Invited member of organizing committee, German-American Frontiers of Engineering symposium for May 2005, National Academy of Engineering

(g) Invited Lead Author, Intergovernmental Panel on Climate Change (IPCC), Revisions to existing guidance on uncertainty analysis of greenhouse gas emissions. Attended lead author meetings in Oslo, Norway, May 4-6, 2004, Manila, the Philippines January 11-13, 2005, and Sydney, Australia, December 15-17, 2005.

(h) Invited participant in World Health Organization (WHO) effort to develop international guidance on probabilistic exposure assessment, 2005-2007. Most recent meeting was in March 2007 in Bradford, England.

(i) Invited participant, NARSTO Multi-pollutant air quality management assessment, 2007. NARSTO is a trilateral Canadian, U.S., and Mexican organization. Attended kick-off meeting in RTP, NC January 9-10,

2007. Will attend ecological effects working group meeting in Burlington, VT, April 12-13, 2007.

(j) Co-organizer of International Seminar on Transportation and Impacts, March 6, 2008, Lisbon, Portugal.

(k) Founding member of core group of the Luso-American Transportation Impact Studies Group (LATIS-G), formed on March 7, 2008 in Lisbon, Portugal.

ERIC M. FUJITA
Research Professor
Division of Atmospheric Sciences
Desert Research Institute
University and Community College System of Nevada

Education

D.Env.	Environmental Science and Engineering	1992	University of California, Los Angeles
M.S.	Organic Chemistry	1976	California State University, Los Angeles
B.S.	Chemistry	1973	University of California, Los Angeles

Experience

Dr. Fujita has over 27 years of experience in managing and conducting air quality studies. He is the principal author of the field study plans for the 2000 Central California Ozone Study and 1997 Southern California Ozone Study (SCOS97-NARSTO). His research interests include chemical characterization of emission sources, reconciliation of emission inventory estimates for VOC and PM with ambient measurements, and measurement and characterization of exposure to toxic air contaminants. Dr. Fujita performed source apportionment analysis of fine particles in Colorado's Northern Front Range, California's South Coast Air Basin and San Francisco Bay Area, Phoenix, and Bangkok Thailand. Current research includes quantifying the relative contribution of gasoline and diesel exhaust to ambient PM and measuring air toxic exposures from mobile sources. Dr. Fujita also performed volatile organic compound source apportionment studies for the 1987 Southern California Air Quality Study (SCAQS), 1990 San Joaquin Valley Air Quality Study (SJVAQS), 1993 Coastal Oxidant Assessment for Southeast Texas (COAST), 1995 Boston and Los Angeles Study, 1996 Phoenix Ozone Study, NARSTO-Northeast 1995 Summer Ozone Study, 1995/96 Washington Ozone Transport Study, 1996 El Paso/Juarez Ozone Study, and 1998 Central Texas On-Road Hydrocarbon Study. He has conducting similar studies in Houston and Mexicali, Mexico. Dr. Fujita also coordinated laboratory comparisons of VOC measurements during the SCOS97-NARTSO, COAST and NARSTO-Northeast ozone studies.

Prior to coming to DRI, Dr. Fujita was an Air Pollution Research Specialist for the Research Division of the California Air Resources Board where he initiated and managed extramural research in emission inventory development, air quality measurements, and atmospheric processes. These studies included developing emission factors for mobile and stationary sources and assessing the effectiveness of emission control measures. Other studies included examining gas and aerosol measurement methods and characterization of organic compounds in ambient air and emission sources.

Professional Experience

2000-Present Research Professor, Division of Atmospheric Sciences, Desert Research Institute, Reno, NV.

2001 Interim Executive Director, Division of Atmospheric Sciences, Desert Research Institute, Reno, NV.

1996-2000 Associate Research Professor, Energy and Environmental Engineering Center, Desert Research Institute, Reno, NV.

1993-1996 Assistant Research Professor, Energy and Environmental Engineering Center, Desert Research Institute, Reno, NV.

1987-1992 Air Pollution Research Specialist, Atmospheric Processes Research Section, Research Division, California Air Resources Board, Sacramento, California.

1983-1987 Air Pollution Research Specialist, Acid Deposition and Aerosol Research Section, Research Division, California Air Resources Board, Sacramento, CA.

1979-1983 Air Pollution Research Specialist, Emission Control Technology Research Section, Research Division, California Air Resources Board, Sacramento, CA.

1978-1979 Associate Air Pollution Specialist, Chemical Strategy Development Section, Stationary Source Division, California Air Resources Board, Sacramento, CA.

1975-1977 Graduate Student Assistant, Aerosol Studies Section, Research Division, California Air Resources Board, El Monte, CA.

Memberships

Air and Waste Management Association
American Geophysical Union
American Association for Aerosol Research

Committees and Offices

Member of the National Academy of Sciences National Research Council/Transportation Research Board study committee to evaluate the Congestion Mitigation and Air Quality Improvement (CMAQ) Program from October, 1999 to April, 2002.
Chairman of the Intersociety Subcommittee #4 on Carbon and Hydrocarbon Compounds
Coordinating Research Council's Air Pollution Research Advisory Committee
Technical Program Committee and editor of the proceedings for the Southern California Air Quality Study Data Analysis Conference

Professional Activities

Invited presentation on Mobile Source Emission and Air Quality Past Present and Future to the staff of the California Air Resources Board, Sacramento CA, March 2, 2011.
Invited presentation on Mobile Source Emission and Air Quality Past Present and Future to the staff of the Bay Area Air Quality Management District, San Francisco, CA, February 28, 2011.

Invited presentation on Inventory of Pollutant Emissions in the United States at the Chilean National Center for the Environment (Centro Nacional de Medio Ambiente, CENMA): Santiago Chile, October 12, 2010.

Invited presentation on Need to Reconsider Future Control Strategies for Reducing Ozone Levels in California. at the Coalition for Clean Air Brainstorming Session, Sacramento, CA, August 17, 2010.

Invited presentation on Ozone Trends in California's South Coast Air Basin. to the staff of the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 29, 2010.

Invited presentation on Mobile Source Emissions and Air Quality in California's South Coast Air Basin Past, Present and Future at a workshop organized by the Chilean National Center for the Environment (Centro Nacional de Medio Ambiente, CENMA), Santiago Chile, June 2010.

Professional Development Course on Recent Advances in Measurement of On-Road Motor Vehicle Emission Factors and Composition Profiles at the 2010 AWMA International Specialty Conference in Xian, China, May 1-14, 2010.

Invited presentation at the Integrated Program on Urban, Regional and Global Air Pollution, Workshop on Mexico Emissions Inventory, Mexico City , February 25-26, 2003 .

Invited presentation at Health Effects Institute Workshop to Improve Estimates of Diesel and Other Emissions for Epidemiologic Studies Baltimore, MD, December 4-6, 2002

Invited presentation to the National Research Council Committee on Air Quality Management in the United States in Denver, CO on July 18, 2001.

Contributing author in the Encyclopedia of Environmetrics (2001), A. H. El-Shaarawi and W.W. Piegorsch, Editors. John Wiley and Sons Ltd. United Kingdom

Invited presentation at the Office of Environmental Health Hazard Assessment's Scientific Meeting on Approaches to Assessing Health Impacts of Gasoline-Related Exposures in California - "Ambient Apportionment of Toxic Air Contaminants from Gasoline-Powered On-Road Vehicles" in Oakland, CA June 26-27, 2000

Invited participant at the Centre for Science and Environment's workshop to develop an air quality index for Delhi, India and review current air quality monitoring programs in Delhi, India on June 6-8, 2000.

Invited presentation at the Society of Toxicology Workshop on "What You've Always Wanted to Know about Airborne Particulate Matter, but Were Afraid to Ask" in Philadelphia, PA on March 19-23, 2000.

Respondent at the Health Effects Institute Workshop on Mobile Source Air Toxics: Exposure and Risk in Washington, DC on February 8, 2000.

Invited presentation at the California Air Resources Boards workshop on "Air Pollution Health Effects: Data Gaps and Immediate Research Needs" in Sacramento, CA on July 29-30, 1999.

Invited presentation at the 1999 Urban Air Toxics Summer Symposium at Dedham, MA on July 8-10, 1999 on HAPs monitoring data.

Invited presentation to the National Research Council Committee to Review EPA's Mobile Source Emission Factor (MOBILE) Model in Irvine, CA on March 4, 1999.

Invited presentation to the Air Quality Planning and Assessment Division of the Texas Natural Resource Conservation Commission in Austin, TX on July 27, 1998 on the Northern Front Range Air Quality Study.

Invited presentation at the Western States Air Resources (WESTAR) Council's PM2.5 Emissions Inventory Workshop held in Reno on July 22 and 23, 1998.

Served on expert panel for the PM2.5 Monitoring Forum held in Sacramento on March 17, 1998 by the California Air Resources Board.

Invited presentation at the meeting of the U.S./Mexico Air Quality Workgroup in San Diego on October 16, 1997 on apportionment of ambient hydrocarbon in Paso del Norte region.

Invited presentation in Washington D.C. on October 16, 1997 to the Federal Advisory Committee Act (FACA) Subcommittees on Modeling and In-Use Vehicle Deterioration on the use of ambient data to evaluate emission inventories.

Invited presentation at the Cascadia Tropospheric Ozone Peer Review Meeting in Seattle, WA. on September 9, 1997 on apportionment of volatile organic compounds in western Washington.

Reviewer of U.S. EPA Internal Research Proposals.

Vice Chair, Session 15P, 1995 A&WMA 88th Annual Meeting, San Antonio, TX

Reviewer of the North American Strategy for Tropospheric Ozone

Invited reviewer of EPA's Western Conifer Research Cooperative's Study the Effects of Acid Deposition on Western Forests (1986-87)

Invited reviewer of the National Acid Precipitation Assessment Program National Acid Deposition Monitoring Program

Publications

Pine, S. and E. Fujita (1977). Ylide Autoxidation During the Stevens Rearrangement. J. Organic Chemistry, 42, 1460.

Fujita, E. and B. Croes (1990). Formaldehyde Emissions in the South Coast Air Basin Derived from Ambient Measurements. In Transactions, Tropospheric Ozone and the Environment, R.L. Berglund, D.R. Lawson and D.J. McKee, eds. Air & Waste Management Association, Pittsburgh, PA, pp. 717-739.

Grosjean, D., E. Tuazon and E. Fujita (1990). Ambient Formic Acid in Southern California Air: A Comparison of Two Methods, Fourier Transform Infrared Spectroscopy and Alkaline Trap-Liquid Chromatography with UV Detection. Environ. Sci. Technol., 24, 144.

Fujita, E., B. Croes, C. Bennett, D. Lawson, F. Lurmann and H. Main (1992). Comparison of Emission Inventory and Ambient Concentration Ratios of CO, NMOG, and NOx in California's South Coast Air Basin. J. Air Waste Manage. Assoc., 42, 264.

Chow, J.C., J.G. Watson, E.M. Fujita, Z. Lu, D.R. Lawson and L.L. Ashbaugh (1993). Temporal and Spatial Variations of PM2.5 and PM10 Aerosol in the Southern California Air Quality Study. Submitted to J. Exposure Anal. Environ. Epidemiology.

Fujita, E.M., editor (1993). Proceedings of the SCAQS Data Analysis Conference. Air & Waste Management Association, Pittsburgh, PA.

Fung, K., M. Porter, D. Fitz and E.M. Fujita (1993). Examination of Factors Affecting the Measurement of Hydrocarbons and Carbonyl Compounds for the Collaborative SJVAQS/AUSPEX Program. In Planning Air Quality Measurement and Modeling Studies: A Perspective Through SJVAQS/AUSPEX, P. Solomon, ed., Air & Waste Management Association, Pittsburgh, PA.

Chow, J.C., E.M. Fujita, J.G. Watson, Z. Lu, D.R. Lawson and L.L. Ashbaugh (1994). Evaluation of Filter-Based Aerosol Measurements During the 1987 Southern California Air Quality Study. Environ. Monitor. Assess. 30, 49-80.

Chow, J.C., J.G. Watson, E.M. Fujita, Z. Lu, D.R. Lawson and L.L. Ashbaugh (1994). Temporal and Spatial Variations of PM2.5 and PM10 Aerosol in the Southern California Air Quality Study. Atmos. Environ., 28, 2061-2080.

Fujita, E.M., D.R. Goff, D.R. Lawson, A. Barnett, J.H. Price, J. Gibich, K.W. Rozacky, C.L. Martin, W.A. Lonneman, S.D. Hoyt, R.A. Rasmussen, W.L. Crow and L.D. Ogle (1994). Interlaboratory Comparison for Analysis of Hydrocarbons During the Coastal Oxidant Assessment for Southeast Texas (COAST) Project. In Proceedings of the 1994 U.S. EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC, 2-6 May 1994, Air & Waste Management Association, Pittsburgh, PA, pp. 173-183.

Fujita, E.M., J.G. Watson, J.C. Chow and Z. Lu (1994). Validation of the Chemical Mass Balance Receptor Model Applied to Hydrocarbon Source Apportionment in the Southern California Air Quality Study. Environ. Sci. Technol., 28, 1633-1649.

Fung, K., M. Porter, D. Fitz and E.M. Fujita (1994). Evaluation and Development of Methods for the Measurement of Hydrocarbons and Carbonyl Compounds. In Planning and Managing Regional Air Quality Modeling and Measurement Studies, P.A. Solomon, ed. Lewis Publishers, Boca Raton, FL, pp. 711-736.

Gertler, A.W., E.M. Fujita, W.R. Pierson and D.N. Wittorff (1994). Apportionment of VOC Tailpipe vs Non-Tailpipe Emissions in the Fort McHenry and Tuscarora Tunnels. In Proceedings of an International Specialty Conference on the Emission Inventory: Perception and Reality, Pasadena, California, 18-20 October 1993, W.R. Oliver, ed. Air & Waste Management Association, Pittsburgh, PA, 1994, pp. 28-38.

Watson, J.G., J.C. Chow, E. Fujita, Z. Lu, S.L. Heisler and T. Moore (1994). Wintertime Source Contributions to Light Extinction in Tuscon, AZ. In Proceedings of the International Specialty Conference on Aerosols and Atmospheric Optics: Radiative Balance and Visual Air Quality, Snowbird, UT, 26-30 September 1994, Air & Waste Management Association, Pittsburgh, PA, p. 1187.

Watson, J.G., J.C. Chow, Z. Lu, E.M. Fujita, D.H. Lowenthal, D.R. Lawson and L.L. Ashbaugh (1994). Chemical Mass Balance Source Apportionment of PM10 During the Southern California Air Quality Study. Aerosol Sci. Technol., 21, 1-36.

Zielinska, B. and E.M. Fujita (1994). The Composition and Concentration of Hydrocarbons in the Range of C2 to C18 in Downtown Los Angeles, CA. Res. Chem. Intermed., 20, 321-334.

Zielinska, B. and E.M. Fujita (1994). Organic Gas Sampling. In Environmental Sampling for Trace Analysis, B. Markert, ed. VCH, Weinheim, Germany, 7, 163-184.

Chow, J.C., D. Fairley, J.G. Watson, R. De Mandel, E.M. Fujita, D.H. Lowenthal, Z. Lu, C.A. Frazier, G. Long and J. Cordova (1995). Source Apportionment of Wintertime PM10 at San Jose, CA. J. Environ. Engineering, 21, 378-387.

Fujita, E.M., J.G. Watson, J.C. Chow and K.L. Magliano (1995). Receptor Model and Emissions Inventory Source Apportionments of Nonmethane Organic Gases in California's San Joaquin Valley and San Francisco Bay Area. Atmos. Environ., 29(21), 3019-3035.

Lawson, D.R., E.M. Fujita, J.R. Holmes, L.L. Ashbaugh and B.E. Croes (1995). The Southern California Air Quality Study: A Prototype for Collaborative Research. In Ozone: Science and Policy, M.O. Rodgers and P.A. Solomon, eds. Lewis Publishers, Chelsea, Michigan, to be submitted.

Watson, J.G., J.C. Chow, E.M. Fujita, D.R. Lawson and D.L. Blumenthal (1995). A Survey of Emissions, Meteorology, Chemical Transformations, and Data Sets Relevant to Receptor Modeling in Southern California. Submitted to Atmos. Environ.

Gertler, A.W., E.M. Fujita, W.R. Pierson and D.N. Wittorff (1996). Apportionment of NMHC Tailpipe vs Non-Tailpipe Emissions in the Fort McHenry and Tuscarora Mountain Tunnels. Atmos. Environ. 30, 2297-2305.

Harshfield, G., B. Zielinska, E.M. Fujita and J. Sagebiel (1996). Comparison of Tenax-TA Data Versus Canister and Continuous Gas Chromatographic Data for Gas-Phase Hydrocarbons with Carbon Number >C8. Measurements of Toxic and Related Air Pollutants VIP-50, A&WMA, 109-118.

Keislar, R.E., J.B. Bowen, E.M. Fujita, D.R. Lawson and W.R. Pierson (1997). Effects of Oxygenated Fuels on Ambient Carbon Monoxide Concentrations in Provo, Utah, Int. J. of Vehicle Design, 18(3) (Special Issue), 1997.

Zielinska, B., E. Fujita, J. Sagebiel, G. Harshfield, E. Uberna, T. Hayes, and F. Keene (1998). Arizona Hazardous Air Pollutants Monitoring Program. *J. Air Waste Manage. Assoc.*, 48: 1038-1050.

Watson, J., J.C. Chow, and E. Fujita (2001). Review of Volatile Organic Compound Source Apportionment by Chemical Mass Balance. *Atmos. Environ*. 35:1567-1584.

Apel, E., J. Calvert, D. Riemer, W. Pos, R. Zika, T. Kleindienst, W. Lonneman, K. Fung, E. Fujita, P. Shepson, and T. Starn (1998). Measurements Comparison of Oxygenated Volatile Organic Compounds at a Rural site During the 1995 SOS Nashville Intensive. *J. Geophys. Res.*, 98JD01753.

Apel, E., J. Calvert, J. Greenberg, D. Riemer, R. Zika, T. Kleindienst, W. Lonneman, K. Fung, and E. Fujita (1998). Generation and Validation of Oxygenated Volatile Organic Carbon Standards for the 1995 Southern Oxidants Study Nashville Intensive. J. Geophys. Res., in press.

