Peer Review of March 2015 Speciation Profiles and Toxic Emission Factors for Nonroad Engines Report

September 15, 2015

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Acronyms and Abbreviations

Acronym / Abbreviation	Stands For
EPA	U.S. Environmental Protection Agency
ICF	ICF International
LDV	Light-Duty Vehicle
NMHC	Non-Methane Hydrocarbon Emissions
NMOG	Non-Methane Organic Gases
OTAQ	Office of Transportation and Air Quality
THC	Total Hydrocarbon
TOG	Total Organic Gas
VOC	Volatile Organic Compound
WAM	Work Assignment Manager

1. Introduction

The Office of Transportation and Air Quality (OTAQ) of the U.S. Environmental Protection Agency (EPA) is responsible for developing regulations to reduce the emissions of greenhouse gases (GHG) from light-duty vehicles (LDV) in the U.S. As new policy options are brought forth, there is a need to evaluate the soundness and utility of such policies. Modeling questions may yield approximations from smaller sets of real data when questions of policy tend to be too large to study directly. For example, models can provide insights into how drivers will change their vehicle operating patterns in response to a mandated increase in fuel economy across the light-duty vehicle fleet. EPA's MOVES2014 model is part of a comprehensive EPA approach to address the impacts of light- and heavy-duty vehicles on air quality and public health.

EPA documented the inclusion of development of NONROAD toxic emission rates that are proposed to be incorporated into MOVES2014a, as well as parameters used to derive methane, non-methane hydrocarbon emissions (NMHC), non-methane organic gases (NMOG), volatile organic compound (VOC), and total organic gas (TOG) emission rates from NONROAD total hydrocarbon (THC) emission rates. In addition, they documented the development of speciation profiles that will be applied to TOG and PM2.5 by SMOKE to compute air quality model ready species.

This report details the peer review of the subject report, *Speciation Profiles and Toxic Emission Factors for Nonroad Engines (March 2015)*. A number of independent subject matter experts were identified and the process managed to provide reviews and comments on the methodology of the report. This peer review process was carried out under EPA's peer review guidelines[1].

This report is organized as follows:

- Chapter 2 details the selection of the peer reviewers
- Chapter 3 details the peer review process
- Appendix A provides resumes and conflict of interest statements for the two selected reviewers
- Appendix B provides the charge letter sent to the selected reviewers
- Appendix C and D provide the actual reviews submitted by the two selected reviewers

[1] U.S. Environmental Protection Agency, Peer Review Handbook, 3rd Edition with appendices. Prepared for the U.S. EPA by Members of the Peer Review Advisory Group, for EPA's Science Policy Council, EPA/100/B-06/002. Available at http://www.epa.gov/peerreview

2. Selection of Peer Reviewers

The EPA and ICF International (ICF) Work Assignment Manager (WAM) compiled a list of 11 reviewers who would be capable of reviewing the subject report. They are listed in Table 2-1. ICF contacted these potential reviewers to determine their availability to participate and obtain a CV.

Table 2-1. Potential Reviewers

Potential Reviewer	Affiliation	Availability	Degree	Depth of Experience	Recency of Contributions
DeFries, Timothy	Eastern Research Group, Inc., Principal Scientist	Yes	Ph.D. Physical Chemistry, University of Illinois B.S. Chemistry, Purdue University	High	High
Durbin, Thomas	UC Riverside, Research Engineer II, Center for Environmental Research and Technology (CE-CERT)	Yes	UC Riverside: Ph.D., Physics M.S., Physics B.S., Physics	High	High
Fanick, Robert	Southwest Research Institute, Manager of the Emissions Chemistry Section	Yes	B.S., Chemistry, Texas A&M University	Med-high	n/a *(CV did not include list of recent projects or publications)*
Gordon, Timothy	NOAA ESRL	No response	n/a	n/a	n/a
Hoekman, Kent	Desert Research Institute, Division of Atmospheric Sciences	Yes	Ph.D. Organic Chemistry, Iowa State University B.S. Chemistry, Calvin College	Med	Med
Lindhjem, Chris	ENVIRON International Corp., Senior Manager	Yes	Ph.D., Chemical Engineering, Rensselaer Polytechnic Institute M.S., Chemical Engineering, University of Michigan B.S., Chemical Engineering, Rose-Hulman Institute of Technology	High	High

Potential Reviewer	Affiliation	Availability	Degree	Depth of Experience	Recency of Contributions
Liu, Gerald	Cummins Inc., Executive Scientist / Director of Research & Development	Yes	University of Wisconsin-Madison: Ph.D., Environmental Engineering M.S., Atmospheric Sciences Xian University, China: M.S., & B.s, Mechanical Engineering	Med-high	High
Miller, Wayne	UC Riverside, Adjunct Professor CEE & Associate Director, CE-CERT	Yes	Ph.D., Chemical Engineering, California Institute of Technology B.S., Chemical Engineering, Worcester Polytechnic Institute	Med-high	Low
Rideout, Greg	Environment Canada	No response	n/a	n/a	n/a
Thiruvengadam, Arvind	West Virginia University	No response	n/a	n/a	n/a
Yanowitz, Janet	EcoEngineering, Inc., Principal	Yes	Ph.D., Environmental Science and Engineering, Colorado School of Mines B.S., Chemical Engineering, Massachusetts Institute of Technology	Med	Low

The two selected reviewers are listed in Table 2-2. Each had the necessary expertise, were available to review the report in a timely manner and had no conflict of interest. All were agreed upon by the EPA WAM.

Table 2-2. Final Reviewers

Reviewer	Contact Information	Necessary Expertise	Conflict of Interest
Timothy DeFries	Eastern Research Group P: 512-407-1824 Tim.DeFries@erg.com	Yes	No

Reviewer	Contact Information	Necessary Expertise	Conflict of Interest
Thomas Durbin	UC Riverside Center for Environment Research and Technology (CE-CERT) P: 951-781-5794 durbin@cert.ucr.edu	Yes	No

Resumes and conflict of interest statements for the three reviewers can be found in Appendix A.

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3. Peer Review Process

Once the three reviewers had been decided upon and approved by the EPA WAM, a charge letter (see Appendix B) and supporting materials for the peer review were distributed. During the review process, one reviewer had question a question about the definition of a COI. A teleconference was held with EPA to discuss how a COI is defined. It was determined that there was no COI for the reviewer. Each reviewer provided a written peer review in a timely manner. These were sent to ICF who forwarded them directly to the EPA WAM.

ICF managed the peer review process to ensure that each peer reviewer had sufficient time to complete their review of the data analysis by the deliverable date. An extension of the timeline was granted due to a schedule conflict for one reviewer. ICF adhered to the provisions of EPA's Peer Review Handbook guidelines to ensure that all segments of the peer review conformed to EPA peer review policy.

Appendix A. **Resumes and Conflict of Interest Statements**

TIMOTHY H. DeFRIES

Education

Ph.D., 1978, Physical Chemistry, University of Illinois, Urbana, IL.
B.S., 1969, Chemistry (majors in Chemistry and Physics), Purdue University, West Lafayette, IN.

Experience

Principal Scientist, Eastern Research Group, Inc., Austin, TX, 2003-Present
Senior Staff Scientist, Eastern Research Group, Inc., Austin, TX, 1999-2003
Senior Staff Scientist, Radian International LLC, Austin, TX, 1993-1999.
Senior Scientist, Radian Corporation, Austin, TX, 1986-1992.
Staff Chemist, Exxon Research and Engineering Company, Linden, NJ, 1982-1986.
Senior Chemist, Exxon Research and Engineering Company, Linden, NJ, 1980-1982.
Research Chemist, Exxon Research and Engineering Company, Linden, NJ, 1978-1980.
Special Chemistry Technician, U.S. Naval Hospital, Philadelphia, PA, 1970-1973.

Fields of Experience

Dr. DeFries' interests lie in the areas of mobile source emissions, plume opacity, engineered process modeling and optimization, experimental design, flue gas particle sizing, meteorology, and data analysis using statistical and neural network techniques. He has taken lead roles in many projects.

Tim DeFries has a wide variety of experience in the use of statistical tools for the analysis of mobile source data. He has used SAS continuously since 1980 first at Exxon Research and Engineering Company, then at Radian Corporation, and now at Eastern Research Group.

While at Exxon, he learned statistical experimental design techniques from Stuart Hunter. After applying those techniques for several years in the study of motor fuels, including emissions effects in a photochemical smog chamber, he worked on the review committee that guided Exxon's development of its internal experimental design course. This course integrated these advanced design techniques with the benefits of SAS for use by Exxon scientists. Now at Eastern Research Group, he regularly applies statistical experimental design techniques.

Through his long association with SAS and resident statisticians, he has a daily familiarity with ordinary least squares regression, multiple linear regression, nonlinear regression, analysis of variance, logistic regression, variance stabilizing transformations, and measurement-error modeling. As a member of the mobile sources group, he maintains close working relationships with statisticians to help bridge the gap between a project's practical need for data analysis and fundamental statistical techniques.

In the mobile source area, he has used statistics to simulate the benefits of vehicle inspection/maintenance programs, develop high emitter profile models for vehicles, develop representative driving cycles for Bangkok motorcycles, evaluate exhaust and evaporative emissions of "off-FTP" driving, design a test program to collect vehicle data to improve evaporative emissions modeling, and analyze literature data to evaluate the effects of oxygenated gasoline blending components on exhaust and evaporative emissions.

He has applied neural network modeling techniques to mobile source emissions, engineered process optimization, and ambient ozone forecasting. His knowledge of statistics serves as a valuable background for the analysis of data by neural network modeling, for which robust model evaluation tools have not been developed to the point of statistical model evaluation tools.

Mobile Source Evaluations

- **Sensitivity Analysis of MOVES Using National Emissions Inventory Submittals as Inputs** – EPA's Motor Vehicle Emissions Simulator (MOVES) is used by states to report each county's contributions of motor vehicle emissions to the National Emission Inventory. Each state estimates emissions by selecting data that describe the factors that affect emissions in each county. The factors, which are inputs to MOVES and which may be based on measurements, estimates, or MOVES defaults, are chosen by each state to represent the best information available given the state's resources. Consequently, the range of values for each factor submitted for the counties approximate the range of values that a reasonable MOVES run could use in normal practice. Dr. DeFries developed fractional factorial and mixture statistical experimental designs to produce a series of "experiments" used to exercise the MOVES model over the ranges of factors observed in the county submissions. The designed runs constituted a sensitivity analysis of MOVES using real-world inputs to determine main effects of the factors that were most influential on vehicle emissions. The results provide guidance to states so that they can cost-effectively improve emissions estimates by spending limited resources on the most influential factors. [198]

- **Investigation of Evaporative Emissions Control System Canister Degradation** – [196]
T.H. DeFries, "Task Proposals for Canister Degradation Investigations, Version 2," Report, EPA-130926, prepared for U.S. Environmental Protection Agency, September 26, 2013.

- **Analysis of Off-Road Emissions Corrections** – [188]
J. Koupal, T.H. DeFries, "Analysis of Off-Road Emissions Correction Factors," Report, ARB-130510, prepared for California Air Resources Board, May 10, 2013.

- **NONROAD Load Factors** – [186, 187]
T.H. DeFries, M.F. Weatherby, C.F. Palacios, "Development of NONROAD Load Factors, Emission Factors, Duty Cycles, and Activity Estimates, Version 2," Report, EPA-130212, prepared for U.S. Environmental Protection Agency, February 12, 2013.
T.H. DeFries, E. Glover, J. Warila, S. Kishan, "Load Factors, Emission Factors, Duty Cycles, and Activity of Diesel NonRoad Vehicles," CRC-130410, presented by T.H. DeFries at the 23rd Coordinating Research Council On-Road Vehicle Emissions Workshop, San Diego, California, April 10, 2013.

- **Pilot Study for Light-Duty Vehicle Fuel Economy and Influencing Factors** – ERG conducted a pilot study to investigate the feasibility of using second-by-second information from the

Onboard Diagnostic (OBD) link of 1996 and newer vehicles for the purposes of quantifying light-duty vehicle fuel economy and the factors that influence it. Dr. DeFries used existing information on fuel economy to develop a plan and cost for the size and structure of a stratified, random sample of vehicles that would be instrumented with OBD dataloggers for one year. He also developed candidate recruitment plans that could be used to select vehicles from all areas of the U.S. To help confirm that OBD data on modern vehicles contains information sufficient to calculate or estimate second-by-second fuel economy, he analyzed paired chassis dynamometer data and OBD datalogger data on a 2009 gasoline direct-injection vehicle. The neural network models indicated that the OBD data stream could be used to calculate fuel flow rate under stoichiometric combustion, fuel cut-off, and cold-start engine operating conditions. Neural network scoping models built on OBD data from a 2012 turbo diesel engine indicated that OBD data could be used to calculate diesel fuel flow even though diesel engines operate non-stoichiometrically. [185, 191, 195, 197]

- **Hot-Soak Evaporative Emissions Distribution of the 2010 Denver Fleet** – Model year 1961-2010 light-duty gasoline vehicles were randomly targeted for hot-soak testing from strata based on estimated probability of elevated evaporative emissions used remote sensing measurement of hydrocarbons as vehicles entered the driveways of two IM stations in Denver. After suitable vehicle conditioning, the hot-soak emissions of targeted vehicles whose drivers were willing to participate were measured in a portable enclosure. Dr. DeFries de-stratified the hot-soak emissions results from his experimental design using the targeting fraction for each stratum and the observed driver participation rate for each vehicle model year group to arrive at the estimated hot-soak emissions distributions of the portion of the Denver light-duty fleet that is inspected at IM stations. Dr. DeFries adjusted and combined the measured hot-soak distributions of the two IM stations for the eligibility requirements of the IM program, the characteristics of the city-wide clean-screening program, and the model-year distribution of the registered fleet. This produced overall and by-model-year estimates of the hot-soak distributions of the on-road Denver fleet vehicles, whether they are required to be inspected in the IM program or not. [184]

- **MOVES Activity Tables** – [182, 183]

- **Influences of Model Year and Previous-Cycle IM Results on RSD Exhaust Concentration** – As part of their effort to update EMFAC, the California Air Resources Board asked ERG to investigate the influences of model year, vehicle age, and previous-IM-cycle results on the on-road tailpipe emissions of California vehicles as measured by the 2004-2005 California RSD Pilot study. Dr. DeFries guided this analysis, which matched RSD readings with the previous-cycle initial ASM or OBD results. The analysis indicated that, for 1971-2003 vehicles, higher average RSD HC, CO, and NOx concentrations were associated with older model year vehicles and vehicles that had failed their previous-cycle initial ASM test – even though that failure had caused the vehicles to be repaired and certified as a passing vehicle. Similarly, for 1996-2002 vehicles, higher average RSD HC, CO, and NOx concentrations were associated with older model year vehicles and vehicles that had failed their previous-cycle initial OBD test. [179, 180]

- **OBD Trouble Code Performance vs. SHED and RSD Measures of Evaporative Emissions** – Three collaborative studies (Lipan station, Karyl station, and Denver repair effectiveness) on privately-owned light-duty gasoline vehicles produced evaporative emissions running loss data by RSD and hot-soak evaporative emissions data by portable SHED. In addition, the I/M inspections of the 1996 and newer vehicles contained OBDII results. In this study Dr. DeFries helped use those matched datasets to determine if RSD and SHED measurements were correlated with OBDII evaporative emissions diagnostic trouble codes (DTCs) from those vehicles. He helped guide the technical analyses of this study. Also, he built logistic regression models that showed that the probability of evaporative DTCs being set was correlated with elevated hot-soak SHED emissions but not by vehicle age alone. On the other hand, similar logistic regressions could not find a correlation between the probability of evaporative DTCs being set and RSD measures of running losses. He attributed this lack of correlation to interferences from speed and exhaust HC emissions on the RSD evaporative emissions index that was use to analyze the data. [178]