Pierson, W., E. Schorran, E. Fujita, J. Sagebiel, D. Lawson, and R. Tanner (1999). Assessment of Non-Tailpipe Hydrocarbon Emissions from Motor Vehicles. *J. Air Waste Manage. Assoc*., 49: 498-519.

McDonald, J. D., B. Zielinska, E.M. Fujita, J.C. Sagebiel, J.C. Chow, and J.G. Watson (2000). Fine Particle and Gaseous Emission Rates from Residential Wood Combustion. Submitted to Environmental Science and Technology, 34: 2080-2091.

Watson, J.G., T. Zhu, J.C. Chow, J. Engelbrecht, E.M. Fujita, and W.W. Wilson (2001). Receptor Models for Particulate Source Apportionment. *Atmos. Environ.* 35, 1567-1584.

Fujita E.M. (2001). Hydrocarbon Source Apportionment for the 1996 Paso del Norte Ozone Study. *Science of the Total Environment* 276, 171-184.

The Committee's final report entitled "Congestion Mitigation and Air Quality: A National Need for Local Experiments", 2002. National Academy of Sciences National Research Council/Transportation Research Board study committee to evaluate the Congestion Mitigation and Air Quality Improvement (CMAQ) Program.

McDonald, J. D., B. Zielinska, E.M. Fujita, J.C. Sagebiel, J.C. Chow, and J.G. Watson Jacob (2003). Emissions from Charbroiling and Grilling of Chicken and Beef. *J. Air & Waste Manage. Assoc*. 53: 185-194.

Rogers, C.F., J.C. Sagebiel, B. Zielinska, W. P. Arnott, E.M. Fujita, J.D. McDonald, J.B. Griggin, K. Kelly, D. Overacker, D. Wagner, J.S. Lighty, A. Srofim and G. Palmer (2003). Characterization of Submicron Exhaust Particles from Engines Operating Without Load on Diesel and JP-8 Fuels. *Aerosol Sci. Technol.* **37**:355-368.

Fujita, E.M., W.R. Stockwell, D.E. Campbell, and R.E. Keislar (2003). Evolution of the Magnitude and Spatial Extent of the Weekend Ozone Effect in California's South Coast Air Basin from 1981 to 2000. *J. Air & Waste Manage. Assoc*. **53**:802-815

Fujita, E.M., D.E. Campbell, B. Zielinska, J.C. Sagebiel, J.L. Bowen, W. Goliff, W.R. Stockwell, and D.R. Lawson (2003). Diurnal and Weekday Variations in Source Contributions of Ozone Precursors in California's South Coast Air Basin. *J. Air & Waste Manage. Assoc*. **53**: 844-863.

Fujita, E.M., G. Harshfield, and L.H. Sheetz (2003). Performance Audits and Laboratory Comparisons for SCOS97-NARSTO Measurements of Speciated Volatile Organic Compounds. *Atmos. Environ.* 37, Supplement No. 2, S135-S147.

Zielinska, B and E.M. Fujita (2003). Characterization of Ambient Volatile Organic Compounds at the Western Boundary of the SCOS97-NARSTO Modeling Domain. *Atmos. Environ.* 37, Supplement No. 2, S171-S180.

Croes, B.E. and E.M Fujita, (2003). The 1997 Southern California Ozone Study (SCOS97-NARSTO): Introduction and Perspective. *Atmos. Environ.* 37, Supplement No. 2, S3-S26.

Rinehart, L.R., E,M. Fujita, J.C. Chow and B. Zielinska (2006). Spatial Distribution of PM2.5 Associated Organic Compounds in the San Joaquin Valley. *Atmos. Environ.* 40. 290-303.

Melvin Zeldin, Yushuo Chang, Thomas Christofk, David Campbell, Eric Fujita, and Richard Countess (2007). The Roseville Rail Yard Project: A Cooperative Program to Reduce Air Toxics Risk. *Environmental Manager*, January 2007

Ceballos, D.M., B. Zielinska, J. Sagebiel and E.M. Fujita (2007) Characterization Of Solid Phase Micro Extraction And Gas Chromatography For The Analysis Of Gasoline Tracers In Different Microenvironments. *J. Air Waste Manage. Assoc.* **57**: 355-365.

Fujita, E.M., B. Zielinska, D.E. Campbell, W.P. Arnott, J. Sagebiel, L. Mazzoleni, J.C. Chow, N. P.A. Gabele, W. Crews, R. Snow, N. Clark, S. Wayne and D.R. Lawson (2007). Variations in speciated emissions from spark-ignition and compression ignition motor vehicles in the California's South Coast Air Basin. *J. Air Waste Manage. Assoc.* **57**: 705-720.

Fujita, E. M., D. E. Campbell, W. P. Arnott, B. Zielinska (2007). Evaluations Of Source Apportionment Methods for Determining Contributions Of Gasoline and Diesel Exhaust to Ambient Carbonaceous Aerosols. *J. Air Waste Manage. Assoc.* **57**: 721-740.

Fulper, C.R., S. Kishan, R.W. Baldauf, M. Sabisch, J. Warila, E.M. Fujita, C. Scarbro1 W.C. Crews, R. Snow, P. Gabele, R. Santos, G. Tierney, and B. Cantrell (2010). Methods of Characterizing the Distribution of Exhaust Emissions from Light-Duty, Gasoline-Powered Motor Vehicles in the U.S. Fleet. J. Air & Waste Manage. Assoc. 60:1376-1387.

Watson, J. G., J.C. Chow, L.-W. A. Chen, D.H. Lowenthal, E.M. Fujita, H.D. Kuhns, D.A. Sodeman, D.E. Campbell, H. Moosmüller, D. Zhu and N. Motallebi (2011). Particulate Emission Factors for Mobile Fossil Fuel and Biomass Combustion Sources. STOTEN, in press.

Zielinska, B., E. Fujita, W. Ollison, D. Campbell, J. Sagebiel, P. Merritt and L. Smith (2011). Relationships of Attached Garage and Home Exposures to Fuel Type and Emission Levels of Garage Sources, Air Quality, Atmosphere and Health, in press

Mason, J. Brooks E.M. Fujita, D.E. Campbell and B. Zielinska (2011): Evaluation of Passive Samplers for Assessment of Community Exposure to Toxic Air Contaminants and Related Pollutants, ES&T, in press

Fujita, E.M.; Campbell, D.E.; Zielinska, B.; Chow, J.C.; Lindhjem, C.E.; DenBleyker, A; Bishop, G.A; Schuchmann B.G.; Stedman, D.H.; Lawson, D.L. (2012). Comparison of the MOVES2010a, MOBILE6.2 and EMFAC2007 Mobile Source Emissions Models with On-Road Traffic Tunnel and Remote Sensing Measurements. J. Air & Waste Manage. Assoc. 62:xxxx-xxxx.

Presentations

Fujita, E. and J. Collins (1989). Quality Assurance for the Southern California Air Quality Study. Paper No. 89-111.5, presented at the 82nd Annual Meeting of the Air and Waste Management Association, Anaheim, CA, 25-30 June 1989.

Fujita, E. (1990). Volatile Organic Compound Measurements for SJVAQS/AUSPEX. Presented at the CARB/CSUF Symposium on the San Joaquin Valley Air Quality Study, Fresno, CA, 7-8 May 1990.

Fujita, E., B. Croes and F. Lurmann (1990). Comparisons of Ambient and Emission Inventory Data in the South Coast Air Basin. Presented at the CRC-APRAC Vehicle Emission Modeling Workshop, Newport Beach, CA, 30-31 October 1990.

Ashbaugh, L., B. Croes, E. Fujita and D. Lawson (1990). Emission Characteristics of California's 1989 Random Roadside Survey. Presented at the 13th North American Motor Vehicle Emissions Control Conference, Tampa, FL, 11-14 December 1990.

Fung K., M. Porter, D. Fitz and E. Fujita (1991). Evaluation and Development of Methods for the Measurement of Hydrocarbons and Carbonyl Compounds for the Collaborative SJVAQS/AUSPEX Program. Paper 91-72.4, presented at the 84th Annual Meeting of the Air and Waste Management Association, Vancouver, British Columbia, 16-21 June 1991.

Main, H., F. Lurmann and E. Fujita (1991). Analysis of Southern California Air Quality Study (SCAQS) NMOC Data: Spatial and Temporal Issues. Paper 91-66.10, presented at the 84th Annual Meeting of the Air and Waste Management Association, Vancouver, British Columbia, June 16-21, 1991.

Fujita, E., B. Croes, C. Bennett, D. Lawson, H. Main and F. Lurmann (1991). Comparison of Emission Estimates and Ambient Concentrations of CO, NMOC, and NOx in California's South Coast Air Basin. Presented at the International Specialty Conference on Emission Inventory Issues in the 1990's, Durham, NC, 9-12 September 1991.

Fujita, E. (1992). Evaluation of SCAQS Gas-Phase Measurements. Presented at the Southern California Air Quality Study Data Analysis Conference, Los Angeles, CA, 21-23 July 1992.

Fujita, E. (1992). Trends in Emissions and Ambient Concentrations of CO, NMHC and NOX in the South Coast Air Basin. Presented at the Southern California Air Quality Study Data Analysis Conference, Los Angeles, CA, 21-23 July 1992.

Chow, J.C., J.G. Watson, E.M. Fujita, D.H. Lowenthal, Z. Lu, C.A. Frazier, D. Fairley, R. De Mandel, G. Long and J. Cordova (1993). Results from the 1991-92 Pilot Study of Wintertime PM10 in the San Francisco Bay Area. Paper 93-WA-75.05, presented at the Air & Waste Management Association 86th Annual Meeting, Denver, CO, 13-18 June 1993.

Fujita, E., J.G. Watson, J.C. Chow and K.L. Magliano (1993). Source Contributions to Volatile Organic Compounds in Central California During SJVAQS/AUSPEX. Paper No. 93-OT3-I.5, presented at the A&WMA International Specialty Conference on Regional Photochemical Measurement and Modeling Studies, San Diego, CA, 8-12 November 1993.

Gertler, A.W., E.M. Fujita, W.R. Pierson and D.N. Wittorff (1993). Apportionment of VOC Tailpipe vs. Running and Resting Losses in Tuscarora and Fort McHenry Tunnels. Presented at the EPA/A&WMA International Conference on the Emission Inventory: Perception and Reality, Pasadena, CA, 18-20 October 1993.

Gertler, A.W., E.M. Fujita, W.R. Pierson and D.N. Wittorff (1993). Apportionment of NMHC Tailpipe vs. Non-Tailpipe Emissions in Tuscarora and Fort McHenry Tunnels. Paper No. 93-OT3-P.2, presented at the A&WMA International Specialty Conference on Regional Photochemical Measurement and Modeling Studies, San Diego, CA, 8-12 November 1993.

Korc, M.E., L.R. Chinkin, P.T. Roberts, F.W. Lurmann, H.H. Main, E. Fujita and K. Magliano (1993). Reconciliation of Emission Inventory and Ambient Data: Current State of Knowledge and Implications for Photochemical Modeling. Paper No. 93-OT3-I.2, presented at the A&WMA International Specialty Conference on Regional Photochemical Measurement and Modeling Studies, San Diego, CA, 8-12 November 1993.

Lawson, D.R., E.M. Fujita, A.W. Gertler, R.L. Tanner and W.R. Pierson (1993). Mobile, Stationary and Area Source Emission Research Needs and Policy Issues—Where Do We Go from Here? Paper No. C1-I.4, presented at the A&WMA International Specialty Conference on Regional Photochemical Measurement and Modeling Studies, San Diego, CA, 8-12 November 1993.

Lawson, D.R., E.M. Fujita, J.R. Holmes, L.L. Ashbaugh and B.E. Croes (1993). The Southern California Air Quality Study: A Prototype for Collaborative Research. Paper No. 93-OT1-I.3, presented at the A&WMA International Specialty Conference on Regional Photochemical Measurement and Modeling Studies, San Diego, CA, 8-12 November 1993.

Fujita, E.M., D.R. Goff, D.R. Lawson, J.H. Price, J. Gibich, C.L. Martin, W.L. Lonneman, S.D. Hoyt, R.A. Rasmussen, W.L. Crow and L.D. Ogle (1994). Interlaboratory Comparison for Analysis of Hydrocarbons During the Coastal Oxidant Assessment for Southeast Texas (COAST) Project. Presented at the A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC, 2-6 May 1994.

Watson, J.G., J.C. Chow, E.M. Fujita, C.A. Frazier, Z. Lu, S.L. Heisler and C.T. Moore (1994). Aerosol Data Validation for the 1992-93 Tucson Urban Haze Study. Paper No. 94-TA24.02, presented at the Air & Waste Management Association 87th Annual Meeting, Cincinnati, OH, 19-24 June 1994.

Watson, J.G., J.C. Chow, E. Fujita, Z. Lu, S.L. Heisler and T. Moore (1994). Wintertime Source Contributions to Light Extinction in Tucson, AZ. Presented at the A&WMA/AGU International Specialty Conference on Aerosols and Atmospheric Optics: Radiative Balance and Visual Air Quality, Snowbird, UT, 26-30 September 1994.

Fujita, E.M. (1995) Evaluation of the Emission Inventory in the South Coast Air Basin. Presented at the Fifth CRC On-Road Vehicle Emissions Workshop, San Diego, CA, April 1995.

Fujita, E.M. (1995). Ambient Versus Emission Inventory NMHC, CO, NOx Trends in the South Coast Air Basin (1987-1993). Paper 95-RP113B.01, presented at the Air & Waste Management Association 88th Annual Meeting, San Antonio, TX, 18-23 June 1995.

Fujita, E.M., Z. Lu, J.H. Price, K.W. Rozacky, D. Brymer and J. Gibich (1995). Validation and Evaluation of the Coastal Oxidant Assessment for Southeast Texas (COAST) Volatile Organic Compound Data. Poster 95-TP15P.01, presented at the Air & Waste Management Association 88th Annual Meeting, San Antonio, TX, 18-23 June 1995.

Harshfield, G., B. Zielinska, E.M. Fujita and J.C. Sagebiel (1995). Comparison of Tenax-TA Data Versus Canister and Continuous Gas Chromatographic Data for Gas-Phase Hydrocarbons with Carbon Number >C8. Presented at the A&WMA/EPA International Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC, 16-18 May 1995.

Zielinska, B., E.M. Fujita, J.C. Sagebiel, C. Fernandez, F. Keene, G. Monroy and J. Burchard (1995). Arizona Hazardous Air Pollutants Monitoring Program. Paper 95-WP82.05, presented at the Air & Waste Management Association 88th Annual Meeting, San Antonio, TX, 18-23 June 1995.

Zielinska, B., J.C. Sagebiel, W.R. Pierson, A.W. Gertler and E.M. Fujita (1995). Volatile Toxic Organic Compounds Emitted from Motor Vehicles – Diesel versus Spark Ignition. Presented at the Fourth International Congress on Toxic Combustion Byproducts, Berkeley, CA, 5-7 June 1995.

Fujita, E.M. (1996). Determination of Mobile Source Emission Source Fraction Using Ambient Field Measurements. Presented at the Sixth CRC On-Road Vehicle emissions workshop, San Diego, CA, March 18-20, 1996.

Fujita, E.M., W.A. Lonneman, A. Van Arsdale and A. Oi (1996). Narsto-NE Hydrocarbon Laboratory Comparison. Presented at the A&WMA Conference and Courses: Measurement of Toxic and Related Air Pollutants, RTP, NC, May 7-9, 1996.

Fujita, E.M., Z. Lu, N.F. Robinson and J.G. Watson (1996). Application of Chemical Mass Balance Model to Coastal Oxidant Assessment for Southeast Texas Volatile Organic Compound Data. To be presented at the Air & Waste Management Association 89th Annual Meeting, Nashville, TN, June 23-28, 1996.

Keislar, R.E., J.L. Bowen, E.M. Fujita, D.R. Lawson and W.R. Pierson (1996). Effects of Oxygenated Fuels on Ambient Carbon Monoxide Concentrations in Provo, Utah. Presented at the Sixth CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 18-20 March 1996.

Keislar, R.E., J.L. Bowen, E.M. Fujita, D.R. Lawson and W.R. Pierson (1996). Effect of Oxygenated Fuels on Ambient Carbon Monoxide Concentrations in Provo, Utah, U.S.A. Presented at the 3rd Symposium, Traffic Induced Air Pollution - Emissions, Impact and Air Quality, Graz, Austria, 29-30 April 1996.

Keislar, R.E., J.L. Bowen, E.M. Fujita, D.R. Lawson and W.R. Pierson (1996). Effect of Oxygenated Fuels on Ambient Carbon Monoxide Concentrations in Provo, Utah. Paper 96-WP89.07, presented at the Air & Waste Management Association 89th Annual Meeting, Nashville, TN, 23-28 June 1996.

Fujita, E.M., B. Zielinska, L.H. Sheetz, G. Harshfield, and E. Urberna (1996). Hydrocarbon and Carbonyl Audits for NARST-Northeast 1996 Field Study. Presented at the First NARSTO-Northeast Data Analysis Symposium and Workshop, Norfolk, VA, 10-12 December, 1996.

Fujita, E.M., Z. Lu, L.H. Sheetz, G. Harshfield, and B. Zielinska (1997). Determination of Mobile Source Fraction Using Ambient Data. Presented at the Seventh CRC Mobile Source Emission Workshop, San Diego, CA, 9-11 April 1997.

Zielinska, B., G. Harshfield, E. Fujita, and J. Sagebiel (1997). Volatile Organic Compound Concentrations in the South Coast Air Basin (CA) during the Summers of 1995 and 1996. Presented at the A&WMA 90th Annual Meeting, Toronto, Ontario, Canada, 9-13 June 1997.

Fujita, E., J. Shire, G. Harshfield, E. Uberna, and B. Zielinska (1997). Performance Audits for Measurements of Carbonyl Compounds during the NARSTO-Northeast 1996 Summer Ozone Study. Presented at the American Geophysical Union 1997 Fall Meeting, Sand Francisco, CA, 8-12 Dec. 1997

Fujita, E., T. Hayes, J. McDonald, J. Sagebiel, B. Zielinska, J.C. Chow, and J.G. Watson (1998). Source Apportionment of Ambient PM2.5 Carbon in the Northern Front Range of Colorado. Presented at the 8th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 20-22 April, 1998.