- **Sampling of Drayage Trucks using RSD Data** – ERG and EPA conducted an instrumentation project at the Port of Houston to gather second-by-second emissions and activity measurements on drayage trucks for EPA's new MOVES model. At the beginning of the project, RSD measurements were obtained on trucks entering the port. Dr. DeFries analyzed the RSD NOx data to prioritize the trucks that would be most beneficial for characterizing the emissions of the drayage truck fleet at the port. He used the multiple RSD NOx measurements on each truck to characterize the variability of RSD NOx measurements and then to determine the distribution of the true RSD NOx values for the fleet. He divided that distribution into several RSD NOx bins and model-year bins. For each vehicle, he calculated the probability that it would actually be in its assigned RSD NOx bin. The vehicles with the highest in-bin probabilities were targeted with the highest priority for instrumentation. In addition, the same number of vehicles was selected from each of the RSD NOx bins so that the entire range of NOx emissions from cleanest to dirtiest was covered by the test program. [172]

- **Development of Stratified Random Sampling for Vehicle Exhaust Testing Using RSD Data** – The U.S. Environmental Protection Agency initiated a 10-year, long-term private vehicle emissions and activity testing program throughout major cities in the U.S. This longitudinal study will instrument 100 vehicles in each of two cities each year. The second-by-second data from each vehicle will be used to support updates to EPA's MOVES model. Since the 100 vehicles in each city will represent the exhaust HC, CO, and NOx emissions and activity trends for the fleet, the vehicles need to be carefully selected. DeFries developed a stratified random sampling design that will use RSD data obtained in each city to select a 100-vehicle sample that is likely to have a relatively flat emissions distribution for all three pollutants. He used variance-stabilizing transformations of the RSD pollutant measurements followed by a rotation of axes to produce a single variable that is associated with the overall emissions level tendency of each vehicle. [170, 181]

- **Development of RSD to Identify Vehicles with Elevated Running Losses** – On-road remote sensing to identify vehicles with elevated exhaust emissions and to determine the average exhaust emissions of a fleet of vehicles has been used since about 1995. Work done around 2007 indicated that RSD might be able to detect evaporative emissions from gasoline-powered vehicles. A series of joint studies among Colorado Department of Public Health and Environment, ESP, U.S. Environmental Protection Agency, and ERG was undertaken to determine if RSD had this capability and to develop it. Dr. DeFries led several aspects of this effort in several different phases. He designed controlled tests of RSD's sensitivity to simulated running loss emissions (propane releases and liquid gasoline releases) from test vehicles at different speeds and exhaust HC conditions. Analysis of that data confirmed that RSD had potential. He designed a stratified random sampling plan to select private vehicles for evaporative emissions testing using a portable SHED and an electronic handheld HC vapor sniffer. In the first study, private vehicles were selected at a Denver I/M station. Subsequent studies on private vehicles were performed in San Antonio and then at another Denver I/M station. In each study he led data archiving and quality assurance. From the results of each study, he developed an ever-improving Evaporative Emissions Index based on RSD time series data collected at each RSD beam block. He has developed first generation techniques for identifying individual vehicles with elevated running losses and for estimating the elevated running loss fraction of a fleet using new or historical RSD data. He de-stratified the results of the hot-soak measurements taken at Denver's Ken Caryl IM station to estimate the hot-soak evaporative emissions distributions of the light-duty vehicles by model year group. [167, 168, 169, 171, 173, 174, 175, 176, 177, 189, 190]

- **Determination of Mileage Accumulation Rates from IM Data** – Mobile source emissions inventory models commonly use mileage accumulation rates (MARs) to estimate the emissions inventory of a fleet. In this study for the Colorado Department of Public Health and Environment, DeFries helped determine the MARs of different vehicle classes as a function of vehicle age using Colorado's I/M data. During each I/M inspection the odometer reading is recorded. However, the odometer readings are visually read and manually entered by the I/M inspector. Accordingly, the readings contain typographical errors, and for older vehicles, are subject to rollovers as the mileage passes through 100,000 miles. In this study, ERG developed statistical techniques using the multiple odometer readings on each vehicle to identify and correct these errors in the readings of individual vehicles to arrive at accurate MAR estimates. Vehicles whose readings could not be confidently corrected were removed from the analysis to minimize bias. [165]

- **Georgia IM Program Operation Analyses** – The Georgia Environmental Protection Division prepares an annual operations report for the Georgia Enhanced I/M Program. Drawing on his I/M program evaluation experience, Dr. DeFries helped identify analyses of 10 years of Georgia I/M program data (covert audits, waivers, tailpipe emissions measurements, OBD, and repair information) that would improve the characterization of the I/M program. The results were reported to Georgia to help improve the I/M program and to EPA to meet I/M program reporting requirements. [163, 164]

- **Relationships between OBD Data and IM240 Emissions** – Most states with I/M programs perform inspections of OBDII-equipped vehicles (1996 and newer model years) instead of measuring tailpipe emissions. However, Colorado bases a vehicle's emission inspection result on the IM240 tailpipe emissions test. At the same time, the OBD status of each vehicle is recorded for informational purposes. This I/M approach and the data that it generates open up the possibility of estimating the emissions effect of an OBD I/M program. Dr. DeFries was the project director of a study to explore data analyses that could be used to establish the OBD/emissions connections. The study indicated that adding a requirement to pass OBD in addition to passing IM240 would detect additional vehicles with elevated emissions. Vehicles that had initial inspections accompanied by the most commonly set Diagnostic Trouble Codes had emissions that differed from the average initial emissions of all vehicles with DTCs set. The directions of the emissions differences of initial inspections were consistent with the type of DTC that was set. For example, the initial emissions of vehicles with exhaust gas recirculation DTCs set had lower HC, lower CO, and higher NOx IM240 emissions than vehicles with any DTCs set. [157, 158]

- **Development of Driving Cycles for Heavy-Duty Drayage Trucks** – In a study for the Houston Advanced Research Center (HARC) and the Texas Environmental Research Consortium (TERC), researchers at the University of Texas at Austin were to evaluate the NOx-reduction benefits of double wide tires developed by Michelin. Two of these tires can replace the four tires on the axles of heavy-duty trucks. Dr. DeFries led the effort to develop the heavy-duty drayage truck driving cycles that were used on a test track to test the emissions of drayage trucks with the standard four tires and with the new double wide tires. Drayage trucks are typically used at seaports to load and unload cargo ships. [156, 162]

- **Estimating I/M Program Aggressiveness for the MOVES Model** – The U.S. Environmental Protection Agency is developing MOVES to replace MOBILE6. EPA asked ERG to develop a concept for software that could estimate the effectiveness of different I/M program designs to reduce emissions. Dr. DeFries provided a proposed system based on the I/M simulator developed for the California RSD pilot study. The system is designed to be a Monte Carlo simulator that is able to calculate an I/M program aggressiveness factor based on inputs for the type of I/M program emissions test, I/M cutpoints, model years eligible for I/M, I/M inspection frequency, special I/M program supplemental strategies, and the mix of I/M fleet vehicle technologies. He proposed new methods for estimating the emissions of vehicles that do not participate in the I/M program. In addition, he described a method for analyzing RSD data in conjunction with VID data that would produce a simulator that estimates the effects of different I/M program designs on on-road exhaust emissions. [155]

- **Relative I/M Inspection Station Performance** – The California I/M program uses several types of inspection stations in its statewide decentralized system including test-and-repair, test-only, referee, and consumer-assistance-program-certified stations. The program administrators have an ongoing desire to evaluate the relative performance of stations so that higher risk vehicles can be directed to better quality stations for regular I/M inspections. However, evaluating station performance has always been difficult because measures of station performance are confounded with the different vehicle clientele that patronize individual stations. Dr. DeFries used the I/M program simulator, which he developed for the RSD pilot study, to estimate the average-station probability of ASM failure of individual vehicles at the time those vehicles received RSD measurements on the road. The failure probability estimates take into account vehicle description, vehicle age, vehicle I/M inspection history, and the time between the previous I/M inspection and the RSD. A comparison of the rate of measured RSD failures with the fraction of vehicles expected to fail the RSD reveals how much the set of vehicles certified at a given station deviates for the average station. Thus, stations whose clientele had lower on-road fail rates than expected by the probability models are higher-performing stations than those stations whose clientele had higher on-road fail rates than expected by the probability models. [151]

- **Evaluating the Texas 2004/2005 IM Program** – The U.S. EPA requires that I/M programs be evaluated for performance every two years. Dr. DeFries was the project director for the evaluation of the Texas I/M program during 2004/2005. He designed this project for the Texas Commission on Environmental Quality to conform to EPA "Guidance on Use of In-Program Data for Evaluation of I/M Program Performance" and EPA "Guidance on Use of Remote Sensing for Evaluation of I/M Program Performance." The project focused on process-based and results-based measures of performance. Process-based measures are coverage, inspection, repair, and enforcement. Results-based measures are determined from the repair-induced changes in emissions as measured by the I/M program inspections (in-program data) and by on-road RSD measurements (out-of-program data). His ERG evaluation team worked with data from the Vehicle Information Database, Department of Public Safety Station audit data, and remote sensing data to evaluate various aspects of I/M program performance. [122, 144, 153]

- **Effectiveness and Cost-Effectiveness of Adding RSD to an Existing I/M Program** – The goal of this California Air Resources Board and Bureau of Automotive Repair project was to determine if and how adding remote sensing could benefit its existing I/M program and how RSD could be most cost-effectively used. Dr. DeFries led the analysis effort. The analysis required the ability to forecast FTP-basis mass emissions for individual vehicles as a function of time. He conceived and built a probabilistic I/M program simulator to do this for the California fleet as a function of individual vehicle description, vehicle age, I/M inspection history, time since the most recent I/M inspection, and with or without RSD measurements. That system was built using California's nine-year historical I/M inspection database and the 2.2-million RSD measurements collected in the project. Because the forecasts are time-dependent and are a function of I/M inspection history, the system has the ability to predict the FTP-basis mass emissions benefits – integrated over one biennial inspection period – of modifications to the I/M program. For this study we investigated four main modifications: calling in high-emitting vehicles for inspection and repair mid-cycle, directing high-emitting vehicles to high-performing I/M stations, exempting low-emitting vehicles from I/M inspection, and scrapping high-emitting, low-value vehicles. The study found that adding RSD to the existing I/M program would produce a small reduction in mass emissions, but the cost per ton for getting the reductions was quite high, making adding RSD cost-ineffective. On the other hand, we found that supplementing the existing I/M program with strategies for selecting vehicles for directing, exempting, and scrapping using vehicle description and I/M inspection history (that is, without RSD) could save the I/M program millions of dollars while at the same time reducing mass emissions substantially. [136, 137, 138, 148, 150, 152, 154, 159, 160, 161]

- **Consumer Response to MIL Illumination in Non-I/M Areas** – Malfunction Indicator Lights are built into the dashes of all 1996 and newer light-duty vehicles to indicate system malfunctions that may affect a vehicle's emission control capabilities. Dr. DeFries was the lead analyst in this Coordinating Research Council project to determine how non-I/M area vehicle owners respond to MIL illuminations. He helped design a telephone survey of vehicle owners, and he analyzed the results of the survey. The results suggest that most owners respond positively shortly after an illumination occurs by investigating the cause of the lit MIL and in most cases getting their vehicles repaired. [147, 149]

- **Toxic/THC Ratios Predicted by MOBILE6.2** – This study for the U.S. EPA compared the ratios of emission rates of toxic compounds (benzene, 1,3-butadiene, formaldehyde, acetaldehyde, methyl-t-butyl ether, acrolein) to total hydrocarbon as calculated by MOBILE6.2 and as measured on vehicles. Dr. DeFries was the project director. MOBILE 6.2 forecasts future toxic emission rates by multiplying the projected future THC by the toxic/THC ratios. However, the toxic/THC ratios used by MOBILE6.2 were determined from measurements on 1990 technology vehicles. The comparison in this study was done to determine if MOBILE6.2 toxic/THC ratios are indeed representative of late model vehicle technologies. He determined the statistical significance of the difference between the lab-measured toxic/THC values for late model vehicles and the MOBILE6.2 toxic/THC values for those same late model vehicles. [146]

- **Quantifying the Effects of Specific Emission Control System Repairs on Emissions** – The goal of this project for the Texas Council on Environmental Technology was to develop a system for predicting the emission control system repairs needed by a light-duty vehicle based on the vehicle's measured ASM2525 emissions. The project builds on earlier findings that ASM emissions of a vehicle may be a "fingerprint" that is associated with the failure of certain emission control system components. Dr. DeFries was the project director and data analyst for this project. The models made the connection between component failures and the changes in measured ASM emissions using I/M program data from the British Columbia I/M program. DeFries modeled the change in ASM2525 emissions (before repair to after repair) as a function of 32 specific types of repairs that were made to vehicles. Vehicles were grouped and modeled in five separate fuel-metering/catalyst technology types. The results, which were consistent with engineering knowledge, quantified the size and statistical significance of each of the 32 repair types on ASM HC, CO, and NOx tailpipe emissions. From this same dataset, he also performed a discriminant analysis. This analysis was used to demonstrate the potential for a "repair aid." This analysis showed that the vehicle's VIN and ASM2525 inspection concentrations can be used to determine the probabilities that the vehicle needs one of several types of specific repairs or that the vehicle is problem-free and to estimate the after-repair ASM2525 emissions for each of the different repair options. [141, 145]

- **Effects of Emulsified Diesel Fuel on Emissions, Fuel Economy, and Performance of Heavy-Duty Vehicles** – The Texas Department of Transportation funded a project conducted by the University of Texas at Austin to determine the benefits and cost-effectiveness of Lubrizol PuriNOx, a water-emulsion diesel fuel. ERG was a subcontractor to the university; Dr. DeFries was one of ERG's task leaders. His team built and used three types of dataloggers to record second-by-second diesel engine and vehicle operating parameters on several types of on-road and off-road heavy-duty diesel vehicles for several weeks in normal work environments and in simulated work activities during a "Road-E-O." From the logged information, Dr. DeFries built chassis dynamometer test cycles for the on-road vehicles (speed vs. time) and engine dynamometer test cycles for the off-road vehicles (RPM and torque vs. time). Those cycles were subsequently used to test vehicles and diesel engines for emissions and fuel economy at Southwest Research Institute. He used the logged information from the Road-E-O work activities to quantify performance penalties (for example, reduced acceleration) associated with the fuel because of its 10% water content. [133, 139, 140, 142, 143]

- **Quality Assurance / Quality Control Activities** - In around 1994, while at Radian Corporation, Dr. DeFries started the Mobile Sources library. The library, which is now at ERG, contains paper and electronic copies of reports, draft reports, technical notes, memos, and proposals produced by the group from 1986 to the present. In addition, the library contains relevant mobile source reference materials and documents produced by other individuals and organizations active in mobile sources research. He guides the maintenance of the library. As the ERG's Mobile Sources QA/QC coordinator, he requires that copies of all documents submitted to clients for fulfillment of a contract be sent to the library for archiving. By examining the documents that are submitted, he is able to monitor the research techniques and writing of ERG Mobile Sources staff. He helps train them to ensure a certain level of quality in ERG products. QA/QC activities are part of all of Dr. DeFries' projects. In addition, he passes on his QA/QC experience to his co-workers in the ERG Mobile Sources group through informal training and by example. Occasionally, we recommend to a client that we create an EPA-quality Quality Assurance Project Plan (QAPP). Large field projects, where time and money pass by quickly with little time for thinking about fixes to unforeseen problems, can especially benefit from the development of a QAPP. The QAPP, which he developed for the U.S. EPA as project director of the 1991 Federal Test Procedure revision project, serves as the example for all of the QAPPs that we develop. [27]

- **FTP Emission Rate Projections for Houston and Dallas** – This I/M program effectiveness study, which was done for the Texas Commission on Environmental Quality, used Texas I/M program ASM inspection data to estimate the FTP-basis emissions of vehicles at the beginning and end of each inspection cycle. Dr. DeFries was the project director. The Texas I/M program uses ASM emissions tests. When a vehicle fails an ASM, the ASM test is full duration; however, when a vehicle passes an ASM, the analyzer performs a fast-pass ASM, which produces concentration values that are biased high with respect to full-duration values. Using a special California dataset of second-by-second ASM inspections, DeFries developed a model to convert fast-pass ASM values to full-duration ASM values. Applying these corrections to the Texas I/M program ASM data helped minimize the bias in ASM concentrations caused by fast passes. He then converted the corrected ASM concentrations to FTP values using the ASM-to-FTP models developed for California. The results indicated that vehicles, that initially fail an inspection, but after repair, ultimately pass and are certified, are being repaired to the same ASM and FTP emission levels as those vehicles that pass their initial inspection. [135]