Zielinska, B., E. Fujita, T. Hayes, J. Sagebiel, J.C. Chow, and J.G. Watson (1998). Development of the Mobile Source Chemical Composition Profiles for Application in the Source Attribution Study. Presented at the 8th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 20-22 April, 1998.

Hyde, P. and E. Fujita (1998). Evaluating VOC Inventories with Receptor Modeling and UAM Modeling. Presented at A&WMA 91st Annual Meeting & Exhibition, San Diego, CA, 14-18 June, 1998.

Fujita, E., J. McDonald, T. Hayes, B. Zielinska, J. Sagebiel, J.C. Chow, and J.G. Watson (1998). Northern Front Range Air Quality Study: Apportionment of Carbonaceous Particles. Presented at A&WMA 91st Annual Meeting & Exhibition, San Diego, CA, 14-18 June, 1998.

Fujita, E., J. Bowen, M. Green, H. Moosmuller (1998) The 1997 Southern California Ozone Study-NARSTO: Quality Assurance and Data Management. Presented at A&WMA 91st Annual Meeting & Exhibition, San Diego, CA, 14-18 June, 1998.

Zielinska, B., E. Uberna, E. Fujita, J. McDonald, and T. Hayes (1998). Northern Front Range Air Quality Study: The Analysis of Ambient Fine Particle Organic Matter. Presented at A&WMA 91st Annual Meeting & Exhibition, San Diego, CA, 14-18 June, 1998.

Fujita, E. and J.G. Watson (1998). Validation and Applications Protocol for Source Apportionment of Volatile Organic Compounds and Fine Particles. Presented at EPA/A&WMA 18th Symposium on Measurement of Toxic and Related Air Pollutants, Cary, NC, 1-3 September, 1998.

Fujita, E., T. Hayes, R. Keislar, W. Goliff, L. Sheetz, M. Keith, J. Sagebiel, and B. Zielinska, C. Harder, S. Torpey, D. Castro, L. Moon, R. Ramon, and E. Collins (1999). 1998 On-Road Hydrocarbon Study. Presented at the 9th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 20-22 April, 1999.

Keislar, R., H. Moosmuller, F. Rogers, H. Kuhns, E. Fujita and J. Watson (1999). Measurement of on-road particulate matter emissions by LIDAR. Presented at the Ninth CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 20-22 April, 1999.

Fujita, E., (1999). Hydrocarbon source apportionment for the 1996 Paso del Norte Ozone Study. Presented at A&WMA 92nd Annual Meeting & Exhibition, St. Louis, MO, 20-24 June, 1999.

Fujita, E., R. Keislar, and W. Stockwell (2000). What do on-road motor vehicle have to do with higher ozone on weekends in the South Coast Air Basin?. Presented at the 10th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 27-29 March, 2000.

Keislar, R., H. Moosmuller, C. Mazzoleni, H. Kuhns, V. Etyemezian, E. Fujita, and J. Watson (2000). Evaluation of Lidar Measurement of On-Road Particulate Matter Emissions.. Presented at the 10th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 27-29 March, 2000.

Arnott, P.W., C.F. Rogers, J. Sagebiel, B. Zielinska, E. Fujita, and H. Moosmuller (2000). Evaluation of Aerosol-Bound PAHs and Elemental Carbon Aerosol in Diesel and Gasoline Vehicles. Presented at the 10th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 27-29 March, 2000.

Fujita, E., (2000). Technical issues related to on-road vehicle emissions. Presented at the 2nd Annual Meeting of the Nevada Section of Air & Waste Management Association Conference on Air Quality Planning for Transportation Conformity and Smoke Management in Reno, NV on May 19, 2000.

Zielinska, B., J. Sagebiel, J. Mc Donald, and E. Fujita (2000). Measurement of Diesel Emissions in Underground Gold Mines. Presented at the NARSTO 2000 Technical Symposium on Tropospheric Aerosols: Science and Decisions in an International Community, Queretaro, Mexico, October 23-36, 2000.

Fujita, E., (2001). SCOS97-NARSTO: Quality Assurance Issues. Presented at the SCOS97-NARSTO Data Analysis Conference, Diamond Bar, CA February 13-15, 2001.

Fujita, E., (2001). Source Attribution of Ambient Hydrocarbons in the South Coast Air Basin. Presented at the SCOS97-NARSTO Data Analysis Conference, Diamond Bar, CA February 13-15, 2001.

Fujita, E., R. Keislar, and W. Stockwell (2001). Why Ozone is Higher on Weekends in the South Coast Air Basin – A 20-Year Perspective. Presented at the SCOS97-NARSTO Data Analysis Conference, Diamond Bar, CA February 13-15, 2001.

Fujita, E., (2001). Contributions of Motor Vehicles to Ambient Concentrations of $PM_{2.5}$. Presented at the World Truck Conference, Monterey, CA March 4-6, 2001.

Fujita, E., R. Keislar, and W. Stockwell (2001). Weekend/Weekday Ozone Observations in the South Coast Air Basin – Phase 2 Field Study. Presented at the 11th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 26-28 March, 2001.

Fujita, E.M. B. Zielinska, J.C. Sagebiel, J. Bowen, W.R. Stockwell, M. McDaniel, D.E. Campbell, T.H. Funk, D.Coe, H.H. Main, C.P. McDonald, L.R. Chinkin, P.T. Roberts, and D.R. Lawson (2001). OHVT Weekend/Weekday Ozone Study in the South Coast Air Basin, Presented at the 7th Diesel Engine Emission Reduction (DEER) Workshop, Portsmouth, VA August 5-9, 2001.

Fujita, E.M., (2002). Ambient Versus Emission Inventory Reconciliation in the South Coast Air Basin from1987 to 2000. Presented at the 12th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 15-17 April, 2002.

Fujita, E.M., (2002). Ambient Versus Emission Inventory Reconciliation in the South Coast Air Basin from1987 to 2000. Presented at the 12th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 15-17 April, 2002.

Fujita, E.M., W.R. Stockwell, D.E. Campbell, and D.R. Lawson (2002). OHVT Weekend/Weekday Ozone Study In The South Coast Air Basin. Presented at the 8th Diesel Engine Emission Reduction (DEER) Workshop, San Diego, CA, August 25-29, 2002.

Fujita, E.M. and B. Zielinska (2002). Diesel Signature Studies and Uncertainties. Presented at the HEI Workshop to Improve Estimates of Diesel and Other Emissions for Epidemiologic Studies Baltimore, MD, December 4-6, 2002.

Fujita, E.M. (2003). Source Receptor Analysis for VOC and fine PM; Source Identification and Apportionment. Presented at the Integrated Program on Urban, Regional and Global Air Pollution, Workshop on Mexico Emissions Inventory, Mexico City , February 25-26, 2003 .

Fujita, E.M. (2003). On-Road Vehicle Particulate Emissions, Chemical Characterization and Source Apportionment. Presented at the World Truck Conference, Monterey, California, March 2-4, 2003.

Arnott, W.P., D. Campbell, E.M. Fujita, J.W. Walker, and H. Moosmüller (2003). Continuous Measurements of PM 2.5 and Black Carbon Mass: Gasoline/Diesel PM Split Study. Presented at the 13th CRC On-Road Vehicle Emissions Workshop, San Diego, California, April 8, 2003

Fujita, E.M., D.E. Campbell, W.P. Arnott, J.W. Walker, B. Zielinska, and J.C. Chow (2003). DOE's Gasoline/Diesel PM Split Study – Ambient Measurements. Presented at the 13th CRC On-Road Vehicle Emissions Workshop, San Diego, California, April 8, 2003

Schauer, J., C. Christensen, E. Fujita, B. Zielinska, N. Clark, P. Gabele, and D. Lawson (2003). Molecular Marker Fingerprints For Si And Ci Vehicles Operating Over Different Driving Cycles. Presented at the 13th CRC On-Road Vehicle Emissions Workshop, San Diego, California, April 8, 2003.

Zielinska, B., E.M. Fujita, J.C. Sagebiel, M. McDaniel and D.E. Campbell (2003). The Correlation of Lubricating Oil and Fuel Organic Composition with Tailpipe Emissions. Presented at the 13th CRC On-Road Vehicle Emissions Workshop, San Diego, California, April 8, 2003.

Fujita, E.M., W.R. Stockwell, D.E. Campbell, J. Engelbrecht, R. Keislar, J. Lewis, B. Zielinska, and J.C. Chow (2003). Weekday/Weekend PM Nitrate Observations in the South Coast Air Basin. Presented at the 13th CRC On-Road Vehicle Emissions Workshop, San Diego, California, April 8, 2003.

Fujita, E.M., D.E. Campbell, W.P. Arnott, B. Zielinska, J.C. Chow and Douglas R. Lawson (2003). Doe's Gasoline/Diesel Pm Split Study – Characterizations Of The Variations In Chemical Composition Of Pm2.5 In The South Coast Air Basin. Presented at the 9th Diesel Engine Emission Reduction (DEER) Workshop, Newport, RI, August 27, 2003.

Fujita, E.M. (2003). Evaluation of the On-Road Emission Inventory: Historic Perspective in California's South Coast Air Basin. Presented at the NARSTO Workshop on Innovative Methods for Emission Inventory Development and Evaluation, Austin, Texas, October 14-17, 2003.

Fujita, E.M., D.E. Campbell, W.P. Arnott, B. Zielinska and J.C. Chow (2003). DOE's Gasoline/Diesel PM Split Study: Source Characterization and Apportionment. Presented at the 22nd Annual American Association for Aerosol Research Conference, Anaheim CA, October 20-24, 2003.

Zielinska, B., E.M. Fujita, J.C. Sagebiel, M. McDaniel and D.E. Campbell (2003). The Correlation of Lubricating Oil and Fuel Organic Composition with Tailpipe Emissions. Presented at the 22nd Annual American Association for Aerosol Research Conference, Anaheim CA, October 20-24, 2003.

Fujita, E.M. (2004). Organic Speciation Related to Source Receptor Modeling. Presented at the International State of Science Workshop on Organic Speciation in Atmospheric Aerosols Research, Las Vegas Nevada, April 5-7, 2004.

Fujita, E.M., D.E. Campbell, B. Zielinska, W.P. Arnott, J.C. Chow and D.R. Lawson (2004). Doe's Gasoline/Diesel PM Split Study – Source Apportionment. Presented at the 14th CRC On-Road Vehicle Emissions Workshop, San Diego CA, March 29-31, 2004.

Lawson, D.R., P. Gabele, R. Snow, W.P. Arnott, E.M. Fujita, D.E. Campbell, J.W. Walker, H. Moosmüller (2004). Analysis of Second-by-Second Emissions Data from Gasoline Vehicles in DOE's Gasoline/Diesel PM Split Study. Presented at the 14th CRC On-Road Vehicle Emissions Workshop, San Diego CA, March 29-31, 2004.

Yarwood, G., E. Fujita, C. Tran and S. Lau (2004). Sensitivity of Los Angeles Area Ozone Modeling And Ambient/Inventory Reconciliation To EMFAC Updates (CRC Project A-38). Presented at the 14th CRC On-Road Vehicle Emissions Workshop, San Diego CA, March 29-31, 2004.

Fujita E.M., D.E. Campbell, B. Zielinska, and W.P. Arnott (2004). Assessing Exposure to Air Toxics in Microenvironments Dominated by Mobile Sources. Poster presented at 2004 Hei Annual Conference, Boston, MA, May 2–4, 2004

Fujita, E.M., D.E. Campbell, W.P. Arnott, B. Zielinska and J.C. Chow (2004). Source Contributions to Ambient Black Carbon in Colorado's Northern Front Range and California's South Coast Air Basin. Presented at the Black Carbon Emissions and Climate Change: A Technical Workshop, San Diego CA, October 13-15, 2004.

Fujita, E.M., B. Zielinska, D.E. Campbell, W.P. Arnott and D.R. Lawson (2004). Apportionment Of Mobile Source Air Toxics In The South Coast Air Basin. Presented at the CRC Mobile Source Air Toxics Workshop, Scottsdale, AZ, November 30 – December 2, 2004.

Lawson, D.R., P. Gabele, R. Snow, W.P. Arnott, E.M. Fujita, D.E. Campbell, J.W. Walker, H. Moosmüller (2004). Second-By-Second Gas-Phase And Pm Emissions Data And Their Relationship To Mobile Source Air Toxics Emissions From Gasoline Vehicles In Doe’s Gasoline/Diesel Pm Split Study. Presented at the CRC Mobile Source Air Toxics Workshop, Scottsdale, AZ, November 30 – December 2, 2004.

Zielinska, B., E.M. Fujita, J. Sagebiel, D.E. Campbell and W.M. Ollison (2004). Exposures To Mobile Source Toxics In High-End Microenvironments In Three U.S. Cities. Presented at the CRC Mobile Source Air Toxics Workshop, Scottsdale, AZ, November 30 – December 2, 2004.

Fujita, E.M., D.E. Campbell, B. Zielinska and W.P. Arnott (2004). Assessing Exposure To Air Toxics In Microenvironments Dominated By Mobile Sources. Poster presented at the CRC Mobile Source Air Toxics Workshop, Scottsdale, AZ, November 30 – December 2, 2004.

Fujita, E.M., Barbara Zielinska, William P. Arnott and David E. Campbell (2005). Recent Chemical Characterization Of Mobile Source Emissions – Relation To Ambient Measurements In Vehicle Dominated And Urban Background Locations. Presented at the AAAR PM Supersites Program and Related Studies, International Specialty Conference, Atlanta, GA, February 7-11, 2005

Fujita, E.M., B. Zielinska and D.E. Campbell (2005). Characterizing Exhaust Emissions from Light-Duty Gasoline Vehicles In The Kansas City Metropolitan Area – Chemical Speciation. Presneted at the 15th CRC On-Road Vehicle Emissions Workshop, San Diego CA, April 4-6, 2005.

Lawson D., E. Fujita, D. Campbell, B. Zielinska, W. Arnott, J. Chow, J. Schauer, C. Christensen, N. Clark, P. Gabele and W.Crews (2005). DOE's Gasoline/Diesel PM Split Study – Source Apportionment Results. Presented at the 15th CRC On-Road Vehicle Emissions Workshop, San Diego CA, April 4-6, 2005.

Fujita, E.M., D.E. Campbell, A. Centric, W.P. Arnott, B. Zielinska, and J.C.Chow (2005) Exposure to Air Toxics Along Southern California Roadways. Presented at the Health Effects Institute Annual Meeting, Baltimore, MD, April 17-19, 2005

Fujita, E.M., B. Zielinska, D.E. Campbell, W.P. Arnott, and J.C. Chow (2005). DOE's Gasoline/Diesel PM Split Study. Presented at the 11th Diesel Engine Emission Reduction (DEER) Workshop, Chicago, Il , August 21-25, 2005

Fujita, E.M., B. Zielinska, D.E. Campbell, W.P. Arnott, and J.C. Chow (2005). DOE's Gasoline/Diesel PM Split Study. Presented California Air Resources Board Chairman's Air Pollution Seminar Series, Sacramento, CA, September 7, 2005

Fujita, E.M., D.E. Campbell, W.P. Arnott, A. Centric, B. Zielinska and J.C. Chow (2005). Assessing Exposure to Air Toxics in Microenvironments Dominated by Mobile Sources. Presented at the 24th Annual American Association for Aerosol Research Conference, Austin, Texas, October 17-21, 2005.

Fujita , E.M., B. Zielinska, D.E. Campbell, W.P. Arnott, and J.C. Chow (2005). Contributions of Gasoline and Diesel Vehicle Emissions to Urban, Near-Road and On-Road Exposures to Carbonaceous Particles in Southern California. Presented at the 4th Asian Aerosol Conference, Mumbai, India, December 13-16, 2005.

Fujita , E.M. and B. Zielinska (2006). Ambient Measurements of 1,3-Butadiene, Acrolein and Particulate Organic Compounds: Challenges and Lessons. Presented at the Conference on Community Environmental Monitoring Programs, AWMA Golden West Chapter, San Francisco, CA, February 1, 2006.

Fujita , E.M. and B. Zielinska (2006). Application of Organic Molecular Markers for Ambient Apportionment of Fine Particulate Matter. Presented at the Bay Area Air Quality Management District Community Air Risk Evaluation Task Force Meeting, San Francisco, February 23, 2006.

Fujita, E.M. (2006). Source Apportionment of Ambient PM. Presented at the Bay Area Air Quality Management District Advisory Council Meeting, San Francisco, March 22, 2006

Fujita, E.M., D.E. Campbell, S. Uppapalli, A. King, B. Zielinska and J.C. Chow (2006). Characterizing Exhaust Emissions from LDGVs in the Kansas City Metropolitan Area – Chemical Speciation. Presented at the 15th CRC On-Road Vehicle Emissions Workshop San Diego, CA, March 28 – 30, 2006.

Fujita, E.M., D.E. Campbell and B. Zielinska (2006). Assessing Exposure to Air Toxics in Microenvironments Dominated by Mobile Sources. Poster Presentation at the 2006 Health Effects Institute Annual Conference, San Francisco, California, April 9– 11, 2006

Fujita , E.M. and B. Zielinska (2006). Source Apportionment of Fine Particulate Matter. Presented at the Conference on Ultrafine Particles, Los Angeles, California, April 30 - May 2, 2006.

Fujita, E.M., W.R. Stockwell, D.E. Campbell1, and D.R. Lawson (2006). Evolution of the Magnitude and Spatial Extent of the Weekend Ozone Effect in California's South Coast Air Basin from 1981 to 2004. Presented at the AWMA's 99th Annual Conference New Orleans, Louisiana, June 20-23, 2006.

Fujita, E.M., D.E. Campbell, W.P. Arnott and B. Zielinska (2006). Source Attribution of Mobile Source Air Toxics. Presented at the 2006 CRC MSAT Workshop Phoenix, AZ, October 23-25, 2006.

Fujita, E.M., D.E. Campbell, J. Sagebiel and B. Zielinska (2006). Assessing Exposure to Air Toxics in Microenvironments Dominated by Mobile Sources. Presented at the 2006 CRC MSAT Workshop Phoenix, AZ, October 23-25, 2006.

Campbell, D.E., E.M. Fujita, B. Zielinska, and J.C. Chow (2006). Characterization of Mobile Source Air Toxics Emissions from LDGVs in the Kansas City Metropolitan Area (A Preliminary Assessment). Presented at the 2006 CRC MSAT Workshop Phoenix, AZ, October 23-25, 2006.

Campbell D.E., E.M. Fujita, W.P. Arnott, and J. Walker (2007). Real-Time Measurements Of Pm And Black Carbon Emissions Compared To Filter-Based Pm And Elemental Carbon For Gasoline And Diesel Vehicles. Presented at the 16th CRC On-Road Vehicle Emissions Workshop San Diego, CA, March 26 – 28, 2007.

Fujita, E.M., D.E. Campbell and B. Zielinska (2007). Chemical Analysis of Lubrication Oil Samples from LDGV in the Kansas City Metropolitan Area. Presented at the 16th CRC On-Road Vehicle Emissions Workshop San Diego, CA, March 26 – 28, 2007.

Lawson, D.R., P. Gabele, E.M. Fujita, D.E. Campbell, B. Zielinska, and W.P. Arnott (2007). Gas-Phase and PM Emissions Characteristics from Gasoline Vehicles in DOE's Gasoline/Diesel PM Split Study. Presented at the 16th CRC On-Road Vehicle Emissions Workshop San Diego, CA, March 26 – 28, 2007.

Fujita, E.M. (2007). Assessment of Exposures to Mobile Source Air Toxics. Presented at the Air Toxics Workshop, Houston, TX, June 12-13, 2007.

Fujita, E., D. Campbell, and B. Zielinska (2007). Characterization of Particle Emission from Light-Duty Gasoline Vehicles in the Kansas City Metropolitan Area. Presented at the 5th Asian Aerosol Conference in Kaoshiung, Taiwan, August 26-29, 2007.

Fujita, E.M. (2007). Mobile Source Emissions and Air Quality inCalifornia's South Coast Air Basin – Past, Present and Future. Presented to the Japanese Automotive Manufacturers Association in Tokyo Japan on September 4, 2007.

Fujita, E.M. (2007). Community and Microenvironmental Exposure Assessment. Presented at the Conference on Health Impacts of Air Pollution on Communities in Carson, CA on September 19-20, 2007.

Zielinska, B., E.Fujita, W. Ollison, D. Campbell, P. Merritt, L. Smith, and J. Sagebiel (2010) Relationships of Attached Garage and Home Exposures to Fuel Type and Emission Levels of Garage Sources, presented at the AAAR Specialty Conference, Air Pollution and Health San Diego, CA March 22-26, 2010

Fujita, E.M., D.E. Campbell, P. Arnott, B. Zielinska, T. Johnson and J. Mozier (2010) Measurements of Mobile Source Air Pollutants in Urban Microenvironments, presented at the AAAR Specialty Conference, Air Pollution and Health San Diego, CA March 22-26, 2010

Fujita, E.M., J.B. Mason, D.E. Campbell and B. Zielinska (2010). Harbor Communites Monitoring Study (HCMS) Saturation Monitoring of Toxic Air Contaminants and Related Pollutans. California Air Resources Board Webcast Seminar, Sacramento, CA, April 26, 2010.

Fujita, E.M., J.B. Mason, D.E. Campbell and B. Zielinska (2010): Saturation Monitoring for Assessment of Community Exposure to Toxic Air Contaminants and Related Pollutants, poster presented at the 2010 AWMA International Specialty Conference in Xian, China, May 1-14, 2010.

Zielinska, B., E. Fujita and I.A. Khalek (2010) Comparison of New and Old Diesel Engine Emissions, presented at the 29th Annual AAAR Conference, October 25-29, Portland, OR

Zielinska, B., E. Fujita and D. Campbell (2010) Monitoring of Emissions from Barnett Shale Natural Gas Production Facilities for Population Exposure Assessment, invited presentation at the Mickey Leland NUATRC 2010 Symposium Credible Science to Address Texan's Health: Exposure to Air Toxics Dallas TX, November 16, 2010.

Zielinska, B., E. Fujita, D. Campbell, V. Samburova, E. Hendler and C.S. Beskid (2010): Monitoring of Emissions from Natural Gas Production Facilities in Barnett Shale Area for Population Exposure Assessment, poster presented at the AGU Fall meting in San Francisco, Dec 13-17, 2010

Campbell, D., E. Fujita, W.Patrick Arnott, P. Martien and V. Lau (2010). West Oakland Monitoring Study Saturation Monitoring of Air Toxics. Presented at the 2010 CRC Mobile Source Air Toxics Workshop, November 30 - December 2, 2010, Sacramento, CA

Fujita, E., B. Zielinska, J. Carroll, K. Whitney, I. Khalek, L. Smith and D. Lawson (2010). Collaborative Lubricating Oil Study on Emissions (CLOSE) Project Update - Role of Fuel and Lubricating Oil in PM Emissions from a Normal- and a High-Emitting Light-Duty Gasoline Vehicle. Presented at the 2010 CRC Mobile Source Air Toxics Workshop, November 30 - December 2, 2010, Sacramento, CA

Reports

Fujita, E. and L. Shepard (1978). Consideration of Model Rule for the Control of Volatile Organic Emissions from Metal Furniture and Fixture Coating Operations. Prepared for California Air Resources Board, Sacramento, CA, June 1978.

Fujita, E., L. Shepard, D. Saito, R. Cargill, J. Pantalone and G. Shiroma (1978). Consideration of a Proposed Model Rule for the Control of Volatile Organic Compound Emissions from the Surface Coating of Manufactured Metal Parts and Products. Prepared for California Air Resources Board, Sacramento, CA, September 1978.

Sanders, J., E. Fujita, K. Tonnessen, D. Westerdahl, L. Ashbaugh, M. Ahuja, C. Robertson and P. Amar (1984). Second Annual Report to the Governor and the Legislature on the Air Resources Board's Acid Deposition Research and Monitoring Program. Prepared for the Research Division, California Air Resources Board, Sacramento, CA, December 1984.

Ashbaugh, L., E. Fujita, M. Ahuja, J. Sanders, K. Tonnessen, D. Westerdahl and P. Amar (1985). The Third Annual Report to the Governor and the Legislature on the Air Resources Board's Acid Deposition Research and Monitoring Program. Prepared for the Research Division, California Air Resources Board, Sacramento, CA, December 1985.

Fujita, E., P. Amar, L. Ashbaugh, W. Walker, K. Tonnessen, M. Ahuja and D. Westerdahl (1986). The Fourth Annual Report to the Governor and the Legislature on the Air Resources Board's Acid Deposition Research and Monitoring Program. Prepared for the Research Division, California Air Resources Board, Sacramento, CA, December 1986.

Amar, P., L. Ashbaugh, E. Fujita, K. Tonnessen, M. Ahuja, D. Westerdahl, H. Cabrera, E. Ota, C. Unger, S. Champomier and N. Weir (1988). Fifth Annual Report to the Governor and the Legislature on the Air Resources Board's Acid Deposition Research and Monitoring Program. Prepared for the Research Division, California Air Resources Board, Sacramento, CA, January 1988.

Blanchard, C., M. Ahuja, L. Ashbaugh, S. Champomier, B. Croes, E. Fujita, S. Prasad, K. Wagner and D. Westerdahl (1989). The Health and Welfare Effects of Acid Deposition in California: Technical Assessment. Prepared for California Air Resources Board, Sacramento, CA, June 1989.

Bode, R., A. Delao, L. Dolislager, J. Fernandez, E. Fujita, N. Montez, M. Nystrom and G. Shahinian (1991). Amendments to Regulations Regarding the State 24-Hour Ambient Air Quality Standard for Sulfur Dioxide, Staff Report. Prepared for the Research Division, California Air Resources Board, Sacramento, CA, August 1991.

Chow, J.C., J.G. Watson, R. De Mandel, W. Chan, J. Cordova, D. Fairley, E.M. Fujita, D. Levaggi, G. Long, T. Perardi, and M. Rothenberg (1993). Measurements and Modeling of PM10 in San Francisco's Bay Area Volume I: Program Plan. DRI Document No. 3654.1D3. Prepared for Bay Area Air Quality Management District, San Francisco, CA, June 1993.

Diaz, S., E.M. Fujita and D.R. Lawson (1994). On-Road Vehicle Emissions Measurements Test Sites–Sacramento Pilot Project First Interim Report. Prepared for Bureau of Automotive Repair, May 23, 1994.

Diaz, S., E.M. Fujita and D.R. Lawson (1994). On-Road Vehicle Emissions Measurements Test Sites–Sacramento Pilot Project Second Interim Report. Prepared for Bureau of Automotive Repair, June 17, 1994.

Fujita, E.M., D.R. Lawson, J.C. Sagebiel, J.G. Watson, P.T. Roberts, P.M. Roth and S.D. Reynolds (1994). Quantification of Underestimates in the SARMAP Emissions Inventory. Draft Final Report, prepared for California Air Resources Board, Sacramento, CA, 20 October 1994.

Stoeckenius, T.E., G. Yarwood, M.P. Ligocki, J.P. Cohen, S.B. Shepard, R.E. Looker, E.M. Fujita, H.H. Main and P.T. Roberts (1995). Feasibility Study for a 1995-1996 Southern California Air Quality Monitoring Program. Final Report, prepared for Coordinating Research Council, Atlanta, GA by Systems Applications International, San Rafael, CA, January 1995.

Diaz, S., E.M. Fujita and D.R. Lawson (1995). Program for the Use of Remote Sensing Devices to Detect High-Emitting Vehicles—Program Plan. Final Report, prepared for the South Coast Air Quality Management District, Diamond Bar, CA, by the Desert Research Institute, Reno, NV, 30 January 1995.

Fujita, E.M., N. Robinson, Z. Lu, and R.T. Egami (1995). Database Utilities for Estimating and Compiling Hazardous Air Pollutant Emissions Using Emission Factors and Source Composition Profiles. Final Report. Prepared for State of Nevada, Department of Conservation and Natural Resources, Division of Environmental Protection, Carson City, NV.

Keislar, R.E., J.L. Bowen, E.M. Fujita,and D.R. Lawson (1995). Effect of Oxygenated Fuels on Ambient Carbon Monoxide Concentrations in Provo, Utah, Final Report. Prepared for Geneva Steel Company, P.O. Box 2500, Provo, Utah, 31 August 1995.

Fujita, E.M., Z. Lu, J. Sagebiel, G. Harshfield, and B. Zielinska (1995). Validation and Evaluation of the Coast Oxidant Assessment for Southeast Texas (COAST) Volatile Compound Data. Final report prepared for the Texas Natural Resource Conservation Commission, August 1995.

Fujita, E.M., Z. Lu, J. Sagebiel, N.F. Robinson, and J. G. Watson (1995). VOC Source Apportionment for the Coast Oxidant Assessment for Southeast Texas. Final report prepared for the Texas Natural Resource Conservation Commission, August 1995.

Fujita, E.M., M.C. Green, R.E. Keislar, D.R. Koracin, H. Moosmuller, and J.G. Watson (1996). 1997 Southern California Ozone Study (SCOS97) Operational Program Plan – Working Draft. Prepared for the California Air Resource Board, Sacramento, CA, February, 1996.

Lawson, D.R., S. Diaz, E.M. Fujita, S.L. Wardenburg, R.E. Keislar, Z. Lu and D.E. Schorran (1996). Program for the Use of Remote Sensing Devices to Detect High-Emitting Vehicles. Final Report. Prepared for Technology Advancement Office, South Coast Air Quality Management District, Diamond Bar, CA, April 16, 1996.

Fujita, E., J.G. Watson, D. Cobb, D. Dietrich, W. Neff, and L.W. Richards (1996). Northern Front Range Air Quality Study Winter 1996/97 Field Study Plan. Prepared for Colorado State University, Ft. Collins, CO, December, 1996.

Pierson W.R., D.R. Lawson, D.E. Schorran, E.M.Fujita, J.C. Sagebiel, and R.L. Tanner (1996). Assessment of Non-Tailpipe Hydrocarbon Emissions from Motor Vehicles. CRC Project No. VE-11-7. Final Report prepared for the Coordinating Research Council, Atlanta, GA, December 1996

Fujita, E.M., Z. Lu, C. Frazier, and J.G. Watson (1997). Application of the Chemical Mass Balance Receptor Model to Apportionment of Suspended Particulate Matter in the Bangkok Metropolitan Region. Prepared for Radian International, LLC, Austin, TX, January 26, 1997.

Fujita, E., J.G. Watson, B. Zielinska, J. McDonald, L. Sheetz, R. Purcell, J. Sagebiel, and F. Rogers (1997). Northern Front Range Air Quality Study Winter 1996/97 Field Study Plan Measurement and Characterization of Particulate Emissions from Residential Wood Combustion and Meat Cooking. Prepared for Colorado State University, Ft. Collins, CO February 24, 1997.

Fujita, E. and Z. Lu (1997). Hydrocarbon Receptor Modeling for the 1996 Phoenix Ozone Study. Final Report prepared for ENSR, Camarillo, CA, March 5, 1997.

Fujita, E.M., J.L. Bowen, M.C. Green, and H. Moosmuller (1997). 1997 Southern California Ozone Study (SCOS97) Quality Assurance Plan. Prepared for the California Air Resource Board, Sacramento, CA April, 1997.

Zielinska, B., J. Sagebiel, G. Harshfield, and E. Fujita (1997). Air Monitoring Program for Determination of the Impacts of the Introduction of California's Phase 2 Reformulated Gasoline on Ambient Air Quality in the South Coast Air Basin. Draft Final Report prepared for the California Air Resources Board, Sacramento, CA May 5, 1997.

Fujita, E.M., Z. Lu, L. Sheetz, G. Harshfield, and B. Zielinska (1997). Determination of Mobile Source Emission Source Fraction Using Ambient Field Measurements. Final Report prepared for the Coordinating Research Council, Atlanta, GA, July 1997.

Fujita, E., Z. Lu, G. Harshfield, and B. Zielinska (1997). NARSTO-Northeast: Hydrocarbon and Carbonyl Measurement Audits for the 1995 Field Study. Final Report prepared for the Electric Power Research Institute, Palo Alto, CA, July 1997

Fujita, E.M. (1997). Technical Review of the Phoenix Voluntary Early Ozone Plan – Application of Hydrocarbon Speciation Measurements and Source Apportionment in the Development of the VEOP Alternative Plausible Emission Inventory. Prepared for ENVAIR, September 1997.

Fujita, E., Z. Lu, G. Harshfield, and B. Zielinska (1997). NARSTO-Northeast: Hydrocarbon and Carbonyl Measurement Audits for the 1995 Field Study. Final Report prepared for the Electric Power Research Institute, Palo Alto, CA, July 1997

Fujita, E.M., Z. Lu, L. Sheetz, G. Harshfield, T. Hayes, and B. Zielinska (1997). Hydrocarbon Source Apportionment in Western Washington. Report prepared for the State of Washington Department of Ecology, Lacy, WA, September, 1997.

Yarwood, G., J. Heiken, C. Tran, M. Jiminez, E. Fujita, and Z. Lu (1997). Speciated VOC Emissions for the Dallas/Fort Worth Nonattainment Area. Final report prepared for the Texas Natural Resource Conservation Commission, Austin, TX, October 1997

Chow J., B. Zielinska, J.G. Watson, E. Fujita, L. Richards, W. Neff, D. Dietrich, and S. Herring (1998). Northern Front Range Air Quality Study Volume A: Ambient Measurements. Final report prepared for the Colorado State University, Fort Collins, CO., June 30, 1998

Fujita, E. (1998). Hydrocarbon Source Apportionment for the 1996 Paso del Norte Ozone Study. EPA Contract No. 68-D3-0030. Final report prepared for U.S. Environmental Protection Agency, Dallas, TX., March 1998.

Fujita, E., and Z. Lu (1998). Analysis of Data From the 1995 NARSTO-Northeast Study. Volume III: Chemical Mass Balance Receptor Modeling. Draft final report prepared for Coordinating Research Council, Atlanta, GA, April 1998.

Fujita, E., J.G. Watson, J.C. Chow, N. Robinson, L. Richards, and N. Kumar (1998). Northern Front Range Air Quality Study. Volume C: Source Apportionment and Simulation Methods and Evaluation. Final report prepared for Colorado State University, Fort Collins, CO, June 30, 1998.

Watson, J., E. Fujita, J.C. Chow, B. Zielinska, L. Richards, W. Neff, and D. Dietrich (1998). Northern Front Range Air Quality Study. Final report prepared for Colorado State University, Fort Collins, CO, June 30, 1998.

Watson, J.G., N.F. Robinson, E.M. Fujita, J.C. Chow, T.G. Pace, C. Lewis, and T. Coulter (1998). CMB8 Applications and Validation Protocol for PM2.5 and VOCs. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC, by Desert Research Institute, Reno, NV.

Zielinska, B. J. McDonald, T. Hayes, J.C. Chow, E. Fujita, and J.G. Watson (1998). Northern Front Range Air Quality Study. Volume B: Source Measurements. Final report prepared for Colorado State University, Fort Collins, CO, June 30, 1998.

Fujita, E. (1998). Emission Source Profiles Applicable to CMB Receptor Modeling of Texas PAMS VOC Data. TNRCC Contract No. 98 80078200. Final report prepared for the Texas Natural Resource Conservation Commission, Austin, TX, November 1998.

Fujita, E. (1998). MAG Brown Cloud Study Source Attribution of PM2.5. MAG Contract 0069 Work Task 7.1. Final Report prepared for the Maricopa Association of Governments, Phoenix, AZ, December, 1998.

Zielinska, B., J. Sagebiel, G. Harshfield, and E. Fujita (1999). Air Monitoring Program for Determination of the Impacts of the Introduction of California's Phase 2 Reformulated Gasoline on Ambient Air Quality in the South Coast Air Basin. Prepared for the California Air Resources Board, Sacramento, CA, February, 1999.

Fujita, E.M., R.E. Keislar, J.L. Bowen, W. Goliff, F. Zhang, L.H. Sheetz, M.D. Keith, J.C. Sagebiel, and B. Zielinska (1999). 1998 Central Texas On-Road Hydrocarbon Study. Draft final report prepared for the Texas Department of Transportation, Austin, TX under subcontract to PBS&J, Austin, TX, March, 1999.