- **Development of On-Road Heavy-Duty Vehicle Driving Cycles for MOVES** – The U.S. EPA asked ERG to use existing heavy-duty vehicle activity data to develop speed vs. time driving cycles for heavy-duty vehicles for use in the MOVES mobile source emissions model. Dr. DeFries was the project director of this work assignment. The activity data were from three sources: 4 TxDOT dump trucks datalogged by connection to the vehicle's serial data port, 120 trucks datalogged by Battelle using GPS, and 30 trucks datalogged by Jack Faucett and Associates using GPS. DeFries built the cycles using the ERG micro-trip technique to match the speed, acceleration, and vehicle specific power characteristics of the non-idle driving portions of the supplied second-by-second data. Separate cycles were built for heavy heavy-duty vehicles, parcel medium heavy-duty vehicles, and non-parcel medium heavy-duty vehicles. The GPS data was challenging to use because of frequent "dropouts" caused by loss of satellite communication and no engine RPM data to serve as "back-up" and because of time-stamp errors. [134]

- **Estimating Virginia IM240 Emissions from ASM Inspection Concentrations** – As part of its I/M program biennial evaluation for EPA, Virginia chose to estimate the program's emissions reduction on an IM240 basis as calculated from the program's ASM inspection measurements. This approach required statistical models that could convert ASM emissions concentrations to IM240 emission rates. Dr. DeFries was the project director for this modeling effort. He designed a stratified random testing plan to collect the data needed to build the models. Based on his plan, TESTCOM tested 1702 vehicles to acquire ASM/IM240 pairs, ASM duplicates, and IM240 duplicates. DeFries then used the data to quantify ASM emissions variability, IM240 emissions variability, and to create measurement-error models that can convert ASM values to IM240 values. [132]

- **Opportunities for Assessing Human Behavioral Factors in I/M Programs** – The behavior of vehicle owner/drivers as they interact with the requirements of an I/M program is widely acknowledged as an important factor in the effectiveness of an I/M program. In this study for the U.S. EPA, Dr. DeFries looked for opportunities for using surveys to characterize the human behavioral contributions to program performance so that I/M programs can be modified to improve performance. [130]

- **Analysis of I/M Program Repair Data** – This project for the Arizona Department of Environmental Quality used a dataset that paired the repairs made to vehicles and their IM147 emissions inspection results before and after the repairs. The goal of the analysis, which Dr. DeFries conducted, was to determine if the data could be used to associate emissions reductions with particular repairs. Since repair costs were also a part of the database, the cost-effectiveness was also investigated. His analysis revealed that the repair data were of high enough quality to be useful in understanding how repairs influence emissions. Emissions “fingerprints” were most distinct for EGR, catalyst, and dwell/timing repairs. These repairs were also found to produce the largest reduction in NOx emissions. [129]

- **Prediction of IM147 Pass/Fails Using RSD and Non-RSD Information** – The goal of this project for the Arizona Department of Environmental Quality was to determine if an RSD unit set up at the entrance to an inspection station could be used to improve upon the clean-screening ability of non-RSD methods. Dr. DeFries was the task leader for this analysis task, which was part of a larger Arizona project. The project team collected 1451 paired RSD and IM147 measurements. He used logistic regression to develop models that calculated the overall IM147 failure probability for various combinations of RSD and non-RSD input parameters. The results of the analysis indicated that RSD was not able to improve upon clean-screening methods that use generic vehicle information such as historical failure probability. On the other hand, the study indicated that RSD could improve upon the dirty-screening ability of methods that use generic vehicle information. [128]

- **I/M Simulator Concept** – I/M program operators want to be able to design and operate a program that is effective and cost-effective at maintaining good emissions control of the mobile source fleet. However, they have no effective tool that provides them with the information they need (tons of reduction and program costs) as a function of the details of an I/M program design. Few I/M program operators are willing to undertake full-scale “experiments” of the in-use fleet. Dr. DeFries realized that in this situation a software simulation of an I/M program – an I/M simulator – could be beneficial. He presented an internally-funded design concept to EPA in 2002. Based on that concept, he has worked in various subsequent projects for various clients with an eye on building the multiple capabilities required for the creation of an I/M simulator. As of 2006 many of the needed components have been built. [125, 148, 150, 159]

- **Important Parameters for CO_2 and CH_4 Emission Factor Modeling for MOVES** – The U.S. EPA's future emissions factor model MOVES will include code for estimating the greenhouse gases CO_2 and CH_4. In this work assignment, EPA asked Dr. DeFries to identify the variables that have important influences on vehicle emissions of those gases. Gasoline and diesel vehicles were considered separately. EPA's Mobile Source Observations Database, which contains hundreds of thousands of emissions measurements, was used as the data source. He used an analysis of variance as the analysis tool. The average total power used during driving explained about three-quarters of the variability in CO_2 emission rate for gasoline and diesel vehicles. After that, the characteristics of the driving cycle were the next most important. For CH_4 emission rate no combination of vehicle characteristic and operation explained a large part of the variability. [124]

- **High Emitter Profile Evaluations** – Eastern Research Group has been a leader in the development of High Emitter Profile models and their brother the Low Emitter Profile. These models use various types of information associated with individual vehicles, such as vehicle description and inspection history, to forecast if a vehicle is likely to pass or fail an upcoming I/M inspection. Dr. DeFries has been the developer of four generations of these probabilistic models for the California Bureau of Automotive Repair. In addition to developing HEPs, he has performed studies that evaluate the effectiveness of their performance in different situations. [106, 115, 123]

- **Evaluation of California Gold Shield I/M Stations** – The California I/M program has a special category of test-and-repair inspection stations that meet a set of higher station quality standards. Dr. DeFries was the director of a project for the California Bureau of Automotive Repair to quantify the level of improved emissions performance of vehicles certified at these Gold Shield stations versus regular test-and-repair stations. Emissions performance of vehicles certified at different station types was measured using data from BAR's roadside ASM pull-over program. The results indicated that Gold Shield stations were certifying vehicles that had no better roadside ASM emissions performance than regular test-and-repair stations; however, the analysis did not take into account the inherently different vehicle clientele of the two types of stations. [114, 117, 118, 119, 120, 121]

- **Evaluation of NOx Humidity Correction Factor Relationships** – The humidity of the intake air used by an internal combustion engine reduces the engine-out NOx emissions. When vehicles are tested in an I/M program, corrections to the measured tailpipe NOx emissions for ambient humidity need to be made for this effect. The currently used correction equations are based on measurements made in the early 1970s on non-catalyst vehicles. In a study for the California Bureau of Automotive Repair, Dr. DeFries analyzed laboratory data on five late-model catalyst-equipped light-duty vehicles that had been tested at various ambient temperature and humidity conditions to determine if the existing humidity correction equations are applicable to today's vehicle. The results indicated that the existing equations do not describe the humidity effects at all. [113]

- **Development of Protocols to Evaluate I/M Programs Using In-Program Data** – The U.S. EPA requires I/M programs to evaluate the effectiveness of their programs every two years. But what measures are jurisdictions to use for these evaluations? Dr. DeFries was the director of an EPA project that would provide guidance for I/M program evaluations. This project focused on using so-called in-program data, that is, data obtained from the inspection program itself, to perform the evaluation. The first concept that DeFries came up with was to use simple statistics, supported by the inspection database, to demonstrate and document the efforts of the program in four key areas: fleet coverage, inspection, repair, and enforcement. Good performance in these process-based areas does not guarantee overall good program performance, but without them, a program cannot be high performing. The second concept focuses on measures of emissions benefits, that is, results-based performance, which can be supported by in-program data such as the change in emissions when vehicles are repaired. [109, 112]

- **Evaluating an EGR Tester to Supplement a Two-Speed-Idle I/M Program to Reduce NOx Emissions** – A two-speed-idle I/M program can be used only to control HC and CO emissions. A different type of emissions test is required to control NOx emissions. The goal of this project for the Texas Natural Resource Conservation Commission was to determine if it was feasible to add an EGR system tester to its existing TSI program to control HC, CO, and NOx. Dr. DeFries designed the experimental plan for the field testing in San Antonio. The ASM test was used as the reference test by quantifying the HC, CO, and NOx emissions. In-use private vehicles were measured by ASM as they came in. Then, the TSI test and the EGR test were administered. If the vehicle failed the EGR test, its EGR system was repaired, and the ASM test was performed again to document the emissions effect of the repair. DeFries analyzed the emissions and pass/fail data that came from the study. Approximately half of the vehicles in San Antonio (an area that does not have emissions I/M testing) have malfunctioning EGR systems. DeFries projected FTP emissions from the measured ASM results. From this, we estimated that supplementing a two-speed-idle I/M program with the EGR tester could reduce fleet FTP NOx mass emissions by 9% as measured at the time of the repair. [108, 111]

- **EPA MOBILE6 Beta Testing** – In the final stages of EPA's development of the MOBILE6 mobile sources emissions model, EPA had Eastern Research Group perform beta testing of the draft model. DeFries was the project director of this effort and used his familiarity with mobile source emission trends to help evaluate the output of the model. [107]

- **Two-Speed-Idle to IM240 Conversion Models for Texas I/M Program Evaluation** – The Texas Natural Resources Conservation Commission evaluated the Texas I/M program in 2000. The method chosen for the evaluation was by comparison of the fleet average emissions for eligible vehicles on an IM240 basis with the same fleet average emissions for eligible vehicles in Phoenix, Arizona on an IM240 basis. Since the Texas I/M program was based on two-speed idle testing, correlations between two-speed idle emissions concentrations and IM240 emission rates had to be developed. Dr. DeFries led the modeling effort to connect these two emissions measures. The mobile sources group collected two-speed idle and IM240 measurements on a stratified sample of over 500 private vehicles for use as a model training dataset. He determined the stratification structure and the number and type of paired measurements. The modeling effort accounted for the variances and covariances of the two-speed-idle measurements and the variances of the IM240 measurements. An appropriate transformation of the measurements and a measurement-error modeling technique was used to build the models. [87, 88, 100, 104, 105, 116]

- **Predicting FTP Emission Rates from ASM Emission Concentrations –** Dr. DeFries led the significant modeling effort to develop models for the prediction of FTP emission rates for HC, CO, and NO_x from vehicle information and ASM2525 and ASM5015 emission concentration measurements of HC, CO, and NO_x. The models, which are to be used to predict the FTP emissions of a large fleet, were built for the California Bureau of Automotive Repair. The model training data were obtained from the California Air Resources Board. The development of models concentrated on two features: the relationships to predict the average FTP emissions of a fleet and the relationships to predict the uncertainty in the average. The final models were based on the measurement-error modeling technique which avoids biases introduced by the uncertainties in the measurements of the ASMs, as well as the FTPs. FTP measurement errors were evaluated using replicate data from the AQIRP datasets. ASM measurements errors were approximated using the ASM2525 and ASM5015 measurements in the model development dataset. Application of the models to the California Baseline Roadside dataset sample of 14,000 randomly sampled vehicles indicates that the precision of the fleet average FTP values is on the order of ±3%. [86, 89, 94, 96, 97, 98]

- **A Stratified Random Sampling Design to Quantify Fleet FTP Emissions from Roadside ASM Measurements** – The California Bureau of Automotive Repair wanted to use random roadside testing of in-use vehicles to estimate the average FTP emissions of the California fleet. Dr. DeFries was asked to estimate the number of vehicles that would need to be tested using IM240 testing or using ASM testing to estimate the fleet average FTP emissions to a desired uncertainty. He led the effort to develop approximate models to estimate fleet average FTP emission rates from measured vehicle ASM emission concentrations and from measured vehicle IM240 emission rates using California Air Resources Board laboratory data. To answer the question of needed sample size, he had to conduct an analysis of errors derived from the models and from the sample. In the course of this analysis, it was recognized that stratified, rather than random, roadside sampling had definite advantages. In the final report he demonstrated that the uncertainty produced by the ASM to FTP conversion models or by the IM240 to FTP conversion models is a relatively small source of error when estimating the average FTP emission rate of the fleet. Consequently, as long as an unbiased ASM to FTP conversion equation can be developed, the use of roadside ASM testing can produce comparable uncertainties in the average fleet FTP emission rate to roadside IM240 testing, and ASM testing is much easier to perform on the roadside than IM240 testing. [67, 68, 69, 71, 74, 75]

- **Various I/M Program Statistical Analyses** – He has led efforts to answer a number of small but important statistical questions for the California Bureau of Automotive Repair. These include roadside vehicle sampling issues, comparison of the 1997 roadside vehicle sample with the characteristics as expected from CALIMFAC, alternative techniques for measuring I/M program effectiveness, sample size required to quantify binomial variables, day of week differences for roadside samples, metropolitan area differences for roadside samples, day of week and metropolitan area averages of the fleet average FTP emission rates predicted from roadside ASM samples, and frequency distribution of estimated FTP emitter categories predicted from roadside ASM samples. [57, 61, 62, 65]

- **Development of High Emitter Profile Models** – He has served as task leader for development of second and third generation High Emitter Profiling and Low Emitter Profiling techniques. These efforts have included improved logistic regression modeling techniques, improved methods for evaluating and validating profiling models, development of additional models to cover vehicles where only a portion of information is available for profiling, and detailed procedure and improvements for using the High Emitter Profiling software. [81, 102, 103, 106, 115, 123]

- **Influences of Off-FTP-Cycle Emissions** – MOBILE5b was modified to estimate the influence of off-cycle FTP emissions. Dr. DeFries led the data analysis portion of this effort to assist the Texas Natural Resources Conservation Commission in evaluating off-cycle FTP emissions in the interim before the release of MOBILE6. The traditional (3-bag) FTP can under-estimate emission inventories for two reasons: a significant portion of real-world driving is outside of the FTP speed/acceleration envelope and instantaneous emissions rates for off-cycle FTP driving can be orders of magnitude higher that on-cycle FTP driving. From the 1992 Spokane/Baltimore data, 27% of the second-by-second data was found to be off-cycle. Off-cycle emission rate ratios were developed from industry testing of 31 vehicles with the FTP cycle and the US06 cycle. The Basic Emission Rates of MOBILE5b were modified accordingly. [64, 66]

- **Effects of Vehicle Traffic and Meteorology on Bangkok Ambient PM Concentrations** – He conducted a feasibility study to analyze trends in ambient particulate material concentrations in Bangkok, Thailand in terms of meteorological data and other data using neural network software. The Thai Pollution Control Department provided hourly PM10 data at four urban sites for a 6-month period. Hourly meteorological data from the Bangkok airport was retrieved from the U.S. National Climatic Data Center. Since previous work has indicated that a large portion of PM concentrations in Bangkok are associated with vehicle traffic, but no direct measure of hourly vehicle miles traveled for Bangkok was available, vehicles miles traveled per hour from U.S. data was used. The neural network model revealed that the most important variable was the hourly vehicle miles traveled at the hour of the PM measurement. Other less important variables were the temperature and wind speed at the hour of the PM measurement. The model followed the seasonal fluctuations in ambient PM10 concentrations, but the daily peak to valley ratios were not predicted well. [58]

- **Application of VIN Decoder to Automatic Vehicle Refueling Robot** – He led the project to modify the corporate Vehicle Identification Number decoding software so that it could be used to identify vehicles for an automotive refueling robot. International Submarine Engineering developed the robot for an oil company to be used at its gasoline stations. Each participating vehicle was fitting with a radio transmitter that broadcast the vehicle's VIN. When the vehicle entered a participating gas station, the refueling robot decoded the VIN to determine the body of the vehicle. From this information and video imagining of the vehicle's location, the robot could determine the location of the vehicle's gas cap door so that refueling could commence.

- **First Generation High Emitter Profile Development** – As part of the development of a new hybrid I/M program for California, he assisted the Bureau of Automotive Repair in the development of models to identify high emitting vehicles. These models will enable the resources of the centralized and decentralized testing facilities to focus their efforts on testing and repairing only the high emitting vehicles. He used neural network and logistic regression techniques to build models that predict the probability of a given vehicle being a high emitter. Models were based on a dataset of 3,500 vehicles which had been tested with the IM240 procedure, had been inspected by the standard California idle and high idle emissions tests, and for which the characteristics of the vehicle and engine were known. [54]

- **Bangkok Light-Duty Vehicle and Motorcycle Driving Cycles** – Using the extensive dataset of second-by-second driving data for light-duty vehicles and motorcycles taken in Bangkok, Thailand, he developed a vector algebra methodology for creating driving cycles to represent light-duty vehicle driving and motorcycle driving. The technique builds up a driving cycle from micro-trips selected from the driving behavior database such that a vector describing the driving cycle most closely matches the vector that describes the driving behavior in Bangkok. The driving cycles developed in this project will be used in Bangkok to test the emissions behavior of light-duty vehicles and motorcycles on chassis dynamometers. [50, 52]

- **Consolidated Description of On-Road Tailpipe and Evaporative Emissions** – He evaluated the contributions of exhaust, diurnal, hot-soak, and running loss emissions for on-road driving, which includes "off-FTP cycle" driving. The results, which were obtained by modeling dynamometer emissions behavior, on-road emissions behavior, and on-road driving behavior of car owners, were reported in an SAE paper. [34]

- **Approaches for Collecting Vehicle Activity Data** – He was the task leader of an EPA project to evaluate alternative approaches for collecting data to measure typical vehicle driving patterns. Techniques for advanced data analysis by time series and neutral networks were considered. Alternatives for representative data collection and standard and advanced data analysis techniques were postulated and were discussed and presented at a meeting of government and industry experts. [23, 25]

- **FTP Cycle Revision Data Collection for EPA** – He was the project director of an EPA work assignment to instrument 100 randomly selected private vehicles at Spokane and Baltimore. He led the Radian effort to design, fabricate, and test on-board dataloggers to record vehicle speed, engine rpm, and manifold absolute pressure on a second-by-second basis. This approach provided a better and less expensive instrumentation package than commercially available dataloggers. [26, 27, 29, 30, 31, 32, 33, 34, 49]

- **FTP Cycle Revision Data Collection for MVMA** – He was the project director of a Motor Vehicle Manufacturers Association parallel project to increase the number of instrumented cars in Spokane and Baltimore from 100 to 288. In this project, 98 of the additional cars were instrumented with the Radian datalogger, and 90 of the additional cars were instrumented with commercial dataloggers interfaced to the vehicle Electronic Control Unit by interfaces provided by individual vehicle manufacturers. The manufacturer-provided interfaces acquired data for vehicle speed, engine rpm, engine load, coolant temperature, throttle position, and fuel/air ratio. Fuel/air ratio was monitored with a wide range oxygen sensor attached to the exhaust system. [26, 27, 29, 30, 31, 32, 33, 34, 49]

- **Light-Duty Vehicle Driving Pattern Characteristics** – He was the project director of work for the EPA Office of Mobile Sources to analyze data collected by on-board dataloggers in Spokane, Baltimore, and Atlanta. For example, analyses will determine the effects of cold and warm vehicles on driving behavior. In another area, methods for evaluating and creating representative driving cycles from the data will be used. [37, 38, 39, 40, 41, 42, 43, 44, 45]

- **Development of a Light-Duty Vehicle Evaporative Emissions Model** – He helped develop an Advanced Evaporative Emissions Model for the Coordinating Research Council to predict the evaporative emissions of light duty vehicles under real-world driving conditions. The work involved bringing together existing emissions and vehicle usage data to quantify how key factors influence evaporative emissions. The model incorporates the effects of Reid vapor pressure, vehicle driving patterns, fuel weathering, ambient temperature, vehicle component temperatures, fuel tank level, vehicle tampering and registration rates, vehicle technologies, and vehicle registration information. A sensitivity analysis of evaporative emissions to environmental factors and abundance of available data was used to define where additional experiments should be performed. [9, 10, 11, 14, 16, 28, 35, 36, 37, 46]

- **Refinement of a Light-Duty Vehicle Evaporative Emissions Model** – Based on that sensitivity analysis, he helped design the additional automotive laboratory experiments to get the data that are needed to improve the evaporative emissions model. He was the task leader of the data analysis for the data collected in that effort by Automotive Testing Laboratories. The large amount of new data on 5 test cars was used to develop models for uncontrolled and controlled hot-soak emissions and to verify earlier models of diurnal emissions. The data indicated that fugitive emissions can be important when other emissions are low. [28, 35, 36, 46]

- **Effects of Fuel Volatility and Ambient Temperature on Running Losses** – He provided technical support in a study to investigate automotive running losses for the California Air Resources Board. In this study, available results of other studies were used to design an automotive laboratory test program to determine the effects of fuel volatility and ambient temperature on the running losses of 30 in-use vehicles. Dr. DeFries conducted the data analysis of vehicle running loss data from the vehicle test program conducted by Automotive Testing Laboratories. The data indicated that running losses exhibit a non-linear behavior during the transition at the onset of emissions. Existing EPA data were also examined for comparison with the new running loss data. [24]

- **Effects of Gasoline Oxygenates on Exhaust, Toxic, and Evaporative Emissions** – He was the director of a project for the California Air Resources Board to examine the effects of oxygenated fuel components (ethanol, methyl-t-butyl ether, and ethyl-t-butyl ether) at low concentrations (2.0 to 2.7% oxygen) in gasoline on exhaust and evaporative emissions composition. He recommended a vehicle test design and performed the data analysis. Automotive Testing Laboratories performed the vehicle dynamometer testing. Exhaust CO, HC, NOx, benzene, formaldehyde, acetaldehyde, 1,3-butadiene emissions and evaporative diurnal, hot-soak, and running loss emissions on 13 California vehicles were analyzed using statistical techniques. To quantify the relatively small effects of the oxygenated components, the analysis entailed statistical modeling of the effects of base gasoline blend, Reid vapor pressure, oxygen content, driving cycle, ambient temperature, and engine technology. [47]

- **Effects of Gasoline Oxygenates of Exhaust Emissions** – Dr. DeFries served a major role in the statistical evaluation of the effect of oxygen content on the HC, CO, and NO_x exhaust emissions of gasoline fueled light duty vehicles for the Western States Petroleum Association. Statistical Analysis Systems (SAS) software was used to decipher the overall trends that were present in the data from all known public and private studies on the effect of ethanol and methyl-t-butyl ether on exhaust emissions. In this project, a statistical analysis of the effects of percent oxygen, altitude, Reid vapor pressure, ambient temperature, and engine technology had to be modeled so that the relatively small effects of the oxygenated fuel components could be seen and quantified. [22]

Power Plant Plume Opacity Evaluations

- **Evaluation of the Controlled Condensation Measurement Method for Flue Gas SO_3 Under High Particulate Loading Conditions** – He conducted a literature search for the Electric Power Research Institute to find if high particulate loadings reduce the collection efficiency of a controlled condensation sampling train for the measurement of sulfuric acid vapor concentration and to find if techniques had been developed to avoid thick filter cakes on the pre-condenser filter. The search indicated that the influence of high particulate loadings had not been investigated thoroughly. In addition, no reports of techniques were found to prevent thick filter cakes.

- **Flue Gas Measurement and Modeling of Coal-Fired Power Generating Station Plume Opacity** – The three units of a large electric power generating station in Pennsylvania were producing elevated plume opacity. The fuel was high sulfur coal. The utility wanted to operate at low NOx conditions, but believed that low NOx conditions made the opacity worse. Dr. DeFries reviewed existing data and recommended measurements of particle loading, size distribution, and composition, sulfuric acid vapor concentration, and plume opacity measurements by EPA Method 9 while each unit was operated at normal NOx and low NOx conditions. He assisted with flue gas measurements and then performed modeling of light scattering to demonstrate that the bulk of the optical effects were produced by sulfuric acid mist. His report included estimates of the reduction in sulfuric acid mist that would be required to meet opacity regulations and included techniques that might be considered to reduce acid mist concentrations. In a follow-up study, flue gas measurements were repeated while a medium sulfur coal was used. Modeling indicated that while the sulfuric acid concentrations were lower, the size distribution of the mist shifted so that the resulting opacity was virtually the same. [76, 77, 79, 80, 85, 99, 126]

- **Meteorological Effects on the Opacity of a Distant Plume of a Power Generating Station** – Dr. DeFries was asked to postulate the causes of a distant visible plume from a coal-fired electric generating station in Pennsylvania. Based on existing data and some assumptions, he performed opacity modeling that indicated in the stack, which was above the acid dewpoint, opacity is dominated by fly ash particulate material. In the plume, while no direct measurements of sulfuric acid existed, the modeling indicated that the opacity was probably produced by sulfuric acid from the combustion of fuel sulfur and by sulfuric acid injected to improve electrostatic precipitator efficiency. He postulated that under most meteorological circumstances, the plume is not visible far downwind from the stack, but when an inversion is present, the plume is noticeable when viewed edge-on. His final report recommended specific flue gas measurements, an evaluation of historical meteorological conditions, and a re-evaluation of the need for sulfuric acid injection for ESP conditioning. [78]

- **Root Cause Analysis of a Plume Opacity Problem Using the Engineering Workbook** – Using the EPRI workbook for Estimating Power Plant Exit Plume Opacity, Dr. DeFries evaluated source sampling data taken at a mid-western electric power generating station. While previous investigators believed that the opacity was caused by elevated concentrations of NO_2, his evaluation of the data indicated that sulfuric acid mist was more likely the cause of the opacity. In his report he recommended special source sampling methods that would conclusively demonstrate if the cause of the opacity was sulfuric acid mist. [53]

- **Engineering Workbook for Estimating Plume Opacity Contributions** – Dr. DeFries was the task leader of an EPRI effort to develop an engineering workbook for utility personnel to estimate the effect of flue gas components on in-stack and near stack plume opacity. Field and modeling experience developed in opacity troubleshooting projects was brought together for this workbook. The workbook presents engineering worksheets for calculating the total and relative optical contributions of flue gas NO_2, fine particle emissions (less than 1 µm diameter), and coarse particle emissions (greater than 1 µm diameter) to plume opacity. Worksheet calculations describe opacity both in the stack and within 4 to 10 meters of the stack exit, where vapor-phase sulfuric acid will be condensed and may be visible. Calculations are based on input information readily available at low cost and agree with those of EPA's PLUME model for sulfuric acid condensation in the presence of fine particles. Following the guidelines, utilities can determine the cause of stack or plume opacity, estimate changes in conditions needed to decrease opacity, and make trade-offs to achieve desired opacity. [48, 63]

- **Flue Gas Measurement and Modeling of Coal-Fired Power Generating Station Plume Opacity** – In four studies for the Electric Power Research Institute, he served as project director to evaluate the plume constituent contributions and meteorological contributions toward opacity at four coal-fired power generating station units. The project involved flue gas measurements, particulate material chemical analysis, and theoretical modeling of the in-stack opacity and the plume opacity using the measurements. The modeling included Mie light scattering and reactive dispersive plume modeling. [19, 20]

- **Root Cause Analysis of Coal-Fired Power Generating Station Plume Opacity** – In another study for the Electric Power Research Institute, he directed a field study to investigate the formation of a brown plume from the stack of a 650 MW coal-fired power generating station. The project evaluated the effect of ammonia injected into the flue gas to reduce plume opacity through conversion of sulfuric acid vapor to ammonium sulfate particles, which could be removed by the existing electrostatic precipitators. His effort to evaluate and document plume appearance was a key factor in determining the effect of ammonia injection. [17]

- **Flue Gas Measurement and Modeling of Oil-Fired Power Generating Station Plume Opacity** – Dr. DeFries directed a project to examine the mechanisms of the formation of plume opacity from oil-fired boilers. As part of that program, he designed and assembled stack gas and particulate matter sampling equipment. He has experience with cascade impactors, cyclones, sulfuric acid vapor by controlled condensation, small electrostatic sampling filters, opacity monitors, and stack sampling. Field studies were performed at two Florida 400 MW power-generating stations. With the utility's cooperation the major operating parameters of the units were controlled during emissions sampling according to a statistical experimental plan of his design. Accordingly, he is familiar with the design and operation of oil-fired utility boilers. He applied Mie light scattering theory to the composition and size distribution of the collected particulate material to account for the opacities observed inside and outside of the stack. Following the field work, he simulated power station particulate formation in a 50 hp oil-fired boiler in the laboratory. Emission testing of this small unit was performed to find fuel additives that would reduce plume opacity. From both the field and lab studies he formulated a model to explain the opacities produced by the combustion of high vanadium heavy fuel oil under these conditions.

Petroleum Process Investigations

- **Root Cause Analysis of Refinery Plume Opacity** – A large stack at a refinery in Spain was experiencing elevated in-stack opacity and plume visibility. The 28 sources sending flue gas to the common stack were process heaters, furnaces, boilers, and incinerators. Dr. DeFries reviewed available flue gas measurements, process information, plant engineer test results, and observed the plume. As a first step in solving the problem, while on site, he developed a test plan to determine the major causes of the in-stack opacity and plume visibility. The test plan consisted of measurements of particle loading, size distribution, and composition measurements and sulfuric acid vapor concentration measurements. The measurement results will be used with light scattering theory and a sulfuric acid condensation model for the stack exit to determine the contributions of soot, unburned fuel, ash, and sulfuric acid mist to the in-stack opacity and plume visibility. [84, 90, 91]

- **Root Cause Flue Gas Measurement and Analysis of FCCU Plume Opacity** – As part of an FCCU project to investigate several process problems, he was the task leader of the plume opacity diagnosis task. He specified the flue gas tests and particulate analyses that were necessary to provide inputs to opacity modeling. From the data collected in other tasks, he modeled the plume opacity, diagnosed the most likely causes of the opacity, and suggested alternative approaches to be considered for mitigating the problem. Based on the results, Radian designed a solid adsorbent flue gas injection system. When the system was started up, the opacity immediately went below visible levels.

- **Effects of FCCU Operating Conditions on Flue Gas Particulate Characteristics and NOx** – In a study of an 85,000 barrels/day fluidized catalytic cracking unit, he served as project director to examine particulate concentrations, size distributions, and NOx levels in different sections of the flue gas handling system. He designed a statistical experimental test plan to evaluate these quantities over a typical range of FCCU operation and at the same time estimate the effects of key FCCU operating parameters on these quantities. The results were used to aid the client in efforts to increase the feed rate of the unit subject to emissions requirements.

- **Effects of FCCU Operating Conditions on Stack Particulate Emissions** – He played a major role in the investigation of the stack particulate emissions from a 35,000 barrels/day fluidized catalytic cracking unit. The stack particulate emissions of the unit were variable and occasionally excessive. Given the numerous potential sources of the variability, he devised an experimental plan to isolate the source. To maximize the effectiveness of the plan, he worked extensively with the company's FCCU engineers to get a thorough general understanding of overall FCCU operation. During these discussions he made on-site visits to the unit; later he led a sampling team to take particulate and catalyst measurements.

- **Effects of Ammonia Flue-Gas Injection on ESP Efficiency and NOx Reduction at an FCCU** – He designed and led the effort to carry out a set of process condition experiments to examine the effects of ammonia injection on ESP efficiency and NOx reduction at a fluidized catalytic cracking unit.

- **Opportunities for Improved Processing of Refinery Distillate Streams** – To respond to the growing need for new ways to make larger volumes of quality diesel fuel, he conducted a comprehensive investigation of the diesel ignition quality of distillate process streams at all Exxon U.S.A. refineries. He worked closely with refinery personnel and process engineers for sample collection and data analysis, and identified new ways to increase diesel fuel profitability through alternative processing and blending options. Several of these results were implemented. He is familiar with refinery operations and important petroleum processes, such as fluid catalytic cracking, hydrocracking, hydrotreating, fluid and delayed coking, and fractionation.