Fujita, E. (1999). VOC Source Signatures in Houston, TX Phase 1: Sample Collection. Prepared for the Texas Natural Resource Conservation Commission (Contract No. 980069300) under subcontract to MCNC-North Carolina Supercomputing Center, Research Triangle Park, NC, August, 1999.

Fujita, E. (1999). Analysis of Ambient Air Quality Data in and Near Northern Baja California, Mexico, VOC Sampling and Source Apportionment - Sampling and Quality Assurance Plan. Prepared for the California Air Resources Board (Contract No. 98-541) under subcontract to Sonoma Technology, Inc. Petaluma, CA, September, 1999.

Fujita, E., R. Keislar, W. Stockwell, H. Moosmuller, D. DuBois, D. Koracin, and B. Zielinska (1999). Central California Ozone Study – Volume I Field Study Plan. Prepared for the CCOS Technical Committee c/o California Air Resources Board, Sacramento, CA, November 1999.

Fujita, E.M., H. Moosmuller, M.C. Green, J.L. Bowen, Leon Dolislager, Ash Lashgari, Nehzat Motallebi, Randy Pasek, and Jim Pederson (1997). SCOS97-NARSTO 1997 Southern California Ozone Study and Aerosol Study: Volume IV Summary of Quality Assurance. Prepared for the California Air Resource Board, Sacramento, CA December, 1999.

Zielinska, B., J.C. Sagebiel, J. Mc Donald, C.F. Rogers, and E. Fujita (2000). Diesel Emissions Exposure Measurements in Underground Mines. Draft final report prepared for the Health Effects Institute, Boston, MA, March 2000.

Fujita, E., R. Keislar, W. Stockwell, D. Freeman, J. Bowen, and R. Tropp (2000). Central California Ozone Study – Volume II Field Operations Plan. Prepared for the CCOS Technical Committee c/o California Air Resources Board, Sacramento, CA, May 2000.

Fujita, E.M., W. Stockwell, R.E. Keislar, D.E. Campbell, P.T. Roberts, E.H. Funk, C.P. McDonald, H.H. Main, and LR. Chinkin (2000). Weekend/Weekday Ozone Observations in the South Coast Air Basin: Retrospective Analysis of Ambient and Emissions Data and Refinement of Hypotheses, Volume I – Executive Summary. Prepared for the National Renewable Energy Laboratory, Golden, CO, December 2000.

Fujita, E.M., W. Stockwell, R.E. Keislar, and D.E. Campbell (2000). Weekend/Weekday Ozone Observations in the South Coast Air Basin: Retrospective Analysis of Ambient and Emissions Data and Refinement of Hypotheses, Volume II – Desert Research Institute Tasks 1 and 2. Prepared for the National Renewable Energy Laboratory, Golden, CO, December 2000.

Fujita, E.M., R. Keislar, D. Campbell, R. Keislar, and J. Bowen, (2001). Central California Ozone Study (CCOS) – Volume III: Summary of Field Operations. Final report prepared for the CCOS Technical Committee c/o California Air Resources Board, Sacramento, CA, February 2001.

Fujita, E.M., and D.E. Campbell, W. Stockwell, B. Zielinska, JC. Sagebiel, W. Goliff, M. Keith, J.L. Bowen (2001). Weekend/Weekday Ozone Observations in the South Coast Air Basin: Phase II Field Study. Interim report prepared by the Desert Research Institute for the National Renewable Energy Laboratory, Golden, CO, October 2001.

Fujita, E.M., D.E. Campbell, W. Stockwell, P.T. Roberts, T.H. Funk, C.P. MacDonald, H.H. Main, and LR. Chinkin (2002). Weekend/Weekday Ozone Observations in the South Coast Air Basin Volume I – Executive Summary. Report prepared by the Desert Research Institute, Reno, NV and Sonoma Technology, Petaluma, CA for the National Renewable Energy Laboratory, Golden, CO, and the Coordinating Research Council, May 2002.

Fujita, E.M., D.E. Campbell, W. Stockwell, R. Keislar, B. Zielinska, J.C. Sagebiel, W. Goliff, M. Keith, and J.L. Bowen (2002). Weekend/Weekday Ozone Observations in the South Coast Air Basin Volume II: Analysis of Air Quality Data. Final report prepared by the

Desert Research Institute, Reno, NV for the National Renewable Energy Laboratory, Golden, CO, and the Coordinating Research Council, April 2002.

Fujita, E.M., D.E. Campbell, W. Stockwell, P.T. Roberts, T.H. Funk, C.P. MacDonald, H.H. Main, and LR. Chinkin (2002). Weekend/Weekday Ozone Observations in the South Coast Air Basin Volume I – Executive Summary. Report prepared by the Desert Research Institute, Reno, NV and Sonoma Technology, Petaluma, CA for the National Renewable Energy Laboratory, Golden, CO, and the Coordinating Research Council, May 2002.

Fujita, E.M., D.E. Campbell, W. Stockwell, R. Keislar, B. Zielinska, J.C. Sagebiel, W. Goliff, M. Keith, and J.L. Bowen (2002). Weekend/Weekday Ozone Observations in the South Coast Air Basin Volume II: Analysis of Air Quality Data. Final report prepared by the Desert Research Institute, Reno, NV for the National Renewable Energy Laboratory, Golden, CO, and the Coordinating Research Council, April 2002.

Zielinska, B., J. Sagebiel, E.Fujita, D. Campbell, J. McDonald, T. Kelly and D. Joseph (2002). Section 211(B) Tier 2 High-End Exposure Screening Study Of Baseline and Oxygenated Gasoline – Pilot Study. Report prepared for the American Petroleum Institute, Washington, DC, June 13, 2002.

Zielinska, B., E.Fujita, J. Sagebiel, D. Campbell, J. McDonald, L. Smith, and T. Johnson (2002). Exposure Protocol and Study Plan for the Section 211(B) Tier 2 High End Exposure Screening Study of Baseline and Oxygenated Gasoline. Report prepared for the American Petroleum Institute, Washington, DC, September 30, 2002.

Zielinska, B., E.Fujita, J. Sagebiel, D. Campbell, J. McDonald (2002). Interim Data Report for Section 211(B) Tier 2 High End Exposure Screening Study of Baseline and Oxygenated Gasoline. Report prepared for the American Petroleum Institute, Washington, DC, November 15, 2002.

Fujita, E.M. and D. Campbell (2003). PAMS Data Analysis for Southern California Volume VII: Source Apportionment of Volatile Organic Compounds. Final report prepared for the South Coast Air Quality Management District, Diamond Bar, CA, June 20, 2003.

Fujita, E.M. and D. Campbell (2003). Validation and Application Protocol for Source Apportionment of Photochemical Assessment Monitoring Stations (PAMS) Ambient Volatile Organic Compound (VOC) Data. Final report prepared for the U.S. Environmental Protection Agency under EPA Star Grant #GR826237-01-0, August 31, 2003.

Fujita, E.M., D. Koracin, D. Freeman, R.E. Keislar, D. Podnar, T.E. McCord, D.E. Campbell, and W.R. Stockwell (2003). State Implementation Plan (SIP) Planning Service for the Sacramento Ozone Nonattainment Area: Volume 1 – Data Analysis and Episode Selection for SIP Modeling. Prepared for the Sacramento Metropolitan Air Quality Management District, Sacramento CA, September 9, 2003.

Yarwood, G., C. Tran, S. Lau and E. Fujita (2003). Impact of Updates to On-Road Mobile Source Emission Factor Models (EMFAC) for the Los Angeles Region: Ozone Model Sensitivity and Ambient/Inventory Reconciliation. Final report prepared for the Coordinating Research Council, Alpharetta GA, September 29, 2003.

Fujita, E.M., J.G.Watson, J.C. Chow and B. Zielinska (2003). Demonstration PM Study Plan for Pune, Maharastra, India. Prepared for U.S. Environmental Protection Agency Office of International Affairs, Washington DC, November 24, 2003.

Fujita, E. (2004) Validation Of The U.S. EPA Mobile6 Highway Vehicle Emission Factor Model Crc Project E-64 Task 4 Guidance Document for Validation of On-Road Vehicle Emissions Inventory. Prepared for the Coordinating Research Council, Alpharetta GA, February 12, 2004.

Stockwell W.R., E.M. Fujita, I. Shumyatsky, D. Freeman, D.E. Campbell, D. Koracin, D. Podnar, T.E. McCord, and (2004). State Implementation Plan (SIP) Planning Service for the Sacramento Ozone Nonattainment Area: Volume 2 – Protocol for State Implementation Plan (SIP) Modeling. Draft report prepared for the Sacramento Metropolitan Air Quality Management District, Sacramento CA, April 1, 2004.

Stockwell W.R., E.M. Fujita, I. Shumyatsky, D. Freeman, D.E. Campbell, D. Koracin, D. Podnar, T.E. McCord (2004). State Implementation Plan (SIP) Planning Service for the Sacramento Ozone Nonattainment Area: Volume 3 – State Implementation Plan (SIP) Modeling. Draft report prepared for the Sacramento Metropolitan Air Quality Management District, Sacramento CA, May 28, 2004.

ERG, BKI, NuStats and DRI (2004). Kansas City PM Characterization Study, Draft Pilot Testing Report. Prepared for the U.S. Environmental Protection Agency, Ann Arbor, MI, June 18, 2004

Fujita, E.M., D.E. Campbell and W.P. Arnott (2004). Quality Management Plan (QMP) and Quality Assurance Project Plan (QAPP) for Characterizing Exhaust Emissions from Light-Duty Gasoline Vehicles in the Kansas City Metropolitan Area. Prepared by Division of Atmospheric Sciences, Desert Research Institute for U.S. Environmental Protection Agency under Subcontract to Eastern Research Group Inc. June 23, 2004.

Fujita E.M., D.E. Campbell, R. Keislar and B. Zielinska (2004). Analysis of Ambient Air Quality Data Collected In and Near Northern Baja California, Mexico: Task 4 - VOC Sampling and Source Apportionment. Prepared for the California Air Resources Board, Sacramento CA, August 19, 2004.

Fujita E.M., B. Zielinska, J. Sagebiel and D.E. Campbell (2004) Kansas City PM Characterization Study Pilot Study Testing Report – Addendum: Effect of Sampling Temperature on Chemical Speciation 1,3-Butadiene Stability Experiments. Prepared for U.S. Environmental Protection Agency, Ann Arbor, MI and U.S. Department of Energy National Renewable Energy Laboratory, Golden, CO, October 27, 2004.

Fujita, E. (2005). Validation of the U.S. EPA MOBILE6 Highway Vehicle Emission Factor Model, Task 4: Guidance Document for Validation of On-Road Vehicle Emissions Inventory. Final report submitted to the Lake Michigan Air Directors Consortium, April 24, 2005

Yarwood, G., R. Morris, S. Rao, S. Lau, E.M. Fujita, D.E. Campbell and W. White (2005). Evaluating VOC Receptor Models Using Grid-Model Simulations CRC Project A-34. Final report submitted to Coordinating Research Council, Alpharetta, GA, April 27, 2005.

Campbell, D.E. and E.M. Fujita (2005). Deployment of DRI Mobile Van in Support of the Roseville Rail Yard Air Monitoring Project. Final report submitted to Placer County Air Pollution Control District, Auburn, CA, May 6, 2005.

Fujita, E.M., D.E. Campbell and T. Snorradottir, (2005). Central California Ozone Study (CCOS): Data Validation. Final report submitted to the Joaquin Valleywide Air Pollution Study Agency, c/o California Air Resources Board, Planning and Technical Support Division, Sacramento, CA, May 9, 2005.

Fujita, E.M., B. Zielinska, W.P. Arnott, D.E. Campbell, L. Rinehart, J.C. Sagebiel and J.C. Chow (2006). Gasoline/Diesel PM Split Study: Source and Ambient Sampling, Chemical Analysis, and Apportionment Phase. Final report submitted to the U.S. Department of Energy National Renewable Energy Laboratory, Golden, CO, January 19, 2006.

Campbell, D.E. and E.M Fujita (2006). Data Analysis on the Roseville Rail Yard Air Monitoring Project. Final report submitted to the Placer County Air Pollution Control District, Auburn, CA, March 15, 2006.

Zielinka, B., E.M. Fujita, J.C. Sagebiel, and D.E. Campbell (2006). Section 211(B) Tier 2 High End Exposure Study of Conventional and Oxygenated Gasoline. Final Report submitted to the American Petroleum Institute, Washington, D.C., July 19, 2006.

Kishan, S., A. Burnett, S. Fincher, M. Sabisch, W. Crews, R. Snow, M.Zmud, R. Santos, S. Bricka, E. Fujita, D. Campbell, P.Arnott (2006). Kansas City PM Characterization Study, Final report submitted to the U.S. Environmental Protection Agency, Ann Arbor, MI, October 27, 2006.

Fujita, E.M. and D.E. Campbell (2006). Spatial and Temporal Variations in Exposure to Air Toxics in the South Coast Air Basin. Final report submitted to the National Renewable Energy Laboratory, NREL Contract No. RCL-4-44113, Golden, CO, December 31, 2006.

Fujita, E.M., D.E. Campbell, B. Zielinska (2006). Chemical Analysis of Lubrication Oil Samples from a Study to Characterize Exhaust Emissions from Light-Duty Gasoline Vehicles in the Kansas City Metropolitan Area. Final report submitted to the National Renewable Energy Laboratory, NREL Contract No. ACI-5-55528-01, Golden, CO, and the Coordinating Research Council, CRC E-69A, Alpharetta, GA, December 31, 2006.

Fujita, E.M., D.E. Campbell, B. Zielinska, W.P. Arnott, J.C. Chow (2008). Concentrations of Air Toxics in Motor Vehicle Dominated Microenvironments. Final report submitted to the Health Effects Institute, HEI contract 4704-RFA03-1/02-16, Boston, MA, January 13, 2008.

Fujita, E.M., D.E. Campbell, B. Mason, B. Zielinska (2009). Harbor Community Monitoring Study (HCMS) Saturation Monitoring. Final report submitted to the California Air Resources Board, Sacramento CA, May 15, 2009.

Fujita, E.M., D.E. Campbell, J. Engelbrecht, B. Zielinska (2009). Characterization of Fine Particle Mass Using Particle-Phase Organic Compounds as Tracers. Final report submitted to Southeastern States Air Resources Managers, Inc. Forest Park, NC, June 30, 2009.

Zielinska, B., E. Fujita, and D. Campbell (2010). Barnett Shale Oil and Gas Production. Final report prepared for the Mickey Leland National Urban Air Toxics Research Center, Houston, Texas, July 30, 2010.

Fujita, E.M. and D.E. Campbell (2010). West Oakland Monitoring Study. Final report prepared for the Bay Area Air Quality Management District, San Francisco, CA, October 7, 2010.

KEITH KNOLL
525 Fox Glove Court
Fort Collins, CO 80524
(303) 305-8573
Keith.Knoll@Czero-Solutions.com

HIGHLIGHTS OF QUALIFICATIONS

- Proficiency with light-duty vehicle emissions testing protocols and procedures, emissions calculations, and atmospheric impact analyses.
- Strong background in engine component design and development – primarily diesel fuel injection equipment.
- Proficiency with MATLAB for component design, data analysis, and data presentation.
- Experience in preparing and delivering technical presentations to both expert and non-expert audiences.
- Skill in leading small and large, multi-year research projects managing technical, financial, and contract issues.

EXPERIENCE

Senior Project Engineer   Czero, Inc., Fort Collins, CO   2011 – Present
- Consulting engineering specializing in combustion, emissions and alternative fuels utilization.
- Expertise in early-stage R&D on engines, hydraulics and hybrid powertrain technologies.

Senior Engineer   National Renewable Energy Lab, Golden, CO   2007 – 2011
- Leading numerous biofuel-related vehicle emissions research projects.
- Collaborating with industry partners to conduct vehicle emissions, fuel system, and engine durability impact studies with mid-level ethanol blends. In the process developed critical database used by EPA to for E15 waiver decision.
- Conducting light-duty vehicle emissions research projects to understand air quality impacts of increased flexible-fuel vehicle (FFV) use with E85 fuel.

Project Leader   Sturman Industries, Woodland Park, CO   1998 – 2006
- Led successful $2.4 million HVA (Hydraulic Valve Actuation) project combining objectives from three customers with installations and engine tests at three sites.
- Had direct responsibility for proposal, technical specification, laboratory test and development, and engine start-up / shakedown at customer sites.
- Managed small team of engineers and technicians, providing technical direction for design, analysis, test, and software development.
- Created test specifications, developed test set-up, executed tests, and analyzed and presented data for various HVA and advanced diesel fuel system projects.

Development Engineer   Diesel Technology Company, Grand Rapids, MI   1996 – 1998
- Led advanced FIS (Fuel Injection System) development team developing new fuel system to reduce diesel engine emissions and meet US04 and Euro III standards.

- Implemented new FIS technology at customer sites to verify and document improved engine emissions performance.

Technical Specialist **Cummins Engine Company, Columbus, IN** **1993 – 1996**

- Led common rail injection control valve development, coordinating goals and activities of team to achieve sub-system technical specification.
- Tested and developed injection control valve to optimize performance and recommend design iterations.

Research Engineer II **Babcock & Wilcox, Alliance, OH** **1989 – 1993**

- Analyzed experimental data and documented results in final report for development of next generation steam generator for U.S. Navy nuclear program.
- Developed and evaluated new measurement technologies for thermal-hydraulic application.

EDUCATION

PURDUE UNIVERSITY
M.S., Mechanical Engineering, 1989
GPA: 5.73 / 6.00
Thesis: *Coal Water Slurry Atomization*
NORTH CAROLINA STATE UNIVERSITY
B.S., Mechanical Engineering, 1986
Major GPA: 3.80 / 4.00

PUBLICATIONS

"The Impacts of Mid-level Biofuel Content in Gasoline on SIDI Engine-out and Tailpipe Particulate Matter Emissions," X. He, J. Ireland, B. Zigler, M. Ratcliff, K. Knoll, T. Alleman, and J. Tester, SAE Technical Paper, 2010-01-2125, October 2010.

"Effects of Mid-Level Ethanol Blends on Conventional Vehicle Emissions," K. Knoll, B. West, S. Huff, J. Thomas, J. Orban, and C. Cooper, SAE Technical Paper, 2009-01-2723, November 2009.

"Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1 – Updated," K. Knoll, B. West, W. Clark, R. Graves, J. Orban, S. Przesmitzki, and T. Theiss, NREL/TP-540-43543 and ORNL/TM-2008/117, February 2009.

"Venturi Performance with Internal Sense-Line Configuration," presented at the 1992 ASME Fluids Engineering Conference, Los Angeles, CA, June 1992.

"Investigation of an Electromagnetic Flowmeter for Gas-Liquid Two-Phase Flow Measurement," 7th Proceedings of Nuclear Thermal Hydraulics, ANS, November 1991.

"Flat Sheet Two-Fluid Atomization of High Viscosity Fluids. Part III. Coal-Water Slurries," written with P.E. Sojka, ASME Heat Transfer Division, Vol. 187, pp. 45-50, December 1991.

"Physical Mechanisms and Predictive Equations for Coal-Water Slurry Atomization," presented with P.E. Sojka at the Annual Coal Fuel Heat Engine Cleanup Systems Contractors Review Meeting, Morgantown, WV, June 1989.

"Influence of Nozzle Geometry on Coal-Water Slurry Atomization," presented with P.E. Sojka at the First Annual Conference on Liquid Atomization and Spray Systems, Madison, WI, May 1987.

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.[2]

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,[3] 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.

---

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

[3] 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

High Evaporative Emissions Study 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_X_ 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_X_ 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_X_ 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_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.

H. Christopher Frey______
Name

___________________________ December 8, 2011___
Signature Date

Conflict of Interest and Bias Questionnaire

High Evaporative Emissions Study 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_X_ 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_X_ 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_X_ 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_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.

Eric M. Fujita______
Name

________________ 11/14/11_
Signature Date

Conflict of Interest and Bias Questionnaire

High Evaporative Emissions Study 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_X_ 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_X_ 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_X_ 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_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.

__Keith Knoll______________
Name

__K.E. Knoll______ __12/7/2011_
Signature Date

Appendix C: Peer Review Charge

Charge to Peer Reviewers of *Estimates of the Fraction of the Fleet with High Evaporative Emissions based on the Ken Caryl Station (Denver, Colorado) Field Study*

Gasoline vehicles have evaporative emissions control systems that control excessive evaporative emissions. Gasoline vapors can also be evaporated liquid gasoline, if liquid leaks are present. When these systems or the vehicle's gasoline delivery system malfunction, excessive evaporative emissions can be emitted. Few estimates of the frequency of vehicles in just such a state in the fleet exist, though vapor leaks can have an impact on the inventory of vehicle emissions.

As part of the effort to quantify evaporative emissions from the fleet of gasoline-powered on-road vehicles in the developing MOVES mobile sources inventory model, EPA would like to know the distribution of the mass of evaporative emissions across all vehicles in the fleet. Evaporative emissions occur in light-duty vehicles when volatile components of gasoline are emitted or when raw gasoline leaks from the fuel system and the evaporative emissions control system. To meet the evaporative emissions modeling needs of the MOVES model, EPA and its stakeholders have conducted studies to be able to model these evaporative emissions in MOVES.

The Coordinating Research Council - Real World Group through its E-77 and E-77-2 permeation evaporative emission testing programs has confirmed that leaks, both liquid and vapor, can be a significant part of any fleet hydrocarbon inventory. This indicated a major impact for inventory, establishing the need to define the rate of occurrence of "leakers" in the in-use fleet. The missing piece of information is how often the leaking vehicles are occurring. Subsequent laboratory testing in the E-77-2c program implanted similar size leaks, not only at the gas cap but in other locations which were indicated as high occurrence in the initial field testing work. EPA's initial estimate was that "High Evaps" make up on the order of 1% of the gasoline-fueled vehicles in the fleet but there has been evidence that this was lower than what is occurring in the real world. This report uses Colorado I/M evaporative emission data to estimate the fractions of various levels of high evaporative emission vehicles, the prevalence of High Evaps, in the mix of vehicles that patronized the Denver Ken Caryl I/M station during the summer of 2009. Ultimately, EPA would like to know the distribution of the mass of evaporative emissions across all vehicles in the fleet.

The study performed at the Ken Caryl IM station in Denver, CO built upon the prior CRC/EPA testing experience. Vehicles entering the Ken Caryl station driveway were screened by an RSD unit using an evaporative index described as EI23. A stratified sample of model year 1961 and newer vehicles were offered participation in intensive evaporative emissions testing, which consisted of the portable sealed housing for evaporative determination (SHED) hot-soak test, the visual, olfactory, and electronic sniffer examination of the vehicle (MCM test) and additional RSD measurements. Overall, the study reinforced an earlier connection seen between RSD and portable SHED values for real-world light-duty gasoline vehicles with testing of a wider range of model years and RSD vehicle speeds.

The objective of this report is to provide estimates of the high evaporative emission fraction of the Denver fleet based on portable SHED data. One estimate of this fraction can be made by de-stratifying the portable SHED measurements collected summer of 2009 at the Ken Caryl I/M station according to the distribution of EI23 Bin values observed in the sample of vehicles that patronized that station during the study period. The CRC E-77 and E-77-2 studies and the Lipan (Colorado) I/M Station studies all preceded the Ken Caryl study, which provides the background and data for this report.

From the vehicle selection and testing at Ken Caryl, two data sets are used to perform this analysis. The first is the set of 175 vehicles that were participants in the study and therefore received RSD measurements and portable SHED measurements. The second is the set of all 5830 vehicles that entered the station driveway during the study and represent the fleet of vehicles that patronize Ken Caryl. Most of these vehicles were not participants in the study and these therefore have only RSD measurements but no portable SHED measurements. The portable SHED values of the 175 participants were de-stratified using the RSD index to estimate the distribution of portable SHED values of the 5830 vehicles that entered Ken Caryl during the study period. The results give an estimate of the fraction of "high" portable SHED vehicles for different definitions of a high portable SHED result.

The RSD and portable SHED results on the 175-vehicle stratified sample of vehicles entering Ken Caryl was used to establish a relationship between the EI23 evaporative emissions index and hot-soak emissions as measured by the portable SHED test. This relationship was then applied to the 5830-vehicle random set, which is made up of most vehicles that entered the I/M station driveway during the study period. Standard de-stratification techniques are used to estimate the fraction of the Ken Caryl fleet that is expected to have portable SHED results greater than various definitions of a high portable SHED value, "cutpoint". The de-stratification technique is also applied to the Ken Caryl fleet as a function of model year group. A Monte Carlo simulation provides a means of estimating the influence of various uncertainties in the Ken Caryl data on the uncertainty of the calculated high portable SHED result fraction. An estimate of the uncertainty is critical to understanding the quality of the results of a calculated high portable SHED value fraction. This, in turn, provides important guidance to EPA for using the results of the calculations for MOVES.

You are asked to review and provide expert comments on the *Estimates of the Fraction of the Fleet with High Evaporative Emissions based on the Ken Caryl Station (Denver, Colorado) Field Study (High Evap Study)*. You are being provided the *High Evap Study* under cover of this charge and will be provided a background document separately.

Your written comments should address all aspects of the report (methodologies, analysis, conclusions, and narrative) and should be sufficiently clear and detailed to allow readers to thoroughly understand their relevance to the High Evap Study. ***Please deliver your final written comments to SRA by Friday, December 30.***

All materials provided to you as well as your 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 reports and supporting documentation public, EPA 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

Peer Review of
Estimates of the Fraction of the Fleet with High Evaporative Emissions based on the Ken Caryl Station (Denver, Colorado) Field Study

Prepared by:

H. Christopher Frey, Ph.D.
Independent Consultant
Raleigh, NC

Prepared for:

SRA International, Inc.

December 30, 2011

This is a peer review of a report drafted by Eastern Research Group, Inc. of Austin, TX for the U.S. Environmental Protection Agency. The review was commissioned by SRA International, Inc. on behalf of U.S. EPA.

Synopsis

The subject report is a summary of measurements of evaporative emissions made on samples of vehicles in the Denver, Colorado area using a portable "SHED" method. The term SHED is undefined in the ERG report but refers to Sealed Housing for Evaporative Determination (SHED), and is an existing and established method for measuring evaporative emissions from vehicles. A portable SHED (PSHED) was used at a particular inspection and maintenance (IM) station in the Denver area, known as the Ken Caryl IM Station, to measure a sample of vehicles. Vehicles were selected for PSHED measurements based on a screening measurement made with a Remote Sensing Device (RSD). Remote sensing measurements were used to estimate a quantity "EI23." Depending on the value of the EI23 quantity, each vehicle passing through the screening RSD site was assigned to an EI23 "Bin." A prior estimate was made of the probability that a vehicle in each bin would be a 'high' emitter of evaporative emissions. Based on the assignment to an EI23 bin, and the prior estimated probability of being a high emitter, vehicles were invited at random for additional measurements. If the driver accepted the invitation, the vehicle underwent additional remote sensing measurements and also underwent a PSHED measurement.

In prior work, measurements were made on a different vehicle fleet to assess the concordance between SHED and PSHED measurements. The two methods were found to produce similar results on average, with a small bias in the PSHED measurement compared to the SHED measurement. However, there appears to be substantial random deviation of individual PSHED measurements compared to SHED measurements of the same vehicle under approximately similar conditions. A key assumption in the analysis of Ken Caryl IM Station data is that the PSHED measurement is a suitable substitute for the more widely accepted SHED measurement.

Based on the ‘stratified’ sample of vehicles that underwent additional measurements at the Ken Caryl IM Station, inferences were made regarding the observed fraction of vehicles in each EI23 Bin that had ‘high’ evaporative emissions rates according to PSHED measurements. These data were used to estimate the overall fraction of high evaporative emitters for all vehicles that entered the Ken Caryl IM Station during the study period. The report concludes with some comments about uncertainties in the estimates and regarding a possible future Monte Carlo study to more thoroughly quantify such uncertainties.

Report Writing

The review of this report was significantly hampered by the very poor quality of the report organization and writing.

A key question when writing any report is: Who is the intended audience for this report? The intended audience should include all stakeholders of the MOVES model, since this effort appears to be aimed at providing a technical basis for quantification of the fraction of the on-road fleet that has high evaporative emissions rates. However, as written, the report is aimed at fellow technicians who are familiar with the undefined shop jargon used by the authors. This report contains repeated sloppy use of jargon that may be meaningful to the report authors, but that make the report difficult to read by anyone else. Table 1 is a list of terms that are introduced in the text without definition, without adequate definition, or that should be introduced, defined, and used in the text. The list of terms in Table 1 should be used to construct a glossary for this report. When a term is first used in the text, it should be defined in the text.

Table 1. Terms Introduced in Draft Report Without Definition or Explanation: these terms should be defined/explained when first mentioned. A glossary of these terms with definitions should also be created.

Terms that Need to be Defined	Comment
Aging enhanced evaporative emissions vehicles	? given lack of definition of ‘aging,’ and ‘enhanced,’ the meaning of this is unclear to the readers.
Aging enhanced vehicles	Undefined. Explain this.
Approximate algorithm	No idea what this means. Needs to be explained.
As-received condition	Should explain what this means.
Beam block	This is shop jargon. The intended meaning seems to be exhaust plume measurement. Needs to be defined/explained when first used.
Bench purged	Presumably, this implies that the canister was removed from the vehicle and purged (how) on a lab bench. Needs more explanation for clarity.

(cont.)

Terms that Need to be Defined	Comment
Bias (systematic error, inaccuracy)	See comments
Bin de-stratification	De-stratification with respect to what? How?
De-stratify (and de-stratifications)	This term is used without definition. Not clear what this is.
Detection limit	Mentioned on p 4-31 but not defined.
EI23	Mentioned numerous times without any explanation
EI23 Bins	Define when first mentioned. Introduce in a new methodology chapter prior to using this term in results chapters
Electronic HC sniffer	Is this relevant to the content of the report? If not, delete. If so, then explain.
ESP	? Seems to be the name of a company. ESP, Inc.?
Evaporative emissions canister	Is this a canister that produces evaporative emissions? Need to explain to the reader what this is. A corresponding conceptual diagram of the source of evaporative emissions and methods for prevention and control of evaporative emissions would help in explaining what this (and other relevant vehicle systems or components) is.
g/Qhr	Is not defined until page 4-4, although it is used in earlier parts of the report.
Gross liquid "leakers"	Is there a quantitative definition of this, or at least a working definition? Explain.
HC	As good practice any abbreviation should be defined when first used.
high evaps	This is shop jargon. A formal technical report should have thoughtfully developed and carefully defined terminology.
High running loss emissions	What constitutes "high"? by what criterion or criteria?
High-PSHED, and "high-PSHED fraction"	This term is shop jargon. The intended meaning appears to be "vehicles with high evaporative emissions as measured using the Portable SHED

(cont.)

Terms that Need to be Defined	Comment
Hot 505	This is undefined. Presumably, this is a hot stabilized dyno test cycle. If so, then give the graph of speed versus time and provide some explanation.
Hot soak	define
IM	Yes, most readers will know what this is, but as good practice any abbreviation should be defined when first used.
Implanted leak	Undefined. Explain this. Give an example.
Index/PSHED	This term is unclear
Intrusive pressure test	What is this?
Ken Caryl	Introduced asif the name of a person, this should be consistently termed “Ken Caryl IM Station” or something similarly descriptive (e.g., Caryl Station).
leakers	Is there a quantitative definition of this, or at least a working definition? Explain.
Low evap	More shop jargon. A formal technical report should have thoughtfully developed and carefully defined terminology.
Low running loss emissions	What constitutes “low”? by what criterion or criteria?
Method A	Define. Introduce in methods chapter.
Method B	Define. Introduce in methods chapter.
Modified California Method	Define. If not relevant to this report, delete.
MOVES	MOVES is mentioned but never introduced or explained.
Near-zero vehicle	Undefined. Explain this
Noise, noisy	Used on page 4-31 without definition
OBD code to flag	I know what the authors are trying to say, but many readers will have no idea. First, explain OBD and what is an OBD code. Explain what is meant by ‘flag’.

(cont.)

Terms that Need to be Defined	Comment
OBD evaporative codes	What are these? Needs to be explained
Odometer Resolution	What is the meaning of the codes given in Table 4-1?
ORVR	?
Precision (imprecision)	See comments
Pre-enhanced vehicles	Undefined. Explain this.
Pretesting	Page 4-2
PSHED	PSHED is defined on page 1-1 as “portable SHED”, but “SHED” is not defined.
RSD	The term RSD is used on page 1-1 without definition.
RSD Method B	This method should be introduced and explained in a methodology section of the report.
Running loss emissions	Define/explain
Seal Barometric Pressure	Table 4-2: this term is undefined. There needs to be a footnote to explain what this is.
Seal Temperature (F)	Table 4-2: this term is undefined. There needs to be a footnote to explain what this is.
Selection RSD	Mentioned on page 4-3. An “RSD” is a measurement device, but the term “RSD” is used inappropriately to refer to a measurement of a specific vehicle. The intended meaning of “Selection RSD” is “screening remote sensing measurement.” The screening measurement is used to determine whether the vehicle will be recruited for addition RSD measurements and PSHED measurements.
SHED	Amazingly, SHED is not defined the first time it is mentioned, on page 1-1.
Slow vapor leaks	What is a “slow” leak? Does this refer to a low emissions leak? Of vapor? Of evaporating liquid? Needs to be defined and explained.
Standard de-stratification techniques	? undefined.

(cont.)

Terms that Need to be Defined	Comment
Standard I/M inspection	Explain. Or, if not relevant, delete.
Stratified sample	With respect to what? This term needs to be explained when first used.
Stratified set	Explain in new methods chapter.
Uncertainty	Should be defined – see comments
VDF	Table 4-2: this term is undefined. There needs to be a footnote to explain what this is.
VECI Engine Family	Table 4-1. needs to be defined in a footnote.
VECI Evap Family	Table 4-1. needs to be defined in a footnote.

The report needs substantial copy editing by a competent technical writer. For example, the report contains frequent use of the first person, which is inappropriate in formal technical writing. In numerous places, statements of belief are made (e.g., "we believe"). The reader does not care what the authors 'believe.' The reader cares about what is known and what is not known, and reasonable interpretations based on evidence. The report contains numerous metaphors, which are inappropriate for formal technical writing. For example, several times the authors describe what an instrument 'sees.' Aside from these problems there are numerous instances of unclear yet repetitive statements. If a student had handed me this draft report, I would have read a few pages and then handed it back as unacceptable.

As an example of poor writing, consider the last paragraph on page 4-2.

> What are 'pretesting data'? 'All of that pretesting data was' could simply be "These data were." "receive RSDs" - this doesn't make sense. How does a vehicle receive a remote sensing device? The intended meaning seems to be "were measured using remote sensing." Having read the appendix, I cannot figure out the basis for the statement "Analysis of the EI23 index… " "to allow the EI23 to be less dependent on an exhaust emissions, we developed EI23 Bin" is awkward – should be "To reduce dependence on exhaust emissions, EI23 Bins were developed." Do not use first person. And so on. Aside from the poor wording, the key technical concepts are unclear. What are the dependences and how have they been inferred? It is frustrating to the reader to be told to go elsewhere for definition of EI23 and EI23 Bin but to be provided with details based on knowing what these concepts are, such as "EI23 Bin has integer values of 1 through 7…" These concepts and terms should be defined, developed, explained, etc., in a methods chapter prior to producing results based on these. The paragraph introduces, perhaps for the first time, the term "running loss emissions," without definition. If EI23 Bin is central to the methods and interpretation, it is simply unacceptable to push it to an appendix and to give such short and uninformative treatment to it in the main body of the report.

Aside from the poor writing, the organization of this report should be reconsidered. Methods and results appear to be mixed together. A good technical report will have a chapter devoted to methods, organized in a manner consistent with the order in which the methods are used later in the report.

Furthermore, this report tends to have too much of ‘here’s what we did’ without first introducing the purpose, key concepts, or basis/foundation.