Process Modeling and Optimization

- **Preliminary Analysis of FCCU Operation on NOx Emissions** – He performed an analysis of 16,000 FCCU hourly observations collected during a 2.5 year period to determine the influences of selected process variables on stack NOx concentrations. The FCCU had usually been operated under complete combustion, but about 3 weeks of data were available during partial combustion operation. During partial combustion, stack [NOx] was linear with regenerator [CO]. During complete combustion, increased stack [NOx] was loosely connected with increased regenerator flue gas [O2]. Multivariate neural network modeling using PlantPAx ModelBuilder indicated that the two variables that most strongly increased stack [NOx] were increasing regenerator flue gas flow and decreasing combustion air. [193]

- **Effects of Gas Well Characteristics on CO_2 Emissions from Hydraulic Fracturing** – He analyzed a set of hydraulic fracturing emissions data to determine if the average emissions for completions and workovers were inherently the same. The challenge in the analysis was that the emissions of the individual facilities were also affected by other gas well characteristic variables that were not of particular interest for the analysis but had to be corrected for in order to see the effect of completion vs. workover. Additionally, because the reported emissions values did not vary by event within a facility, the averages and any other statistics had to be weighted appropriately using the number of events for each facility. He analyzed the data using the SAS MEANS and GLM procedures with weighting and with different transformations to determine if completions and workovers had different emissions characteristics for the two different emissions control methods employed. [192, 194]

- **Predictive Emissions Modeling System for a Cogeneration Unit** – He served as task leader of several activities for the development of a Predictive Emissions Monitoring System for a new cogen unit at a Gulf Coast petrochemical facility. The unit is made up of a gas turbine, a heat recovery steam generator, and a steam turbine. He developed the test plan for PEMS data collection after gaining a thorough understanding of process operation through discussions with the construction engineers and chemical plant engineers. After unit construction was completed, emissions data and process data was collected while the unit was tested according to the plan. He then used Pavilion Technologies Process Insights to build models that validated the process sensors and predicted stack NO_x, CO, and O_2 in real time.

- **Neural Network Simulation of Control and Optimization of a Wastewater Treatment Process** – He was the project director of a project to demonstrate the capabilities of Pavilion Technologies Process Insights neural network modeling and optimization software for the control and optimization of a wastewater treatment process. Since very little real data on a wastewater treatment process was available, he worked with Radian engineers to develop an Aspen Plus simulation of a wastewater process. Then, the Aspen Plus model was used to generate a large quantity of data according to a test plan, which Dr. DeFries designed. He then used the data to train Process Insights neural network prediction and control models. Other Radian personnel then fitted the models with a Wonderware In-Touch man/machine interface. The final product was a demo that could be operated in manual mode or automatic mode. In manual mode, the operator can adjust any of the five key controls, and the models calculate the resulting effluent quality. In the automatic mode, the operator sets the four reactor flow rates, and the models recommend set points for the recycle activated sludge and the waste activated sludge flows.

- **Neural Network Simulation of Control and Optimization of a Sludge Remediation Facility** – He was the project director of a project to demonstrate the capabilities of Pavilion Technologies Process Insights neural network modeling and optimization software for the control and optimization of an imaginary sludge remediation facility at a former refinery site. Since very little real data on the treatment processes was available, he worked with Radian engineers to develop Aspen Plus simulations of a desorption and removal process, a liquid slurry reactor, and a stabilization/solidification process. Then, the Aspen Plus models were used to generate a large quantity of data according to a test plan, which Dr. DeFries designed. He then used the data to train Process Insights neural network prediction and control models for each process. The model of each process was set up to operate at lowest cost while meeting production targets and effluent quality specifications and while taking into account current utility and supply costs. Then, he built a "plant manager" model that used its "knowledge" of the capabilities of each of the three processes and current prices to determine the nine flows of three different types of sludges to the three processes to meet the site production targets.

- **Predictive Emissions and Compliance Optimization Modeling System for Gas-Fired Boilers** – He built neural network models to predict and optimize NOx emissions from the common stack of two gas-fired boilers at a grain handling facility. Models were built based on minute-by-minute process and stack emissions data taken according to a set of test conditions he designed to efficiently cover the operating conditions commonly used at the facility. The system was a combined Predictive Emissions Modeling System and a Compliance Optimization Modeling System. The PEMS predicted the NOx emissions, and the COMS provided recommended setpoints to increase boiler efficiency while keeping NOx emissions below regulatory limits.

- **Chemical Process Optimization by Neural Network Modeling** – Dr. DeFries has applied the latest neural network process modeling software to chemical processes. Initial efforts were aimed at creating Predictive Emissions Monitoring Systems for specific units to meet the enhanced monitoring requirements of the Clean Air Act. Processes examined for a variety of clients were a process steam boiler, a steam cracker, a multi-fuel power boiler, a black liquor recovery boiler, and a lime kiln. These models offer the potential of not only predicting process emissions, but also optimizing each unit for efficiency given a variety of economic and operational constraints.

He is working closely with client process engineers to develop parametric test plans, emissions models, and model validation test plans for individual units.

- **Development of Designated Control Parameter Limits for a Process Steam Boiler** – He analyzed test data on a 150,000 lb/hr process steam boiler at a petrochemical facility using Pavilion Technologies Process Insights software. The analysis was used to develop designated control parameter limits (DCPL) to satisfy the state's continuous monitoring requirements for the unit.

- **Predictive Emissions Modeling System for a Low-NOx-Burner Power Boiler** – He was the task leader for model development of on-line Predictive Emissions Modeling Systems to predict NO_x, CO, and O_2 for a 340 MMBtu/hr power boiler at a paperboard facility. Models were built from instantaneous process information. Pavilion Technologies Process Insights software was used. The new boiler used a modern low NO_x burner.

- **Video Game to Demonstrate Neural Network Process Optimization** – Using data from a 3-day unit test of a refinery process steam boiler, he built control models that demonstrate the compliance optimization potential of the neural network process modeling technique. The Process Insights based demonstration is formulated as a video game where the user tries to beat the neural network at optimizing the boiler on a real time basis. The winner of the game is the operator who can produce the required quantity and quality of steam at minimum cost while keeping the CO and NO_x emissions of the unit within regulatory requirements. The neural network invariably beats the human player in this game. The demonstration represented Radian's modeling capabilities at the international Interkamma Conference in Dusseldorf, Germany.

- **Predictive Emissions Modeling System for Process Steam Boilers** – He was the task leader for the development of on-line predictive emissions modeling systems to predict NO_x, O_2, and CO from instantaneous process information on two 430 MMBtu/hr refinery process steam boilers. Process Insights software was used to develop the models. He reviewed and modified the test plan of the proposed test conditions, interviewed the client's unit engineer to understand different process variables, developed neural network models for the emissions predictions and sensor validation, and evaluated the models before installation on the distributed control system. The models passed the subsequent relative accuracy test audit according to state requirements.

- **Predictive Emissions Modeling System for an Ethylene Cracking Furnace** – He developed models to predict the concentrations of NO_x, CO, and O_2 at a major refinery ethylene cracking furnace. The models were built with Pavilion Technologies Process Insights using data collected by Radian during a 3-day test of the unit.

Atmospheric Chemistry and Physics

- **Neural Network Modeling of Atmospheric Processes** – Dr. DeFries has worked extensively with advanced neural network modeling techniques to build ambient air quality forecasting systems for ozone in Houston, Texas and Bangkok, Thailand. He also used these techniques to study the meteorological and human activity variables that are important to ambient concentrations of CO in Denver, SO_2 in Denver, particulate material in Bangkok, and ozone in Beaumont, Texas and Mexico City. He has also applied neural network sensor validation models to provide rapid and powerful on-line quality checking of ambient air monitoring system data. [51, 55, 56, 58, 59, 60, 70]

- **Development of the Bangkok Ozone Forecasting System** – The goal of the Thailand Ministry of Science, Technology, and Environment was to develop and install the first ozone forecasting system in Bangkok. For this large project, Dr. DeFries built the neural network ambient air monitoring data sensor validation and ozone forecasting models from historical Bangkok ambient air monitoring data and historical upper air meteorology forecasts. He combined the outputs of those models to provide for the system's user displays. The system uses on-line forecasted upper air data from the U.S. National Weather Service and ambient air data from the Bangkok monitoring system as model inputs. The system provides sensor validation of hourly ambient air monitoring data, the forecasted value for tomorrow's maximum hourly ozone concentration, and the probability the tomorrow's maximum ozone concentration will be above 160 $\mu g/m^3$. [60, 70]

- **Mexico City Ambient Air Monitor Sensor Validation and Ozone Influences** – He has worked with an extensive 5-year set of hourly data from the Mexico City ambient air monitoring system. Models were built to validate the hourly measured values collected by more than 20 stations in the system. These models demonstrate the power of the sensor validation approach in a multiple station ambient air monitoring system. Models were built to predict hourly ozone at the monitoring stations. Individual station models reflect the various micro-climates that produce differing ozone concentrations in this large city located in a broad high altitude basin. [59]

- **Effects of Meteorology and Vehicle Traffic on Denver Ambient CO** – In a project to demonstrate the ability of neural network models to explain ambient CO concentrations, Dr. DeFries used Pavilion Technologies Process Insights with data from the 1987 to 1988 Denver Brown Cloud Study. The CO concentrations at a key downtown Denver monitoring site were modeled with inputs describing meteorology and vehicle miles traveled. Analysis of the model showed that ambient CO increased with vehicle miles traveled per hour and decreased with increasing wind speed. It also indicated that ambient CO was largest when the wind was from the south, which was the direction of the center of Denver.

- **Development of a Neural Network Ozone Alert System for Houston** – In work for the Houston Regional Monitoring Corporation to assist the Texas Natural Resources Conservation Commission, Dr. DeFries applied neural network modeling to a large historical dataset of daily ozone maximum concentrations in the Houston area and 3-hourly forecasted meteorological parameters to create a model that would forecast the next day's maximum ozone concentration in Houston. The inputs to the model were forecasted maximum temperature, temperature range, average wind speed, wind speed at 1200z, and the previous day's measured maximum ozone concentration. The model was a substantial improvement over the previously used system, which applied cutpoints to forecasted meteorological data; the neural network system cut the number of false alerts and the number of missed ozone alerts in half. [56]

- **Effects of Surface Meteorology, NOx, and Hydrocarbon Species on Houston Hourly Ozone** – Dr. DeFries investigated the use of Process Insights neural network models to explain Houston hourly ambient ozone concentrations in terms of hourly meteorology, hourly speciated hydrocarbon, and hourly NO and NO_2 concentrations. The models, which were created for the Houston Regional Monitoring Corporation, were based on the COAST dataset obtained at the Galleria site from June to November 1993. The hourly hydrocarbon concentrations of 55 species were converted into Carbon Bond IV representation for modeling purposes. The current hour Carbon Bond IV representations of the species, NO, NO_2, net radiation, temperature, wind speed, wind direction, and wind direction standard deviation were used as inputs to predict the current hourly ambient ozone concentration. The resulting model with 14 inputs had an r^2 of 0.91. NO and olefins had the largest influences on ambient ozone concentration. We believe that the hydrocarbon species served primarily as tracers of the effect of meteorology on dispersion in the Houston air shed. [55]

- **Forecasting Houston Hourly Ozone from Forecasted Surface and Upper Air Meteorology** – In another Houston Regional Monitoring project, empirical models were built with Process Insights to evaluate the feasibility of forecasting the next day's ozone peak 24 hours into the future using neural network and logistic regression models. The six-year Houston Regional Monitoring network dataset of surface concentrations and meteorology was augmented with measured meteorology at Houston Intercontinental Airport, high frequency forecasts of upper atmosphere meteorology by the Nested Grid Model, and high frequency forecasts of surface meteorology based on Nested Grid Model output statistics. Analysis of this dataset has indicated that the accuracy of ozone forecasting is closely tied to the forecasted temperature, wind speed, and sky conditions in the few hours before the forecasted hour of ozone. [55, 56, 59]

- **Neural Network Studies of the Influence of Meteorology and Ambient Precursors on Beaumont/Port Arthur Ozone** – He performed a neural network data analysis to determine how ambient ozone in the Beaumont/Port Arthur, Texas area is influenced by meteorology and ambient concentrations. A five-year dataset was analyzed with Process Insights. Empirical models to predict ambient ozone were built with measured surface meteorological variables, ambient concentrations of NO, NO_2, methane and non-methane hydrocarbon, and acoustic sounder data which measures meteorology up to about 1,000 meters altitude. A comparison of measured and predicted ozone values indicated that usually ozone concentrations were predicted well. However, occasionally the measured ozone concentrations far exceeded the predicted ozone concentrations. These episodes tended to happen for a period of several hours during the daytime. [51]

- **Neural Network Studies of the Influence of Meteorology on Houston Ozone** – He used five years of hourly data collected at the seven Houston Regional Monitoring sites for meteorology, NO_x, and ozone to build models using Process Insights to predict ozone 24-hours into the future. The results of the study indicated that the neural network technique has potential to forecast ozone where an abundance of ambient monitoring data and forecasted meteorological data are available. The models indicated that meteorology had a dominating influence on hourly ambient ozone concentrations. In addition, the meteorology in the few hours just before the hour of the ozone prediction was most important of all. [55, 56, 59]

- **Smog Chamber Studies on the Effect of Evaporative Emissions on Ozone Formation** – As part of his work at Exxon Research and Engineering Company, he performed experiments in a 1000 cubic foot environmental smog chamber to determine the contribution of automobile evaporative emissions to urban ozone levels. A mixture of butane and pentane simulated evaporative emissions; a mixture of nine other model hydrocarbon compounds simulated an urban hydrocarbon mix derived from other sources. Various combinations of these two blends were irradiated with ultraviolet light in the presence of nitrogen oxides to determine the role of hydrocarbon source and concentration on ozone formation. The intensity of the UV light was controlled to simulate diurnal solar radiation. All reactants and the ozone formed were monitored with dedicated instruments throughout the 36-hour runs. Thus he worked with methods for measuring ambient levels of total and specific hydrocarbons, nitrogen oxides, ozone, sulfur dioxide, and submicron particulate matter. The study determined the amount of ozone reduction expected for different control scenarios. In general, the amount of ozone reduction depended not only on the reduction in total hydrocarbon, but also on the nature of the compounds that were controlled.

- **Task Force Activities in Atmospheric Chemistry Research** – To enhance his exposure to topics in atmospheric chemistry, he was a member of four Coordinating Research Council and American Petroleum Institute task force committees. They were Determination of Formation Mechanism and Composition of Photochemical Aerosols (CRC CAPA-8), Aerosol Formation in the Atmosphere (CRC CAPA-20), Transport Model for Atmospheric Sulfate Formation (API AQ-2S), and Human Perception of Atmospheric Visibility (API AQ-2V).

Petroleum Product Effects

- **Improving the Efficiency of Natural Gas H_2S Scavenging Agents** – He reviewed test plans used for the evaluation of techniques and agents for scavenging H_2S from natural gas. In this study for the Gas Research Institute, process engineers evaluated several factors in a full scale direct-injection H_2S scavenging test facility: natural gas velocity, scavenging agent nozzle orientation and atomization, scavenger injection rate, pipe diameter, distance down the contactor pipe, and effect of static mixers. He reviewed and recommended modifications to test designs in all three phases of the study: initial investigation, parametric study of important factors, and evaluation of newly discovered techniques. Based on the parametric results of the second phase, he built models that can be used in the field to maximize the efficiency of H_2S scavenging agents.

- **Factors Affecting Bio-Corrosion of Natural Gas Pipelines** – Dr. DeFries designed test plans for a Gas Research Institute study to evaluate the factors that affect the biocorrosion of natural gas pipelines. In the study, small coupons made of different pipeline steels were subjected to different biocorrosion environments for a duration of twelve months. The factors studied were: type of steel, sulfur content of steel inclusions, number of steel inclusions, steel surface finish, and nature of the bio-media (sulfur-reducing bacteria, acid-producing bacteria, and methanogen), and exposure duration. The goal of the design was to minimize the number of coupons in the experiment while attempting to maximize the amount of information gained from the study. [72]

- **Effects of Diesel Fuel Aromaticity on Diesel Injection Pump Leaks** – He was the task leader for diesel fuel analysis, O-ring physical properties, and diesel fuel-injection pump testing on a project for the California Environmental Protection Agency. This project defined possible causes for diesel fuel-injection pump seal leaks that manifested themselves following the October 1993 change in diesel fuel composition mandated by the California Air Resources Board. He recommended standard and investigative diesel fuel tests and rubber O-ring tests. The physical inspections of a variety of diesel fuels and the changes in the physical characteristics of rubber O-rings soaked in each of these fuels were determined and connected using statistical and neural network data analysis. Based on this data collection and analysis effort, he planned and oversaw the laboratory testing of 24 used pumps under different fuel switching scenarios. The project showed that a small fraction of the pumps that had been run on normal aromatic content fuel for several years could develop dramatic fuel leaks in pump seals if the fuel was switched to a low aromatic fuel type.

- **Gasoline Additives for Carburetor Detergency** – In the gasoline field, he tested several competing gasoline detergent additives for carburetor keep-clean behavior and water tolerance properties. The CRC carburetor detergency test, which is an engine dynamometer test, was modified to provide increased severity. Based on this short project, he recommended an additive that provided both significantly improved detergency and significantly reduced cost. Following auto fleet testing, the additive was adopted throughout the company.

- **Measurement of Diesel Ignition Quality by Nuclear Magnetic Resonance** – His use of nuclear magnetic resonance (NMR) to probe the molecular structure of refinery distillate streams uncovered group additivity as a fundamental connection between molecular structure and diesel ignition quality (cetane number). He used Carbon-13 NMR to extend the group additivity principle from pure compounds to petroleum fuels. This new NMR technique for prediction of cetane number on small samples was transferred to pilot plant labs where new refinery processes are developed. Because the cetane number of a sample could now be measured non-destructively by NMR with 1 mL of sample instead of destructively with 1000 mL, which the engine rating method requires, the operating conditions of a laboratory pilot plant could be varied hundreds of times faster than before the NMR method while searching for processing conditions that would improve diesel ignition quality. [8, 14, 15]

Experiments Under Extreme Pressure and Temperature

- **Motions of the Water Molecule Under Extreme Conditions by Nuclear Magnetic Resonance** – At the University of Illinois he investigated the gas and liquid state motions of the water molecule using hydrogen and deuterium nuclear magnetic resonance. To enable the separation of temperature and density effects on the molecular dynamics, Dr. DeFries designed and supervised the construction of gas and liquid pressurized non-magnetic vessels to perform NMR measurements at up to 150,000 psi and 800 ºC. Self-diffusion coefficients and spin-lattice relaxation times were interpreted in terms of the liquid hard sphere model and other theories through the use of viscosity measurements, which he also performed under extreme conditions. [1, 2, 3, 4, 5, 6, 7]

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158. J. Sidebottom, T.H. DeFries, C.F. Palacios, S. Kishan, "Quantifying Emissions Benefits of OBDII I/M," CDPHE-070926, presented by J. Sidebottom at the 23rd Clean Air Conference, Keystone, Colorado, September 26, 2007.

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160. T.H. DeFries, A.D. Burnette, S. Kishan, T.J. Petroski, "Estimating Benefits of Improvement Strategies for the California I/M Program: Implementation Options for Using RSD (Version 9 final)," Report, ARB-080302, prepared for California Air Resources Board and California Bureau of Automotive Repair, March 2, 2008.

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163. C.F. Palacios, T.H. DeFries, J.H. Lindner, "Additional Analysis for Georgia's 2007 I/M Program Annual Operation report (for GEPD Internal)," Final Report, GEPD-080415, prepared for Georgia Environmental Protection Division, April 15, 2008.

164. C.F. Palacios, T.H. DeFries, J.H. Lindner, "Additional Analysis for Georgia's 2007 I/M Program Annual Operation report (for EPA Submission)," Final Report, GEPD-080612, prepared for Georgia Environmental Protection Division, June 12, 2008.

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168. T.H. DeFries, J.H. Lindner, C.F. Palacios, S. Kishan, "Investigation of RSD for High Evaporative Emissions Vehicle Detection: Denver Summer 2008 Pre-Testing Study," Version 1, EPA-090306, prepared for U.S. Environmental Protection Agency, March 6, 2009.

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170. T.H. DeFries, "Stratification Planning for the Longitudinal Study," Memo, EPA-090827, prepared for U.S. Environmental Protection Agency, August 27, 2009.

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176. T.H. DeFries, "Evaporative Emissions Detection Using Conventional RSD," EPA-100929, presented by T.H. DeFries at the 26th Clean Air Conference, Breckenridge, Colorado, September 29, 2010.

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179. C.F. Palacios, T.H. DeFries, S. Kishan, "Analysis of 2004-2005 California RSD Data vs. Previous IM Cycle Initial Smog Check ASM," Memo, ARB-110625, prepared for California Air Resources Board, June 25, 2011.

180. C.F. Palacios, T.H. DeFries, S. Kishan, "Analysis of 2004-2005 California RSD Data vs. Previous IM Cycle Initial Smog Check OBD," Memo, ARB-110628, prepared for California Air Resources Board, June 28, 2011.

181. T.H. DeFries, C.F. Palacios, M.F. Weatherby, "Vehicle Targeting for the Detroit Pilot of the Longitudinal Study, Version 1," Memo, EPA-120227, prepared for U.S. Environmental Protection Agency, February 27, 2012.

182. T.H. DeFries, M.F. Weatherby, F. DiGenova, R. Dulla, K. Boriboonsomsin, T. Durbin, "MOVES Activity, VMT, and Population Update: Data Source Candidates for Task 1a, Version 2," Report, EPA-120608, prepared for U.S. Environmental Protection Agency, June 8, 2012.

183. T.H. DeFries, M.A. Sabisch, "MOVES Activity, VMT, and Population Update, Version 3," Work Plan, EPA-121019, prepared for U.S. Environmental Protection Agency, October 19, 2012.

184. T.H. DeFries, C.F. Palacios, M.F. Weatherby, S. Kishan, "Estimated Summer Hot-Soak Evaporative Emissions Distributions for the Denver Fleet, Version 3," Report, CDPHE-121119, prepared for Colorado Department of Public Health and Environment, November 19, 2012.

185. T.H. DeFries, M.A. Sabisch, S. Kishan, "ICCT Fuel Economy Pilot," Webinar, ICCT-130129, prepared for International Council on Clean Transportation, January 29, 2013.

186. T.H. DeFries, M.F. Weatherby, C.F. Palacios, "Development of NONROAD Load Factors, Emission Factors, Duty Cycles, and Activity Estimates, Version 2," Report, EPA-130212, prepared for U.S. Environmental Protection Agency, February 12, 2013.

187. T.H. DeFries, E. Glover, J. Warila, S. Kishan, "Load Factors, Emission Factors, Duty Cycles, and Activity of Diesel NonRoad Vehicles," CRC-130410, presented by T.H. DeFries at the 23rd Coordinating Research Council On-Road Vehicle Emissions Workshop, San Diego, California, April 10, 2013.

188. J. Koupal, T.H. DeFries, "Analysis of Off-Road Emissions Correction Factors," Report, ARB-130510, prepared for California Air Resources Board, May 10, 2013.

189. T.H. DeFries, C.F. Palacios, M.F. Weatherby, A.P. Stanard, S. Kishan, "Estimated Summer Hot-Soak Distributions for Denver's Ken Caryl IM Station Fleet, Version 6," Report, EPA-130515, prepared for U.S. Environmental Protection Agency, May 15, 2013.

190. T.H. DeFries, J.H. Lindner, M.A. Sabisch, "Evaluation of Portable SHED Characteristics, Version 3," Technical Note, EPA-130619, prepared for U.S. Environmental Protection Agency, June 19, 2013.

191. T.H. DeFries, M.A. Sabisch, S. Kishan, "ICCT Fuel Economy Pilot," Webinar, ICCT-130702, prepared for International Council on Clean Transportation, July 2, 2013.

192. C. MacQueen, T.H. DeFries, C. Burklin, "Using GHGRP Data to Update National Emissions Estimate for Hydraulically Fractured Gas Well Completions and Workovers," Memo, EPA-130721, prepared for U.S. Environmental Protection Agency, July 21, 2013.

193. T.H. DeFries, "Preliminary Modeling of Influences of FCCU Operation on Stack NOx," Memo, EPA-130826, prepared for U.S. Environmental Protection Agency, August 26, 2013.

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195. S. Kishan, T.H. DeFries, M.A. Sabisch, J. German, F. Posada, A. Bandivadekar, "Light-Duty In-Use GHG/Fuel Economy Data Collection and Evlauation," AWMA-130911, presented by S. Kishan at Climate Change: Impacts, Policy, and Regulation Specialty Conference of the Air and Waste Management Association, Herndon, Virginia, September 11, 2013.

196. T.H. DeFries, "Task Proposals for Canister Degradation Investigations, Version 2," Report, EPA-130926, prepared for U.S. Environmental Protection Agency, September 26, 2013.

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198. J. Koupal, T.H. DeFries, C.F. Palacios, S.W. Fincher, "Study of MOVES Information for the National Emissions Inventory: CRC Project A-84, Version 2," Report, CRC-131021, prepared for Coordinating Research Council, October 21, 2013.

ORGANIZATIONAL CONFLICT OF INTEREST CERTIFICATE

Customer: U.S. Environmental Protection Agency

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

Prime Contract: EP-C-12-011

Subcontract/Peer Reviewer: Timothy DeFries

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

__X__ No actual or potential conflict of interest exists.

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

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

Timothy H. DeFries (signature)
Subcontractor/Consultant

3 AUG 2015
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Education

University of California, Riverside (9/88 to 1/94)
Ph.D. in Physics awarded January 1994
M.S. in Physics awarded December 1989

University of California, Riverside (9/84 to 6/88)
B.S. in Physics awarded June 1988 (with High Honors)

Professional Experience

Present as of July 2012	Research Engineer, II, Center for Environmental Research and Technology, University of California, Riverside

Principal investigator for a variety of mobile source related programs with annual budgets of approximately >$1,000,000. Responsibilities include research and program development and management, proposals, project budgeting, the establishment and execution of project plans and schedules, daily oversight of project testing, the analysis and interpretation of test results, and the preparation of project reports and scientific articles.

Previous Experience

2009 – 2012	Research Engineer, I, Center for Environmental Research and Technology, University of California, Riverside
2007 – 2009	Associate Research Engineer, III, Center for Environmental Research and Technology, University of California, Riverside
2005 – 2007	Associate Research Engineer, II, Center for Environmental Research and Technology, University of California, Riverside
2003 – 2005	Associate Research Engineer, I, Center for Environmental Research and Technology, University of California, Riverside
1996 – 2003	Assistant Research Engineer, Levels II-IV, Center for Environmental Research and Technology, University of California, Riverside
1994 – 1996	Post Doctoral Researcher, Center for Environmental Research and Technology, University of California, Riverside
1994	Lecturer, Physics Department, University of California, Riverside
1992 – 1993	Research Assistant, Center for Environmental Research and Technology, University of California, Riverside
1992 – 1993	Astronomy Instructor, Natural and Agricultural Sciences, Riverside Community College, Riverside, CA
1990 – 1994	Graduate Student Researcher, Physics Department, University of California, Riverside
1990	Assistant Technical Staff Member, The Aerospace Corp., El Segundo, CA
1988 – 1994	Teaching Assistant, Physics Department, University of California, Riverside
1985 and 1988	Technical Summer, Rockwell International, Lakewood and El Segundo, CA

Grants

- Engine Manufacturers Association (EMA), "Heavy-Duty Chassis Dynamometer Testing," 10/14-3/15, $220,000 PI.
- California Air Resources Board (CARB), "NCST NG Infrastructure Study," 10/14-4/16, $62,500 PI.

- California Air Resources Board (CARB), “Evaluation of Impacts of Emissions Averaging & Flexibility Programs for all Tier 4 Final Off-road Diesel Engines,” 8/14-2/17, $300,000 Co-PI.
- CARB, “Evaluation of feasibility, cost-effectiveness, & necessity of Equipping Small Off-road Diesel Engines with Advanced PM and/or NOx aftertreatment,” 8/14-8/16, $800,000 PI.
- California Energy Commission (CEC), “CARB LNG Test - Evaluation of Performance & Air Pollutant Emissions of Vehicles Operating on Various Natural Gas Blends - Phase 2,” 8/13-3/15, $120,000 PI.
- CARB, “CARB LNG Test - Evaluation of Performance & Air Pollutant Emissions of Vehicles Operating on Various Natural Gas Blends - Phase 2,” 6/13-3/15, $120,000 PI.
- Coordinating Research Council (CRC), “Very Low PM Measurements for Light-Duty Vehicles (E-99),” 10/12-12/14, $434,600 Co-PI.
- CARB, “Very Low PM Measurements for Light-Duty Vehicles (E-99),” 2/13-7/15, $100,000 Co-PI.
- California Air Resources Board (CARB), “Evaluation of Fuel Additives as Certified Biodiesel B20 NO_x Mitigation Strategies,” 6/12-6/14, $300,000 PI.
- CARB, “Biodiesel Emissions Characterization Study of Engines Fueled with B5 Biodiesel Blends,” 6/12-6/14, $480,000 Co-PI.
- CEC, “RNG and Fungible Fuels Infrastructure Compatibility Study.” 6/12-6/14, $1,200,000, Co-PI.
- CRC, “Biodiesel and Renewable Diesel Characterization & Testing in Modern LD Diesel Passenger Cars & Trucks,” 5/12-7/13, $264,704, Co-PI.
- Electric Power Research Institute (EPRI), “UCR Lab TDL Test Cell Modifications for Investigation of Moisture Interference,”5/12-4/13, $50,211, PI.
- Caltrans, “Developing a Model to Quantify Emissions from HD Construction Equipment as Related to Job Site Activity,” 4/12-4/14, $200,000 Co-PI.
- American Petroleum Institute, “Impacts of Aromatics in Late Model Vehicles,”2/12-2/13, $265,000 PI.
- South Coast Air Quality Management District (SCAQMD), “Determining the Physical & Chemical Composition & Associated Health Effects of Tailpipe PM Emissions,”1/12-7/13, $175,000 PI.
- SCAQMD, “Health Effects of PM Particles Emitted from Heavy-Duty Vehicles – A Comparison Between Different Biodiesel Fuels,”1/12-1/13, $207,000 Co-PI.
- SCAQMD, “Characterization of the Physical, Chemical, & Biological Properties of PM Emissions, VOCs, & Carbonyl Groups from Commercial Cooking,”1/12-4/13, $150,000 Co-PI.
- SCAQMD, “In-Use Emissions Testing and Demonstration of Retrofit Technology for Control of On-Road Heavy-Duty Engines,”8/11-12/13, $689,000 Co-PI.
- CARB, “Air Quality Improvement Program (AQIP): Hybrid Deployment and Testing Evaluation,”6/11-6/13, $2,000,000 Co-PI.
- EPRI, “Laboratory Testing of HCL and HF TDL instrumentation,”4/11-12/12, $104,797 PI.
- CARB, “Development of a Portable In-Use Reference PM Measurement System,”4/11-9/13, $300,000 Co-PI.
- CARB, “Construction of a Low-Level SO_2 DOAS for Installation at a CARB Emissions Test Facility,”4/11-9/13, $90,000 PI.
- CARB, “Biodiesel Certification Testing,” 3/11-6/13, $300,000 PI.
- International Sustainable Systems Research Center, “Evaluation of Air Pollutant Emissions and Fuel Economy of Liquified Petroleum Gas (LPG) Powered Buses/Trucks, 3/11-9/11, $102,458, Co-PI.
- Calumet, “Evaluation of Regulated and Toxic Emissions from 2-Stroke Utility Engines.” 11/10-6/11, $48,071, Co-PI.
- BP Global Fuels Technology, Inc. “Emissions Testing Program.” 11/10-6/11, $250,295, Co-PI.
- CEC “Alternative Fuels/Mixed Alcohols Testing Program.” 7/10-1/14, $1,200,000, PI.
- CARB, “Evaluation of the Performance and Air Pollutant Emissions of Vehicles Operating on Various Natural Gas Blends.,”7/10-8/13, $280,000 Co-PI.
- Sensors, Inc. “Supplemental Testing of PPMD to Resolve Issues with PPMD Observed During the HDIUT PM MA Program,” 7/10-2/11, $67,338, Co-PI.
- Coordinating Research Council (CRC), “Effects of Olefins Content on Exhaust Emissions – Project E-83,” 12/09-12/10, $210,757, PI.
- CARB, “Study of In-Use Engine Deterioration in Diesel Off-Road Equipment,”11/09-5/13, $300,000 PI.
- CEC “PIER Transportation Research Area Alternative Fuel Research Roadmap and Gaps Assessment.” 9/09-10/10, $307,182, PI.