A technical report should have the following elements:

- Introduction
  - states the challenge, problem, issue being addressed,
  - establishes the need for new work
  - **clearly** states the objectives of the work (note: objectives are not a list of tasks – they relate to the purpose of the work)
- Background: Survey of relevant prior work, if needed. Also, a brief review of the types of evaporative emissions and factors to which they are sensitive is needed. For example, evaporative emissions are sensitive to ambient temperature.
- Methods
  - For each major component of the analysis, state the following:
    - Overall purpose
    - Basic concept
    - Empirical or theoretical basis established in prior work (with citations)
  - Provide sufficient information regarding the methods so that someone else could reproduce the work – include definitions of key terms, variables, equations, algorithms, and so on
  - Examples of content for this chapter (illustrative)
    - Schematic of the vehicle path through the various RSDs and PSHED
    - Methods A and B for estimating plume concentrations from remote sensing measurements
    - EI23 definition and definition of EI23 bins
    - Approach to ‘stratification’
- Results
  - Results could be organized into more than one chapter if the subject matter is too much for one chapter
  - Results should include a clearly summary of all input data and assumptions
  - Results obtained should be from application of methods described in the methods chapter.
  - Results should be appropriately interpreted
- Conclusions
  - What are the key findings that are related to the objectives stated in Chapter 1?
  - What are the key conclusions that are related to the objectives stated in Chapter 1?
  - What are the key recommendations that are related to the objectives stated in Chapter 1?

Use of Proprietary Methods

Over the years, EPA has been criticized for making public policy and developing modeling tools to support public policy that are based on proprietary data and methods. The use of proprietary methods precludes a full understanding and review of the underlying science. A case in point are the “Method A” and “Method B” exhaust plume analysis methods associated with the ESP remote sensing instrumentation. Since the distinction between Method A and Method B appears to be an important technical consideration in this study, the lack of disclosure of what these methods are is unacceptable.

Fundamental Questions

There are some fundamental questions related to this work that should be part of the objectives and that should be addressed in the technical results and conclusions:

1. Is PSHED a good surrogate for SHED?
2. Can an RSD, if appropriately interpreted, be a good surrogate for a PSHED measurement?

The first question presumes that SHED is the reference method to which all other methods should be compared. What, however, is really measured in a SHED measurement? There are many evaporative processes. Some, such as refueling, are not addressed by SHED. Which processes are addressed?

In what ways are PSHED measurements similar to those of SHED measurements, and in what ways do they differ? Is PSHED effectively just as good as SHED?

What kinds of evaporative processes can be measured using RSD? There is an unstated hypothesis in this report that RSD measurements can provide information on evaporative emissions in a manner comparable to that of PSHED, if only the RSD measurement is appropriate interpreted. What is the basis for this hypothesis? What evaporative processes affect the quantity of HC that is detected by remote sensing? If there was no error in the measurement, would strong concordance be expected between RSD and PSHED? If so, why? A clearer statement of hypothesis and the theoretical underpinning for it would be helpful when interpreting results.

Specific Technical Comments

Page 1-1. The first sentence refers to 'further developing' something that has not yet been defined in this report. Please, hire a technical editor and have them go through this report very carefully. The first line is poorly written, and the report that follows is also very poorly written.

The purpose of the report is to estimate, not develop, fractions of various levels of high evaporative emissions. However, nowhere is any justification or rationale given as to why this report is focusing on the Denver fleet. Since Denver is at high altitude, and barometric pressure is a factor in evaporation, it is not clear that data from Denver would be representative of other parts of the U.S.

A number of terms are mention on this page without definition, including SHED, Ken Caryl, RSD. This is a bad way to start a report.

Page 1-2 "the real investigation in this study happens in…" this kind of colloquial writing has no place in a formal technical report by what is supposed to be one of the top environmental engineering consulting firms in the country to the Federal agency charged with quantifying and regulating air quality. This report needs to be taken more seriously by the authors.

Background Chapter: this chapter is plagued with undefined jargon, lack of clarity of concepts, and is poorly organized. It is very qualitative and vague and provides little to no insight on the topics being addressed. Examples of content missing from this report include a brief review of the types of evaporative emissions, factors to which such emissions are sensitive, the SHED measurement approach, how PSHED works, what is remote sensing, and how can remote sensing be used to infer information about evaporative emissions. What does the RSD actually measure that is representative of evaporative emissions, and is this similar to what is measured in PSHED? Why is there an expectation that there should be agreement between evaporative emissions inferred from RSD measurements versus those inferred from PSHEDS? Are they measuring the same processes under similar conditions? How might they differ?

The background chapter should be followed by a new chapter 3 that provides an overview of the methods used in this report, including a schematic of the Ken Caryl IM station, the specific instruments deployed, the analysis methods used, etc. Material that is now in Appendix A and B should be rewritten into the methods chapter.

The current Chapter 3 should be rewritten as “Assessment of Concordance Between Portable and Fixed Location Evaporative Emissions Measurements.” This chapter needs technical editing. The basic information is useful and interesting. The technical analysis should include quantification of the statistical significance of each parameter in the regression equation, the standard error of the estimate, the distribution of the residuals, a normality check for the residuals, the coefficient of determination, and other basic information that would commonly be reported as diagnostic goodness-of-fit indicators when developing a regression model. To what extent are results such as in Figures 3-4 and 3-5 actually providing an indication of repeatability of the test – are the conditions really the same in each test? If the repeatability is really this poor, what are the implications for selecting a threshold for what constitutes a ‘high evap’ vehicle? It is more common to report 95% probability ranges, not 68% probability ranges.

Chapter 4:

A schematic of the Ken Caryl station is needed to illustrate what is meant by the “driveway RSD unit” and “Measurement RSDs”

What is the purpose of “stratification.”? Why is achieving stratification a goal in itself? E.g., page 4-3, “to achieve stratification, a higher fraction of vehicles…” The reader can eventually figure this out, but why can’t the authors communicate this more clearly? The purpose seems to be to evaluate a screening procedure for identifying vehicles with high evaporative emissions rates, but what about goals for false positives or false negatives?

Is it literally the case that six RSDs were used? i.e., six remote sensing devices at six locations? Or were the two highway “RSDs” based on repeated passes by the same RSD? The authors need to stop using the term “RSD” to refer to a measurement. RSD = Remote Sensing Device and refers to an instrument. A measurement made using an RSD could be described as a remote sensing measurement. What is an RSD beam block? This is shop jargon (I know what it means, but most readers won’t).

“These two RSDs were measured on the same RSD instrument as the Selection RSDs.” This sentence is extremely sloppy, using the term “RSD” where the concept of a ‘remote sensing measurement’ should be used instead.
How does a vehicle “receive” an “RSD”? I have done measurements with an RSD, and I have never seen a vehicle receive an RSD.

What is the 'standard I/M inspection' – for those of us not from Denver, please explain what this is. Also, explain the "Modified California Method" – both of these should be documented in the new methods chapter that needs to be written. Who does the olfactory examination? What is an 'electronic HC sniffer"? Is this relevant to the report? If not, then delete mention of these.

Page 4-4: Method A was used on ESP 4000 and 4600 instruments, and Method B was used on ESP3000 series instruments. Yet, results for both Methods A and B are reported in Table 4-2. Were two RSD instruments used at each RSD site? Or were both Methods A and B applied to the same data measured from just one RSD instrument at each site? At the end of the paragraph is it mentioned that 'code' was 'added' to the 4000 and 4600 series instruments – it would have helped if this was mentioned up front, and if there was a prior section that more clearly disclosed the study design in terms of what instruments were deployed at what locations and what the vehicle path was through each RSD site. It would help if this text were reorganized so that there was an intro paragraph, one paragraph on Method A, one paragraph on Method B, and then a paragraph that compares Methods A and B. Are the CO, NO, and CO2 results shown in Table 4-2 based on Method B? The distinction between Methods A and B with respect to how they deal with exhaust versus evaporative concentrations of HC is not clear. To merely state that "ESP believes" that one method is responsive to exhaust and another is not is quite tenuous.

Page 4-4 (bottom): regression toward the mean…. This is stated as if it is an underlying principle in a rather didactic manner, but the actual concept is poorly explained here. A measurement is biased if it is systematically high or systematically low. If the error is randomly distributed with a mean of zero, then the measurement is subject to random error, not bias. The random error can lead to false positives or false negatives if used in the context of a binary decision (e.g., vehicle is a high emitter). This context is not clearly articulated. False positives or false negatives are not necessarily a result of bias, but rather a result of imprecision (random error). The discussion here of bias is thus without sufficient context and therefore is unclear.

What role does ambient temperature have in contributing to variability in estimated evaporative emissions based on RSD measurements? Since the "Temperature" in Table 4-2 (ambient temperature at the time of each RSD measurement?) differs from the PSHED "Seal Temperature", what role might this have in confounding the results?

Table 4-2: what is the meaning of negative values for HC Method A (ppmC 3) and how are these interpreted? Table 4-2 values of CO_2 percent appear to be what one would expect in the tailpipe, but this cannot be what was actually measured in the exhaust plume. How is the air-to-fuel ratio inferred, or is it assumed to be stoichiometric? Some discussion is needed. The text barely alludes to this. More detail is needed in a methods chapter.

Table 4-2: terms PSHED and RSD in caption should be spelled out. All nomenclature in column headers need to be properly defined – e.g., use footnotes. Is RSD temperature the ambient temperature at the date and time of the measurement?

The quantity in Figure 4-1 labeled as "RSD EI23" needs to be clearly defined. Is this based on any numbers given in Table 4-2? Which specific column of Table 4-2 is "RSD EI23"? Which specific column of Table 4-2 is "PSHED Mass (g/Qhr)"? Presumably, "Measured PSHED HC at 15 Minute Soak (grams)" in Table 4-2 is the same as "PSHED Mass (g/Qhr)". However, use consistent terminology in both places to avoid ambiguity. The EI23 values need to be added to Table 4-2.

Figure 4-1 needs better formatting. Should use a much larger font size for the numbers on the axes, and consider using scientific notation rather than decimals if showing a log scale. In the caption, spell out PSHED. What is “RSD EI23”?

Table 4-3 is hardly a table and is not formatted well. Add a row for percentages of total to help in the interpretation. Please change the terminology – e.g., ‘Measurement RSDs” (should be Remote Sensing Measurements).

Table 4-4 the term “high PSHEDs” is unacceptable. The intended meaning appears to be “high PSHED measurement” “High-PSHED Definition” should be “High PSHED Measurement threshold” or criterion.

What is ‘de-stratifications’?

Page 4-22: what role does ambient temperature have in the estimation of EI23? The RSD measurements are made at ambient temperature. Evaporative emissions are proportional to ambient temperature (something that needs to be introduced and discussed in a background or methodology section of this report). Is the EI23 metric less responsive to evaporative emissions at lower ambient temperature? Speed is not the only factor that affects inference of evaporative emissions.

“these Selection RSDs can be used to de-stratify the stratified set and provide an estimate of the high-PSHED fraction of the fleet…” given the lack of clear definition of these terms, and the sloppy use of terminology, this sentence is unclear.

‘is not an unbiased’ – why not say ‘is a potentially biased’… positive statements are always more clear than negative statements.

Page 4-23: “For the RSD to be useful…” should be ‘for the remote sensing measurement to be useful…” however, why is model year important? Earlier, a note was made that model year was not part of the EI23 binning method.

If there are multiple EI23 bin values available for some vehicles, these data should be analyzed separately to determine the robustness with which a vehicle is assigned to an EI23 bin. Ambiguity in assignment to an EI23 bin would be a significant factor to consider in evaluating the usefulness of this method.

Table 4-5. the term “Selection RSD” needs to be changed… e.g., “screening remote sensing measurement”? But the table is actually of EI23 bins and model year groups, not screening remote sensing measurements. Thus, the caption is not consistent with the content of the table.

A table prior to Table 4-5 would be more useful… i.e. distribution of vehicles by model year groups and EI23 bins for the selected (stratified?) vehicles.

Page 4-24 “we will get started…” might be okay for a presentation but this is not how a technical report should be worded. Aside from this, the first paragraph in Section 4.4 is unclear and is hampered by repeated use of terms that are not well-defined. Methods for stratification and de-stratification should be in a prior methods chapter.

Try reading aloud the first sentence of the last paragraph on page 4-24. It needs to be rewritten. Aside from being a run-on sentence, it is awkward, contains repetitive points and yet is not very clear.

Page 4-25: The Appendix B should be part of a methods chapter given earlier in this report (could be Chapter 3). N_h is defined in Appendix B but is given a lower case symbol (n_h). To avoid confusion and ambiguity, use consistent mathematical nomenclature. "Fraction of elevated PSHEDs" is given the symbol p_h, which is defined in Appendix B as the "probability"… this is inconsistent. Either it is a frequency or it is a probability- choose one and use the concept consistently. The standard error of fraction of elevated PHEDs is given in Table 4-6 based on a definition involving s_h and N_h, but this definition is not given in Appendix B (it should be). The terms sample and population in the Appendix B need some careful re-thinking or at least more clear definition. Here, the term 'population' is implied to describe the total sample of 5,830 vehicles (which is actually a sample from a larger fleet). That is okay, but at least be clear as to the meaning of the term 'population' as used in Appendix B. W_h is the fraction of the population of vehicles that fall into each EI23 bin. It is not clear as to the definition of "n" in Appendix B – is this the total number of vehicles in the 'population'? (i.e. n=5830?). L=7 (could be stated clearly). The term σ_h is not clearly defined in appendix B in terms of other variables. Is this the standard error of the fraction of elevated measurements in each strata? Appendix B does not actually show how one estimates the estimated fraction of the population that is above the threshold. How was the value 0.127 estimated? This appears to the product $p_h W_h$ summed over all h. Based on the numbers given in Table 4-6, over 75% of the estimated 'elevated PSHEDs' (a sloppy term) are from Bins 1-4, which account for over 96% of the 'population.'

Page 4-27. The last sentence of the first paragraph is unclear. Rewrite. Create a flow diagram or show an algorithm to make this more clear.

Table 4-8. It is not very clear as to what variable is implied by "High-PSHED Fraction…" is this based on p_h and W_h defined in some different way compared to Table 4-6?

"It is important to understand that" should be deleted. "It… that" statements are passive and contain no information. The assumption of the EI23 bins is that they are bins of EI23 values. Since no assumption is made regarding model year, it is not really correct to imply that if there is a dependency on a model year that somehow the use of EI23 is inherently inappropriate. It could be that the fraction of vehicles with high PSHEDs measurements is correlated with EI23 and with model year, but that does not imply that EI23 would not be a useful indicator. Whether EI23 is a useful indicator can be determined with or without consideration of model year. In fact, if EI23 has a trend with respect to model year that is consistent with the trend with respect to PSHED measurements, then there might be increased confidence in the utility of EI23 as an indicator.

Section 4.5: the discussion here suffers from a conceptual problem related to not clearly defining what is meant by "uncertainty." The term uncertainty is used inappropriately as if it refers only to imprecision, and the notion of bias is discussed as if it distinct from "uncertainty." Uncertainty refers to lack of knowledge regarding the true value of a quantity, and includes both random and systematic sources of error. Random error is imprecision. Systematic error is bias and also known as lack of accuracy. Thus, bias is a component of uncertainty, not distinct from it.

Uncertainties associated with small sample size are typically quantified based on random sampling error. The discussion of the role of 'chance alone' is inappropriate as written. Perhaps the intended statement is that if a different random sample of vehicles had been selected, the number of vehicles with PSHED measurements greater than 2 g/Qhr might have been different from the 2 that were observed in the available sample. Because the fraction of vehicles with PSHED measurements greater than 2 g/Qhr is based on a sample, there is 'sampling error' in the estimate. If the sample is assumed to be random, then the error of the estimate can be estimated based on sampling distributions of the statistics (a statistic is a quantity estimated from a sample). The errors shown in Table 4-11 are of unclear basis. For example, the 'size of error for 'high PSHED Definition' of 2 is given as 0.025. There should be more detail on how this number was estimated, based on the data given in Table 4.6.

PSHED measurement error should be more clearly discussed. The text refers to 'two parts' but really only one 'measurement error' is actually addressed. Measurement error typically refers to the imprecision and bias of the measurement method itself. Propane retention and recovery tests are an incomplete indicator of the imprecision and bias of the PSHED method, because actual evaporative emissions are not pure propane. Variability in hot soak emissions is a measurement error only in the context of attempting to assess the repeatability of measurements of the same vehicle under the same conditions. However, it is not clear that such an experiment has actually been done. If there are underlying differences in the state or condition of the vehicle, then the variability in the measurements is not because of the measurement method itself but because of the state of the vehicle being measured. The concept of repeatability of the measurement should be discussed in a separate paragraph or subsection. If the repeatability is only -50% to +200%, then there is significant question as to the usefulness of any kind of PSHED test when compared to a 'brightline' threshold that is a point value.

The discussion of detection limit and how it was inferred is difficult to follow. First, it would help to define what is meant by detection limit. It is not clear how a detection limit can be inferred by making a measurement on a vehicle or any sample for which it is not known as to whether the HC concentration is actually zero. Why not use a 'zero' calibration gas that contains 0 ppm of HC? A baseline before a vehicle enters the PSHED does not guarantee that actual concentration was 0 ppm of HC. However, it does provide a background level. However, the text does not discuss what is background or the role of background in making measurements.

Page 4-32 : the analysis of duplicate EI23 measurements is quite important, and the text refers to Appendix A. Appendix A is very poorly written and very unclear. It is not apparent that there are any data regarding the duplicate EI23 values in the main body of this report or in the appendix. The data and findings from these data should be disclosed.

The rational for the bias in the EI23 values and the implication that it would 'tend to elevate the high-PSHED fraction' needs to be more clearly articulated.

Page 4-33: the apparent confusion regarding detection limit and background level is evident in the second paragraph on this page. One does not subtract a detection limit from a measured value to impute an unbiased estimate. This would be done only for a background level. However, if the background is negligible compared to the measurement, this will have little effect on the results.

"jumps around" – this kind of informal writing needs to be expunged from this report.

The discussion of a possible Monte Carlo simulation is so vague that it hardly merits being in this report. Unless the authors can clearly define terms and propose a meaningful algorithm, the recommendation for future Monte Carlo simulation could be stated briefly, with further development left to those competent to conduct such an analysis.

Chapter 5:

The lead paragraph here is probably the most coherent statement of the objective of this report. Such a statement is needed in the introduction.

The second paragraph is not useful because it is based on evidence not provided in earlier parts of the report.

The purpose of Chapter 5 is unclear. Is this meant to be a conclusions chapter? A summary chapter? A results chapter?