- CARB, “Measurement of Diesel Solid Nanoparticle Emissions using a Catalytic Stripper for Comparison with Europe’s PMP Protocol,”7/09-12/11, $170,000 co-PI.
- CARB, “PM PEMS Validation Testing with a 1065 Compliant PM Laboratory for the PM-PEMS Measurement Allowance Determination for the HDIUT Program,”5/09-12/10, $573,113 PI.
- CARB (from National Biodiesel Board), “Assessment of Emissions from Use of Biodiesel as a Motor Vehicle Fuel in California: Biodiesel Characterization and NO_x Formation and Mitigation Study,” 3/09-6/11, $50,000, PI.
- Neste Oil Corporation, “Assessment of Emissions from Use of California Air Resources Board Qualified Diesel in Comparison with Federal Diesel,” 2/08-6/10, $50,000, PI.
- SCAQMD, “Evaluation of the Performance and Air Pollutant Emissions of Vehicles Operating on Various Natural Gas Blends,” 1/09-8/11, $50,000, PI.
- SCAQMD, “Control Device Verification Testing for Stationary Diesel Engines,” 12/08-6/09, $25,000, PI.
- SCAQMD, “Evaluation of Emission Benefits/Debits of Gasoline Fuels in the South Coast Air Basin,” 10/08-9/10, $250,000, PI.
- CARB, “Comparison of PM PEMS for the HDIUT Program with a 1065 Compliant PM Mobile Laboratory,”12/07-6/09, $284,667 PI.
- SCAQMD, “Assessment of Emissions from Use of Biodiesel as a Motor Vehicle Fuel in California: Biodiesel Characterization and NO_x Formation and Mitigation Study,” 8/08-6/11, $150,000, PI.
- Caltrans, “Measuring and Modeling PM Emissions from Heavy-Duty Construction Equipment.” 7/08-6/11, $150,000, PI.
- Caltrans, “Evaluation of In-Field Emissions Impacts of Biodiesel Fuels.” 7/08-12/09, $100,000, PI.
- CARB, “Assessment of Emissions from Use of California Air Resources Board Qualified Diesel in Comparison with Federal Diesel,” 6/08-5/10, $1,000,000, PI.
- CEC “Evaluation of the Performance and Air Pollutant Emissions of Vehicles Operating on Various Natural Gas Blends.” 12/07-3/13, $400,000, PI.
- Engine Manufacturers Association “PM Measurement Allowance Phase 1: On-Road Testing Using the CE-CERT Mobile Emissions Laboratory.” 11/07-6/09, $192,770, PI.
- CARB, “Assessment of Emissions from Use of Biodiesel as a Motor Vehicle Fuel in California: Biodiesel Characterization and NO_x Formation and Mitigation Study,” 6/07-6/09, $1,360,000, PI.
- CARB, “Assessment of the Emissions from the Use of Biodiesel as a Fuel in California,” 6/06-5/08, $100,000, PI.
- US Environmental Protection Agency (US EPA), “Air Quality and Emissions Measurement at the University of California, Riverside,” 8/06-9/07, $107,200, Co-PI.
- CARB, “Evaluation of the Proposed New European Methodology for Determination of Particle Number Emissions and its Potential in California for In-use Screening”, 6/06-9/07, $250,000, PI.
- CARB, “Measurement Allowance Project,” 7/04-1/08, $500,000, Co-PI.
- CARB, “Evaluate High PM Emitters on Highway,” $249,826, PI.
- O2 Diesel, “Emissions Testing Related to the 02DieselTM Demonstration Program at the Nellis Air Force Base,” 11/05-12/06, $400,000, Co-PI.
- Caltrans, “Evaluating the Emissions from Heavy-Duty Construction Equipment”, 4/05-6/08, $299,641, Co-PI
- UC Berkeley, “Feasibility Study for Biodiesel in the Caltrans Fleet,” 9/05-6/07, $102,307, Co-PI.
- City of Los Angeles, “Implementation Strategies and Training for Alternative Fuel Vehicles,” 4/05-1/07, $90,300, Co-PI.
- US Department of Navy, “Demonstration Plan for Effect for Biodiesel on Diesel Engine Nitrogen Oxide and Other Regulated Emissions,” 8/03-6/06, ~$200,000, Co-PI.
- US Environmental Protection Agency (US EPA), “Air Quality and Emissions Measurement at the University of California, Riverside,” 1/05-9/06, $127,100, Co-PI.
- CARB, “Evaluation of On-Board Diagnostic II (OBD-II) and Tailpipe Test for Use in Smog Check,” 6/03-6/05, $325,666, Co-PI.
- CARB, “Literature Searches for Internal Combustion Engine Air Toxic Emissions and Particulate Matter Mass Measurement and Physical Characterization,” 3/03-6/04, $64,519, Co-PI.
- CRC, “Effects of Ethanol and Volatile Parameters on Exhaust and Evaporative Emissions,” 4/03-3/04, $807,979, Co-PI

- Cal EPA Integrated Waste Management Board, "Yosemite Closing the Loop," 12/02-5/03, $27,500, PI
- CRC, "Ammonia Emissions from Late Model Vehicles – Project E-60," 2/01-12/02, $758,833, Co-PI
- CRC, "Engine Oil Contributions to Emissions – Project E-61," 2/01-12/02, $222,178, Co-PI
- U.S. EPA, "Evaluation of Emissions from Off-Road, 8/01-3/03, $247,799, PI
- NREL & Ford Motor Company, "Emissions Testing of Light Trucks Equipped with Catalyst Particle filters," 3/01-3/02, $117,397, PI
- U.S.EPA, "Investigation of Emission Rates of Ammonia and Other Toxic and Low-Level Compounds as a Function of Gasoline Sulfur Content," 9/00-8/01, $160,500, PI.
- SCAQMD, "Evaluation of the Emissions Impact of Additives, Lubricants, and Engine Flushing Systems," 7/00-7/04, $100,000
- CARB, "Determination of Non-Registration Rates for On-Road Vehicles in California," 4/00-11/01, $210,000, PI
- U.S. EPA, "Evaluation of the Effectiveness of On-Board Diagnostics II (OBD II) in Controlling Emissions," 7/99-3/01, $185,103, PI
- U.S. EPA, "Investigation of Emission Rates of Toxic and Other Low-Level Compounds Using FTIR," 7/99-9/00 $38,070 PI
- CARB, "Off-Highway Motorcycle/All Terrain Vehicle Activity-Data Collection; Personal Watercraft Activity-Data Collection; and Test Cycle Development," 6/99-12/00, $220,000, PI
- SCAQMD, "Evaluation of the Effects of Biodiesel Fuel on Emissions from heavy-duty Non-Road Vehicles: Pilot Study," 6/99-2/00, $25,037, PI
- SCAQMD, "Investigation of Emission Rates of Ammonia and Other Toxic and Low-Level Compounds Using FTIR," 6/99-2/01, $100,000, PI
- SCAQMD, "Evaluation of the Effects of Biodiesel and Biodiesel Blends on Exhaust Emission Rates and Reactivity-Phase 2," 5/99-4/01, $300,000 + gift $25,000, PI
- U.S. EPA, "Investigation of Exhaust Emissions from Light-Duty Vehicles as a Function of Payload," 4/99-3/00, $146,931, PI
- SCAQMD, "Evaluate Effects of Alternative Diesel Fuel Formulation on Exhaust Emission Rates," 6/98-1/99, $258,700, PI
- CARB, "Emissions Testing of Low-Emitting Utility Engines," 3/98-3/99, $49,994, PI
- National Renewable Energy Lab., "Particulate Measurement and Emissions Characterization of Alternative Fuel Vehicle Exhaust," 2/97-10/98, $162,403, pi
- U.S. EPA/Desert Research Institute, "Simple Particulate Emission Measuring System," $36,983, PI
- Magnum Environmental Technologies, Inc., additive testing, 5/00-10/00, $241,636, PI.

Honors and Activities

Contributing Author IPCC 2006 Inventory for Greenhouse Gases
Third Alternate Member of the EPA's Federal Advisory Committee Act
    Mobile Source Technical Review Subcommittee [MSTRC] (1999-2003)
Member of the EPA's OBDII policy workgroup [under the MSTRC] (1999-2003)
Member Society of Automotive Engineering
Event Captain 2002 Future Truck Competition
American Physical Society Student Travel Award (1993)
Early Dean's Graduate Fellowship at UC Riverside (1988-89)
Habitat for Humanity (1997/1998)
Mexico home building volunteer (2007)
Eagle Scout
Fraternity Man of the Year (1989)

Journal Articles (Refereed)

- Tanfeng Cao, Kent C. Johnson, Thomas D. Durbin, David R. Cocker III, Roland Wanker, Thomas Schimpl, Volker Pointner, and Karl Oberguggenberger, 2014, A Comprehensive Evaluation of a Gaseous Portable Emissions Measurement System with a Mobile Reference Laboratory, submitted xxxx, July.

- Tanfeng Cao, Kent C. Johnson, Robert L. Russell, Thomas D. Durbin, David R. Cocker III, Andrew Burnette, Joseph Calavita, and Hector Maldonado, 2014, A Generalized Approach for Characterizing Emissions Benefits of Hybrid Off-Road Equipment via Physical Activity and Engine Work: A Case Study for Excavators, submitted xxxx, July.
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- Tanfeng Cao, Kent C. Johnson, Thomas D. Durbin, Robert L. Russell, David R. Cocker III, and Hector Maldonado, 2014, Evaluations of In-Use Emission Factors from Off-Road Construction Equipment, submitted xxxx, July.
- Daniel Short, Diep Vu, Thomas Durbin, Georgios Karavalakis, and Akua Asa-Awuku, 2014, Particle Speciation of Emissions from Iso-Butanol and Ethanol Blended Gasoline in Light-Duty Vehicles, in preparation.
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ORGANIZATIONAL CONFLICT OF INTEREST CERTIFICATE

Customer: U.S. Environmental Protection Agency

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

Prime Contract: EP-C-12-011

Subcontract/Peer Reviewer: Thomas Durbin

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

___xx (see note below)____ No actual or potential conflict of interest exists.

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

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

____
Subcontractor/Consultant

6/10/2015
____
Date

Note – It should be noted that although there is no conflict of interest directly related to the review of this report, through my affiliation with UC Riverside may be involved in future research projects through EPA or other organizations that would be used in the continuing development of the MOVES model.

100 Cambridgepark Drive, Suite 500 Cambridge MA 02140 617.250.4200 617.250.4261 fax www.icfi.com

Appendix B. **Charge Letter**

May 11th, 2015

Dr. Timothy DeFries
Principal Scientist, Eastern Research Group
3508 Far West Blvd., Ste. 210
Austin, TX 78731

Subject: Peer Review of Speciation Profiles and Toxic Emission Factors for Nonroad Engines

Dear Dr. DeFries,

ICF International has been contracted by EPA to facilitate a peer review. In late April we corresponded by email and you indicated your availability to participate as a paid reviewer to review of the EPA Office of Transportation and Air Quality's report "Speciation Profiles and Toxic Emission Factors for Nonroad Engines". You have been selected to participate on this panel. ICF will compensate you $2,000 for your services. This charge letter provides you with a list of directed questions for your review, the review schedule, and the materials we would like you to send to us at the conclusion of the review. In addition, attached to this letter is a copy of the report that we would like you to review.

Charge Questions

We are submitting this material for you to review the selected methods and their underlying assumptions, their consistency with the current science as you understand it and the clarity and completeness of the presentation. For this review, no independent data analysis is required. Rather, we ask that you assess whether the information provided is representative of the state of current understanding, and whether incorporating this information in MOVES will result in appropriate predictions and conclusions.

We request that you provide us with your comments on the content sequentially. Grammatical/formatting and other minor comments can be provided separately.

Below are questions to define the scope of the review; we are not expecting individual responses to the questions, but would like them to help guide your response.

General Questions to Consider

1. Does the presentation describe the selected data sources sufficiently to allow the reader to form a general view of the quantity, quality and representativeness of data to be used in the development of emission rates? Are you able to recommend alternate data sources that might better allow the model to estimate national or regional default values?

2. Is the description of analytic methods and procedures clear and detailed enough to allow the reader to develop an adequate understanding of the steps taken and the assumptions made by EPA in developing the model inputs? Are examples selected for tables and figures well chosen and do they assist the reader in understanding the intended approaches and methods?

3. Are the methods and procedures employed technically appropriate and reasonable with respect to the relevant disciplines, including physics, chemistry, engineering, mathematics and statistics? Are you able to suggest or recommend alternate approaches that might better achieve the goal of developing accurate and representative model inputs? In making recommendations please distinguish between cases involving reasonable disagreement in adoption of methods as opposed to cases where you conclude that current methods involve specific technical errors.

4. In areas where EPA has concluded that applicable data is meager or unavailable, and consequently has made assumptions to frame approaches and arrive at solutions, do you agree that the assumptions are appropriate and reasonable? If not, and you are so able, please suggest an alternative set(s) of assumptions that might lead to more reasonable or accurate model inputs while allowing a reasonable margin of environmental protection.

5. Are the resulting model inputs appropriate, and to the best of your knowledge and experience, reasonably consistent with physical and chemical processes involved in mobile source emissions formation and control? Are the resulting model inputs empirically consistent with the body of data and literature that has come to your attention?

Schedule
The schedule for this peer review is as follows:

- May 11th, 2015: Charge letter distributed to reviewers
- June 8th 2015: Comment/review due via email to Laurence.O'Rourke@icfi.com

Materials

Upon completion of your review, you should submit your report under a cover letter that states 1) your name, 2) the name and address of your organization, and 3) a statement of any real or perceived conflict(s) of interest.

Should you have any questions or concerns, feel free to contact me via phone at 617-250-4226 or by email. In addition, the EPA project manager for this effort is Kent Helmer and he may be reached at 734-214-4825.

Thanks for your participation!

Sincerely,

Larry O'Rourke
Manager, ICF International

Attachment: Speciation Profiles and Toxic Emission Factors for Nonroad Engines_Draft March 2015

May 11th, 2015

Dr. Thomas Durbin
Research Engineer II
Center for Environmental Research and Technology
University of California, Riverside
Riverside, CA 92521

Subject: Peer Review of Speciation Profiles and Toxic Emission Factors for Nonroad Engines

Dear Dr. Durbin,

ICF International has been contracted by EPA to facilitate a peer review. In late April we corresponded by email and you indicated your availability to participate as a paid reviewer to review of the EPA Office of Transportation and Air Quality's report "Speciation Profiles and Toxic Emission Factors for Nonroad Engines". You have been selected to participate on this panel. ICF will compensate you $2,000 for your services. This charge letter provides you with a list of directed questions for your review, the review schedule, and the materials we would like you to send to us at the conclusion of the review. In addition, attached to this letter is a copy of the report that we would like you to review.

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2. Is the description of analytic methods and procedures clear and detailed enough to allow the reader to develop an adequate understanding of the steps taken and the assumptions made by EPA

in developing the model inputs? Are examples selected for tables and figures well chosen and do they assist the reader in understanding the intended approaches and methods?

3. Are the methods and procedures employed technically appropriate and reasonable with respect to the relevant disciplines, including physics, chemistry, engineering, mathematics and statistics? Are you able to suggest or recommend alternate approaches that might better achieve the goal of developing accurate and representative model inputs? In making recommendations please distinguish between cases involving reasonable disagreement in adoption of methods as opposed to cases where you conclude that current methods involve specific technical errors.

4. In areas where EPA has concluded that applicable data is meager or unavailable, and consequently has made assumptions to frame approaches and arrive at solutions, do you agree that the assumptions are appropriate and reasonable? If not, and you are so able, please suggest an alternative set(s) of assumptions that might lead to more reasonable or accurate model inputs while allowing a reasonable margin of environmental protection.

5. Are the resulting model inputs appropriate, and to the best of your knowledge and experience, reasonably consistent with physical and chemical processes involved in mobile source emissions formation and control? Are the resulting model inputs empirically consistent with the body of data and literature that has come to your attention?

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Thanks for your participation!

Sincerely,

Larry O'Rourke
Manager, ICF International

Attachment: Speciation Profiles and Toxic Emission Factors for Nonroad Engines_Draft March 2015

Appendix C. Timothy DeFries Review Comments

Comments (T.H. DeFries, August 3, 2015) on

"Speciation Profiles and Toxic Emission Factors for Nonroad Engines"
EPA-420-R-14-028
draft, March 2015

1A. In many places the report uses emission data from onroad engine measurements when nonroad emissions measurements are not available. It makes sense to me that the emissions between onroad and nonroad engines would be the same, but maybe I am just naïve. I would like to see a discussion (up front somewhere) of why the emissions of nonroad and onroad engines might be expected to be different. Is it a consequence of different emission standards, different emission controls (as a result of standard differences), and a difference in how the vehicles are used, or what?