The third paragraph is awkward and overly didactic. One can make the point, for example, that the use of EI23 as an indicator of evaporative emissions was explored in this work, and state the findings, conclusions, and recommendations accruing from this work. Subsequently, a recommendation can be made that the existing data could be analyzed using other indicators for the purpose of evaluating whether other indicators might be better than EI23. Whether 'any evap index' can be used depends on what variables are critical to an 'evap index' and whether they were all measured during the study at the Ken Caryl IM station. Since the report lacks even a basic overview of factors that lead to evaporative emissions, it is not clear as to whether all useful factors have been quantified to support development of 'any' evap index.

The paragraph at the bottom of page 5-1 is sufficiently cryptic as to be useless to anyone but those involved in the data collection or project management effort. It is not very clear as to what point is being made here.

Page 5-2 "to measure the RSDs" – this makes no sense. RSDs are devices that make measurement. Why would one make a measurement on the RSD itself?

The intent of the paragraph on "RSDs of the Denver fleet" is unclear. Perhaps this is a recommendation to calculate EI23 for a wider set of vehicles and use the Ken Caryl IM station data for fraction of high emitters to estimate a fraction of high emitters for the larger fleet. If that is the case, the intent is unclear.

Last paragraph on page 5-2 – seems to be introducing a lot of new information but in an unclear manner such that the point(s) here are unclear.

What is the main contribution of this report? What are the key limitations? What additional work is needed? If the purpose is to estimate the fraction of vehicles with evaporative emissions exceeding a threshold, the method described in this report using EI23 Bins and a 'stratification' approach may be reasonable; however, the uncertainty in the estimates made using this method are unknown. Such uncertainties should be estimated as the next step. Without quantification of uncertainty, the utility of this approach is unclear.

Some key issues that should be addressed in the conclusions:

- Is PSHED a useful surrogate for SHED?
- Can RSD measurements, if appropriately interpreted, provide an indicator of evaporative emissions?
- Is EI23 a useful indicator?
- Are the trends in the results for high evaporative emissions fractions in the vehicle fleet consistent with model year? What results developed here provide some confidence that EI23 is operationally useful?
- What are limitations of EI23? What other indicators should be explored?
- What uncertainties have been quantified? What uncertainties have not yet been quantified?
- Need for further evaluation of uncertainties prior to making a decision on acceptance of this approach?
- Application of this or other approaches to fleets that are more representative of the U.S. fleet.
- Others?

Eric M. Fujita's Comments:

The objective of this study is to estimate the fractions of various levels of high evaporative emissions across the Denver fleet. Approach used in the study relates indices of evaporative emissions (EI23) that were derived from RSD readings to levels of PSHED hot-soak evaporative emissions based upon correlations of a smaller stratified set of paired PSHED and RSD readings. The experimental approach and methods are adequately documented in the report and accompanying background document. Presentation of the results, including tables and figures, are generally clear except as noted in the following comments.

The data show that the measured PSHED 15 minute hot-soaks emissions are correlated with EI23, but with considerable scatter (Figure 4-1). We can see from this plot that the detection limit for the RSD EI23 index is poor and considerably worse than for the SHED measurements. Most of the EI23 values are clustered around 100 with corresponding PSHED emissions ranging from 0.01 to 20 g/Qhr. The preliminary study with induced evaporative emissions showed that the RSD evaporative index had a 50% chance of detecting evaporative emissions with PSHED-equivalent running loss level corresponding to about 20 g/Qhr (equivalent to EI23 Bins of 5 or below). While the EI23 evaporative index would be useful for identifying gross evaporative HC emitters, its ability to estimate fractions of high evaporative emissions within various levels of evaporative emission other than the top end of the distribution seems limited.

Conversion of EI23 measurements to Bins provides what appears to be clearer summary of the distribution of EI23 values by PSHED-equivalent running loss levels. As I understand this procedure, this classification assigns the estimated evaporative indices into bins with width that each corresponds to one standard deviation of the variability of a single EI23 measurement (after accounting for the effects of the exhaust HC emissions on EI23). The EI23 Bins are then associated with probabilities of exceeding various threshold PSHED hot-soak emission levels. This approach allows the association to be made without regard to the quality of the correlation between EI23 and PSHED hot-soak levels, which we know is poor. EI23 values in at least the first three EI23 Bins (with PSHED thresholds of greater than 1, 2 and 5 g/Qhr) are probably below the method limit of detection and are really random noise. If so, there is about equal chance that any of the EI23 values in the first three Bins has a corresponding PSHED above the threshold. Therefore, it is not unexpected that fractions of elevated PSHED in Table 4-6 are about the same for Bins 1 (6.7%), 2 (7.6%) and 3 (9.6%). These fractions are likely not valid given the measurement sensitivity. If 20g/Qhr is a reasonable level where the corresponding EI23 values become reliable, then the distribution shown in Table 4-4 for this High PSHED definition is valid for all EI23 Bins. The fractions are progressive less reliable for the lower EI23 Bins at lower thresholds values.

I believe the net result is an overestimation of the fractions of elevated PSHEDS in the lower Bins. Products of these fractions with the proportionally larger numbers of vehicles in these bins for the Random fleet will result in larger fractions of elevated PSHEDs in the larger fleet of vehicles. For example, results of the de-stratification calculations in Table 4-6 shows that 12.7% of the 5830 vehicles in the random sample are estimated to have corresponding high-PSHEDs defined as greater than 2 g/Qhr. If the first three Bins are counted as zero, then this fraction drops to 5.5%. Also dropping Bins 4 and both 4 and 5 reduces the fraction to 2.9% and 1.6%, respectively. The more appropriate fraction is likely between 1.6 to 5.5% rather than 12.7%.

It should also be noted that the distributions are presented without quantitative estimate of uncertainty and bias that are inherent in the study approach. In addition to the poor limits of detection of RSD evaporative index, the following sources of uncertainty and bias were not assessed in the report.

- The distributions are based on static SHED 15-minute hot-soaks and do not include diurnal evaporative emissions and may not fully account for all running emissions.
- The residual hydrocarbon signal in the RSD measurements in excess of the regression line of HC with CO_2 results is a crude measure of the diluted mixture of evaporative emissions from fuel permeation, vaporize fuel leaks, and fuel system venting during vehicle operation. Unlike exhaust pollutant, there are no tracers for evaporative HC emissions to account for dispersion rate of emissions.
- Replicate LSHED and PSHED tests have large variability. Section 4.5 does not address the significance of the large variability of replicate SHED tests to distribution of fractions of "high evaps" at various definitions.

Other General Comments

1. Ambient temperature was not included as a variable in the study design and PSHED and replicate RSD measurements were all made within a short time at about the same temperature. The test sets within each EI23 Bin were conducted at ambient temperature spanning a range of up to about 30^oC. Evaporative emissions are known to increase with ambient temperature with doubling of permeation for 10^oC rise in temperature. This likely would not be issue if ambient temperature was a random variable in the study and test sets within each bin had similar random distribution of temperature. Was this checked? The potential bias due to differences in temperature would be minimal for the high emitter bins, but may be more important for the other bins.
2. It would be helpful in Section 2 (Background) to state how the results of this study and similar future studies will be used in the MOVES model. Should be specific enough to identify the relevant algorithms and inputs.
3. Most vehicles in Bins 6 and 7 had high exhaust HC emissions, which can contribute to the estimated evaporative emissions. The report asserts that this positive interference is mitigated by the binning procedure. From the relevant discussion in Appendix A, it is difficult to determine the significant of the positive interference or the effective of the binning procedure.
4. The report does not include a summary of other testing – modified California Method (olfactory, visual and electronic HC sniffer examination of various vehicle components). If this information is summarized elsewhere, it should be references and a brief summary of the finding should be included within this report.

Specific Comments

1. P. 1-2, line 5. Are there plans for follow-on uncertainty analysis that can be described here?

2. P. 2-2, second full paragraph: Describe briefly the evidence, with appropriate references, that previous estimate of “high evaps” were lower that what is occurring in the real world.
3. P. 3-14, last sentence: Meaning is unclear. Why would large variability of PSHED hot-soaks itself result in overestimation of fraction of vehicles with high hot-soak emissions?
4. P. 4-1, 2nd paragraph, line 13: Rather than “accuracy”, “representativeness” may be more appropriate in this context.
5. P. 4-3, 1st paragraph, last two sentences: States that influence of variability of hot-soak emissions will be discussed later in the section. This discussion appears to be missing.
6. P. 4-3, 2nd full paragraph: References to “not simulated exhaust” and “natural exhaust” in the last two sentences are confusing.
7. P.4-4, 1st full paragraph, last two sentences: The reason for selecting Method B is difficult to understand without prior knowledge that EI23 is based on residuals of the linear regression. This is only explained in Appendix A. It should be mentioned briefly in the Section 4.2 for clarity.
8. P.4-11, Table 4-2. VDF is not defined anywhere in the report.
9. P. 4-24, 1st paragraph, last sentence: Are the quantifications of uncertainties and bias part of a follow-up report? When is this expected?
10. P. 4-25, Table 4-6: What is the basis for S_h in the calculation of standard error of the fraction of elevated PSHEDs? What are the sources of the values used in calculating the standard deviation?
11. P. 4-30, Table 4-10. Unless there is good reason for using natural log, give estimated error for column 2 in units of g/Qhr.
12. P. A-1, item i): Residual rather than N?
13. P. A-2: Add a description of the origin of the constants used in equations shown at the bottom of the page. Explain how this reduces dependence of EI23 on exhaust HC concentrations.

Review of ERG report

"Estimates of the Fraction of the Fleet with High Evaporative Emissions based on the Ken Caryl Station (Denver, CO) Field Study,"

Version 6, September 25, 2010

Reviewed by: Keith Knoll, Czero Inc.
Review Date: 20 January 2012

1.0 Summary:

The subject report describes efforts by ERG and CDPHE to estimate the occurrence of high evaporative emissions vehicles in the Denver fleet. Estimation is based on a fleet study of vehicles from the Ken Caryl I/M station using direct measurements. Three methods were employed for evaporative emissions measurement: RSD, PSHED and LSHED (Remote Sensing Device, Portable Sealed Housing for Evaporative Determination, and Laboratory Sealed Housing for Evaporative Determination, respectively). Results of direct measurements (mostly PSHED) from the study group are extrapolated to the broader Ken Caryl I/M fleet based on a relationship developed between RSD and PSHED results. The analysis relating RSD measurements to SHED results appears valid and well thought out. Uncertainties were investigated and sensitivity analyses were conducted. Use of RSD appears to provide considerable promise for determining high evaporative emissions vehicles from the in-use fleet.

The limited set of vehicles (175 total) that received both RSD and PSHED measurements was used to develop a correlation between RSD readings and measured evaporative emissions. This correlation was applied to the larger set of vehicles (5830 total) that visited the Ken Caryl I/M station during the summer of 2009. In this way, an estimate was made of the percent of vehicles visiting Ken Caryl over the study period that had high evaporative emissions. This projection was well justified based on results presented in the report. Speculation was also made regarding projecting these results to the Denver-wide fleet. Limitations associated with such a broad projection were given. Specifically it was noted that the existing dataset from the Ken Caryl I/M station was limited in relevance to the Denver-wide fleet for two reasons: 1) Colorado exempts about 40% of all registered vehicles from I/M inspection based on RSD measurements and 2) the Ken Caryl I/M stations is located in an affluent section of the Denver metro area. The first caveat means that the study sample (5830 vehicles) is likely to contain a disproportionate percentage of vehicles with high emissions – either evaporative or tailpipe. As such, the study sample is likely to be biased towards those vehicles with high evaporative emissions and is therefore ***not*** a random representation of the Denver fleet. The second caveat means that the study sample is likely to be composed of newer, properly functioning vehicles. Again, this introduces a bias in the database preventing it from being a random representation of the Denver fleet. Speculation was also made regarding projecting these limited results to the nationwide fleet. Limitations associated with this larger projection were not discussed.

Specific comments for each section of the report regarding methodologies, analysis, narrative and conclusions are given below. Many of these comments include specific recommendations to the authors for modifications prior to report publication. None of these recommendations is considered essential; the quality of the report is generally considered acceptable as-is. However, the quality of the report could be improved with some attention to the details included below.

2.0 Background:
A cursory review of CRC's E-77 suite of studies is provided. The E-77 studies showed that vehicle evaporative emissions ***do*** have a significant impact on the emissions inventory. Results also suggested that to quantify this impact, it would be important to determine the rate of occurrences of "leakers" in the on-road fleet. Per the referenced California study (ref 5), high evaporative emissions vehicles make up about 1% of the gasoline fueled vehicles in the on-road fleet. The ERG report suggests that this 1% estimate may be on the low side.

ERG's prior report from the summer of 2008 (the Lipan study) is also briefly reviewed. These results are particularly relevant to the current report as they explain how RSD measurements can be used to estimate vehicle evaporative emissions.

3.0 PSHED and LSHED Hot-Soak Emissions Measurement Characteristics
This study found that PSHED (portable SHED) measurements of evaporative emissions were generally higher than similar LSHED (laboratory SHED) measurements.

- Analysis showed that this bias was not likely a test order issue
- Analysis also showed that this was not a time issue (with the exception of HE-3555 which was shown to have continuously increasing evap emissions with time.)
- It is assumed this was an artifact of the test apparatus.

Comparison of PSHED and LSHED evaporative emissions results generally showed that scatter of the data about the parity line was equally distributed.

Comments to the report authors:

- Elsewhere in the literature, estimates are made providing comparison of PSHED results with EPA's Tier 2 requirements for evaporative emissions.[4] It would be helpful to include that here for context.

- It would be useful to provide some further explanation regarding HE-3555 evaporative emissions behavior. Why did these emissions continue to increase with time? Was the evaporative purge system on the vehicle evaluated for proper functionality? Was any testing done to identify root cause?

- On page 3-12, the statistical analysis leading to the conclusions that "repeated SHED hot-soak measurements for a vehicle would fall between 40% (=1/2.51) and 251% of the vehicle's average (characteristic) hot-soak value 68% of the time" should include a relevant source citation.

- The first bullet point under Summary of LSHED and PSHED states that vehicles with low hot-soak values have PSHED and LSHED results that "are very similar". I think this statement is misleading and may not be correct. The similar scatter shown by the data across three orders of magnitude on a log-log plot suggests that variation at low values was indeed less than at high

[4] [1] "Evaluation of Evaporative Leaks using RSD and Inventory Implications," D. Hawkins, C. Hart, C. Fulper, J. Warila, D. Brzezinski, et. al., Presented at the 19th Annual International Emission Inventory Conference, San Antonio, TX, Sept 27-30, 2010.

values. But it is not clear that the data could be considered nearly the same. This assertion requires further justification from the data analysis.

- The last paragraph in this section providing relevance to the on-road fleet requires clarification, further explanation and a review of the underlying assumptions. I believe the author is saying that because there is high scatter and a small number of samples available, the upper bound on extrapolating this data to the on-road fleet is necessarily high; higher than it would be if there were either a larger number of sample or a smaller variation in the data. If this is his message, it needs to be stated more clearly and with a more definitive confidence level. Also, is a normal distribution being assumed? If so, state it and explain why such an assumption is valid. If not, then what distribution is assumed and why?

4.0 Estimated High-PSHED Fraction of the Ken Caryl IM Station Fleet Using EI23 Bin De-Stratification

Comments to the report authors:

- Use of the term EI23 requires definition prior to use. This term is later defined in the Appendix, however, a general definition in the body of the report would be useful and should be included. Also, it might be useful to include some basis for the use of this term – where did the name "EI23" originate? …not essential, but would be useful.

- "Stratified" data and "de-stratified" data: It would be helpful to the reader (and still helpful to me after reading this report thoroughly) to have a better understanding of what is meant by these two terms. A layman's explanation of these terms near the beginning of Section 4 is advised.

- Paragraph 2 of Section 4: The last sentence of this paragraph suggests that two influence factors complicate extrapolation of the Ken Caryl dataset to the Denver-wide fleet. What exactly those two reasons are, however, is not clear from the paragraph text. My interpretation is summarized in the following bullets. Text of the paragraph should more clearly support the thesis statement given at the end of the paragraph.

  1. The sample of vehicles that visit I/M stations likely has higher emissions than the fleet at-large. The Denver-wide "clean screening" program exempts about 40% of registered vehicles based on low RSD readings. Consequently, the 60% of vehicles that go to I/M stations are the higher emitting fraction of the total Denver fleet. Using this sample population for emissions projection to the Denver-side fleet will likely skew the overall population estimate. However, there is no reason to believe that high tailpipe emissions vehicles are necessarily correlated with high evaporative emissions vehicles. So the real effect of this bias is not clear.

  2. The Ken Caryl I/M station is located in a higher income part of Denver. Consequently, the population of vehicles visiting this I/M station is likely to comprise newer and therefor cleaner vehicles than the Denver fleet as a whole. As far as I can tell, this bias has no mitigating factors.

- Accurate application of the Monte Carlo simulation method assumes a random distribution and a large number of samples. This paragraph should include a statement regarding the limitations of this method for analyzing the current dataset. The author does provide later in this report adequate justification that the sample population truly is random. This was well thought-out and well reported. Including some statement in this paragraph, however, would be helpful. I do not believe the author addressed the limitation of population size. This limitation should be mentioned here. Some comment regarding the potential impacts of this limitation should also be stated.

- In Section 4.4, Table 4-6: It is not clear how the fourth and fifth columns are calculated from columns 2 and 3. This should be explained.

- The last sentence in Section 4.4 appears to be the beginning of an incomplete paragraph. I expected further explanation or evaluation of how the EI23 bins are independent of model year groups. Did some additional text get inadvertently dropped from this section?

5.0 Estimated High-PSHED Fraction of the Denver On-Road Fleet from De-Stratifications Based on Advanced RSD Evaporative Emissions Indices

This section of the report goes on to discuss additional data that is now available for further investigation. Limitations of the additional data are also identified. For example, the PSHED data from Summer 2010 are identified as not being selected using a stratified random design. As such, these data are not suitable to the Denver-wide fleet.

This last section of the report leaves the estimation of the high-PSHED fraction of the Denver-wide fleet incomplete. No estimation is provided because the data are identified as inadequate.

This last section of the report also provides no basis for extrapolating the results obtained to an estimate of the nationwide fleet as is needed by EPA. For EPA to apply this dataset to the nationwide fleet (via MOVES), additional justification would be necessary.