1B. In several (many) places in the report an analysis of emission factors for the sought after nonroad vehicle, fuel type, and emissions type cannot be performed because the needed data does not exist. In each instance a substitute dataset is analyzed. For example, the dioxin and furan emission factors for nonroad CNG exhaust are based on an analysis of onroad gasoline exhaust dioxin and furan data. The reasons why these substitutions might be reasonable are not given – other than the substitute data exists. To me the lack of discussion makes the substitution highly questionable. The argument that "MOVES needs something" doesn't really cut it for me. There are those who would argue that zero is a better guess than a completely incorrect emission factor value.

So, what can be done about this? Let me suggest there be a separate discussion of the believed formation mechanisn or source for each emission category. Ideally, there would be research to reference that identifies the sources. This discussion could be in the Introduction, perhaps in Subsection 1.1, which already has a presentation of each emission category. For example, one category of emissions are the PAHs. Are PAHs in the exhaust derived from PAHs in the fuel, from fuel combustion, from PAHs in the engine oil, from combustion of engine oil, or what? If the predominant source is known, it could provide a reason for choosing the substitute dataset used to determine the PAH emission factors. If none of the sources are known, then the reader at least knows that we tried to find a reasonable substitute based on some sort of logic.

2. The second paragraph of the Intro says that factors are updated using from test program data of gasoline and diesel. Are there no test programs on CNG and LPG?

3. The section heading for 1.1 in the text and in the TOC differ.

4. Section 1.2, second paragraph: benzo(g,h,i)perylene.

5. Section 1.2, fourth paragraph, second line: "chemical mechanism species" is a term I don't recognize.

6. Section 1.3, second paragraph: Why is it "important to note"? Do you expect that emission factors would vary greatly by the factors mentioned? I guess that without any data you don't know, but maybe you could mention that for other emission factors where data does exist as a

function of the factors mentioned, the emission factors vary greatly. By inference the nonroad emission factors are also likely to vary greatly. We just don't know by how much.

7. Section 2.1, first paragraph: I don't understand why the section starts out with "In the absence of data" when it seems that data does exist and it is used for the analysis.

8. Section 2.1, first paragraph: The "single" test program apparently actually measured emissions of nonroad vehicles. Many of the sections that follow mention that nonroad data was not available so onroad data was used for the analysis. So, I think it is important to make clear for Section 2.1 that nonroad data was actually used.

9. Section 2.1, second paragraph: I am a novice when it comes to the definitions and differences among VOC, NMOG, NMHC, THC, and TOG. Then, Equation 2 throws ethane and acetone into the mix, and I am lost. I know this was explained in Section 1.2, but I need a graphic or something to make clear the differences. As it is, when I get to the two paragraphs above Table 5, I just say to myself, "if you say so…" Maybe "those in the know" don't need anything more, and it's OK as is for them.

10. Section 2.2, first paragraph: Is $OC_{2.5}$ the correct term, or is it a typo and should be $PM_{2.5}$? If it's correct, it is out of the blue for me.

11. I thought that I had understood what was going on, but when I got to Section 3.1 I began to get confused. I guess maybe this confusion may have begun in my mind with the introduction of the terms "VOC profiles" and "VOC emission profile," which are first mentioned in Section 3.1. I presume these terms mean a set of VOC fractions. But I then realized that I was not really certain what all of this work was trying to get. I think (but I'm not sure) that it's two things:

1) emission rates for THC, NMHC, NMOG, TOG, VOC, etc., and

2) the fraction of each by species that make up the VOCs.

So, for example, for Item 1, Table 5 says that for 2-stroke, E0 the VOC emission rate is 35586 mg/mi. And for Item 2, Table 6 gives the fractions of the 35586 mg/mi that it attributed to 1,3-butadiene (0.00214), etc. Multiplying, that would mean that the 1,3-butadiene emission rate is 76 mg/mi (=35586*0.00214). Is that what the report is trying to figure? That is what is stated at the beginning of the second paragraph of Section 2.1 "In the MOVES model, individual VOC fractions are multiplied by total VOC emissions to obtain emission factors."

It seems that the toxic fractions (as in Table 6) apply only to VOCs. So, then why are THC, NMHC, NMOG, TOG, and CH4 shown in Table 5? So, it's not clear to me the distinction between 1) how MOVES will do a calculation and 2) how the literature data is being used to come up with emissions numbers to put into MOVES.

I think this could be solved by adding another subsection to the Introduction. It would tell what MOVES needs to do the calculations, that is, what this report is trying to figure out. Section 1.1 starts out by listing the species, but doesn't complete the idea by telling how calculations are done in MOVES. Section 1.2 talks about the operational definitions of THC, NMOG, etc., what previous MOVES versions lacked, … Section 1.3 talks about what literature was used to calculate the numbers in this report. But what is missing is what quantities we are trying to calculate.

The idea would be that for each type of fuel/emission (gasoline exhaust, diesel exhaust, CNG exhaust, LPG exhaust, evaporative emissions, and crankcase running exhaust emissions) we want to calculate X, Y, Z for use in MOVES. Basically the section needs to say: “MOVES needs the following information: X, Y, Z. So, we’re going to estimate these quantities from literature studies.” This could be perhaps most clearly portrayed using a table with blank cells. Please tell me in the Introduction. I think that this new subsection could go between Speciation and Methods, and it might be called something like Emission Factors to be Determined. Then, in the later sections, if the report used the same tabular layout, but now with the numbers for the fuel type, the clarity would be much better.

Somewhere around where you tell what you are going to calculate, you could include Equations 1, 2, 3, 4. It looks to me like they may apply to more fuels than just gasoline exhaust, so putting them early in the report and explaining them may be more appropriate for the Introduction.

12. Section 3.1, fourth paragraph: Why are you talking about MY 2007 all of a sudden?

13. Section 3.1, fifth paragraph, fourth line: Better to say “diesel #2 C:H molar ratio of”. At first I thought it was a weight ratio.

14. Section 3.4, second paragraph: What’s a congener?

15. Table 14: Is it possible to tell what the detection limits are so that we know what the emission factors with ND are less than? I don’t mind that in MOVES NDs will be set to zero, but I think that you should tell in this document what the ND values are.

16. Section 4.1, first paragraph: What does “conservative” mean? “Conservative” from the environmentalist’s point of view or from the engine manufacturer’s point of view? Does it mean that the real emissions, which we have no data for, are expected to be less or more than the emissions that the existing data provides? Let me say that “conservative” is always a poor term for use in a technical report.

17. Section 4.1, first paragraph: It strikes me that a transit bus is quite different from a nonroad vehicle. Can you say anything that might make us think that the CNG transit bus is a reasonable surrogate for a CNG nonroad engine? Are even the overall (i.e., non-speciated) emissions similar?

18. Section 4.2, first paragraph, first sentence: Does “in a manner similar” mean using Equations 3 and 4? If that’s it, say so. My suggestion, as I have stated earlier, is that the technique may best be covered in a new subsection in the Introduction. Then, here, you could just refer to the Introduction.

19. Table 17: Is it possible to tell what the detection limits are so that we know what the emission factors with ND are less than? I don’t mind that in MOVES NDs will be set to zero, but I think that you should tell in this document what the ND values are.

20. Table 18. To follow along with Equation 5, shouldn't the title for Column 2 be Onroad CNG Emission Factor (g/mi) and the title for Column 3 be Nonroad CNG Emission Factor (g/gal)? I think that would make the table clearer. So, I am assuming that Column 3 has the values that we need for nonroad vehicles, and Column 2 just shows the onroad values that they are derived from.

21. Section 4.4: Boy, this is a stretch! CNG dioxins and furans from onroad gasoline engines! All we can do is convert the units using Equation 5? Can you mention ANY reason that these guesses are at all reasonable (see comment 1B)?

22. Table 19. To follow along with Equation 5, shouldn't the title for Column 2 be Onroad CNG Emission Rate TEQ (g/mi) and the title for Column 3 be Nonroad CNG Emission Factor TEQ (g/gal)? I think that would make the table clearer. So, I am assuming that Column 3 has the values that we need for nonroad vehicles, and Column 2 just shows the onroad values that they are derived from.

23. Section 6.1.1: In the case of evaporative emissions using toxic fraction data from onroad vehicles makes complete sense because the mechanism of evaporation is independent of the type of vehicle.

24. Section 6.1.1: An alternate source of toxic fraction information is Sam Reddy's ReddyEvap model. This model uses physical chemistry and compound properties to calculate gasoline vapor compositions for different liquid gasoline compositions. The model also calculates vapor composition for different conditions such as Reid vapor pressure, ethanol content, fuel tank fill level, atmospheric pressure, and tank temperature.

25. Section 6.1.2: I seem to recall (I could be remembering incorrectly) that ReddyEvap also calculates the increased permeation of gasoline hydrocarbon compounds when ethanol is present in the gasoline – a synergistic effect. The data in Table 23 don't seem to show this effect.

Appendix D. Thomas Durbin Review Comments

UNIVERSITY OF CALIFORNIA, RIVERSIDE

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June 5, 2015

Mr. Larry O'Rourke
ICF International
100 Cambridgepark Drive, Suite 500
Cambridge, MA 02140

RE: Peer Review of Report

Dear Mr. O'Rourke:

Please find attached my comments on the documents relating "Speciation Profiles and Toxic Emission Factors for Nonroad Engines Report". I work as a research engineer for the University of California at Riverside, CE-CERT and have no real or perceived conflict of interest related to this evaluation. I have considerable expertise in emissions testing and have conducted a number of major emissions test programs related to the topics presented in this report. Please let me know if you would like further information or have further questions relating to my comments, or would like to discuss the comments via a conference call.

Regards,
Tom Durbin, Ph.D
Research Engineer
University of California
CE-CERT
Riverside, CA 92521

General Summary

Specific comments

1.0 Introduction – footnote A is worded very awkwardly… "incorporated onroad and the NONROAD model"…

Section 1.2

End of 1st paragraph – The current regulation under 1065 require a 2.5 micron cyclone for PM measurements. So, is PM as defined as material collected on a filter using EPA-defined sampling practices thus defined as PM2.5.

4th paragraph – 2nd sentence – The second sentence needs to be clarified about how…. PM2.5 speciation from nonroad sources continue to be conducted in SMOKE with the use of MOVES2014a. What is MOVES2014a used within the SMOKE model. Also, a reference to SMOKE should be given.

Section 1.3

References 3,4,5, which represent the heart of the report, do not seem to be as complete as they should be. Are these documents publically available? Was a report ever done for the 2004 studies? Did they get document numbers? Can someone put these document/work assignment numbers into a web search and find these documents readily?

Section 2.1

The sentence about Equation 2 – The sentence implies that the derivation of VOCs from NMOG by removal of ethane and acetone is clearly defined in the introduction, but the NMOG/ethane/acetone combination is not really alluded to in the introduction.

Equations 3 and 4 need better clarification. Such as, the PAH gaseous and particulate emissions factors are those for the ith species. Also, the term "emissions factor" seems to really be a "fraction".

Section 2.3

3rd paragraph – It talks about using a fuel economy estimate of 17 mpg. A description of where the 17 mpg number is from should be given (just one sentence), and a reference or footnote.

For this and section 2.4, in deriving nonroad emissions factors for metals and dioxins and furans from onroad emission factors, an important consideration should be whether the source has or does not have a catalyst. With the onroad sources predominantly being catalyst equipped, it seems like some discussion should be given on this point. This does not necessary mean that the emissions rates would be significantly higher for these emissions for the nonroad sources without catalysts, but it just seemed like some related discussion would be worthwhile.

Section 3.1

In terms of the estimates for Tier 4 nonroad engines, it is important to point out that the emissions standards are slightly looser than those for the corresponding 2007+ model year onroad engines. Thus, it is my understanding that DPFs are not as universally applied as for the onroad vehicles. While ACES data for newer onroad engines is probably the best estimate for filling in data for

Tier 4 nonroad engines, some explanation of this caveat should be included in this report, as it is an important distinction.

Paragraph 5 – It says NMHC is derived from equation 1, but equation 1 is for NMOG, so some discussion of rearrangement needed to get NMHC should be provided.

It seems commas could be added to the final sentences in both paragraph 5 and 6. Paragraph 5 .. , as document in…. Paragraph 6 …. , which is listed …

Section 3.2

1st paragraph final sentence …. Represent partitioning as seen in the sampled diluted exhaust,

Section 3.3

In the first paragraph, it talks about studies used in developing onroad emissions factor and study specific fuel economy estimates are outlined in the notes of Table 13. I don't see any of that information in Table 13 and it would be useful. This could include some information in the footnotes.

Section 3.4

3rd paragraph – (75hp) add space to (75 hp)

Appendix A

It seems like the numbering system for Appendix A should be different than that used in the main test. Maybe call the section A-1.0 Introduction.

In paragraph 2 of Introduction 1.0, the references 3,4,5 should be superscripted.

Some of the text near the end of the 2nd paragraph on CMAQ/SPECIATE might be worth adding to the main text to strengthen the introduction.

Section 2.1.2

A reference should be added for the ARB study that is discussed in the 1st paragraph.

Section 2.1.3

Paragraph 2. Why were the FTPs for the ATVs and motorcycles run as 4 bag as opposed to 3 bag FTPs.

Paragraph 3. A little more detail should be given on the Phase II Auto-Oil methods for the 4 methods used for C_1-C_4, C_5-C_{12} species (include subscripts), benzene and toluene, and alcohols.

Section 2.1.4

It would be worthwhile discussing a bit more about how many replicate tests were conducted for the different tests.

Paragraph 4 – Is an array of impingers 2 or more impingers?

Section 3.1

At the end of the 2nd paragraph, it talks about there being no outliers, but it then goes on to discuss data adjustments in the 3rd paragraph.

Final paragraph – It indicates that the 2-stroke catalyst data were not utilized due to various issues with the data. First, it would be useful to know how common or what percentage of the nonroad population are 2-stroke catalyst engines, and where would they most commonly be used. Secondly, for the abnormalities in the data, could some of this be due to making measurements at very low emission levels. For example, are the numbers for the abnormalities still much lower than those for the uncatalyzed 2-stroke engines?

Section 3.2

2nd paragraph – 1st sentence …transient data would be used …. Should be written….. transient data was used. Also +50 hp (a space is needed).

4th paragraph right below Table 3-3. It talks about zeroing out a high acetylene value. Doesn't this wind up biasing the 1.15% average low? Maybe it rather be not available (NA) as opposed to being zeroed.

Section 4

The reviewer agrees that data on toxic emissions from NGVs is limited, hence necessitating the use of on-road emissions factors. So this seems to be a reasonable estimate to make. In addition, to the source that is cited in the report, additional data on a subset of toxic species should be available from recent work done by UCR as part of a series of programs that have been conducted to evaluate the effects of varying natural gas fuel composition on emissions. These studies focused on measuring just carbonyl species. Additionally, West Virginia University (WVU) conducted some studies of NGVs that included some toxics measurements, such as BTEX species and carbonyls. It is expected that more work in characterizing CNG emissions from heavy-duty vehicles will be conducted over the next several years as part of additional efforts that are being planned in California.

Sections 4.2 and 4.3 both reference emission factors from the onroad air toxics report. I expect that these also originate from reference 22, but that reference should be included in both sections as the original source of the raw emissions data. It is worth noting that we also conducted some analyses on some of our filters from NGV testing, but no PAHs were detected with the level of sample collected, as these runs were not designed to be elongated to collect higher levels of mass.

The reviewer agrees that dioxin and furan emissions are probably not available for natural gas engines, and the estimates from the onroad gasoline vehicles seems as reasonable as any.

It is worth noting that if it is desired to obtain additional toxics data from natural gas vehicles that the addition of these measurement to the upcoming California efforts to study natural gas vehicle emissions could be considered.

Section 5

It is agreed that there is an absence of toxics data from LPG nonroad engines, and that estimates based on onroad vehicles are needed to fill this category. Profiles developed from the 3 light-duty LPG vehicles are probably not terribly representative of nonroad engines, even if these data may be the only available. It should be worth mentioning that utilizing emission factors from catalyst-equipped vehicles could under report the toxics for engines without catalysts. It might also be useful to compare the relative hydrocarbon levels from the light-duty vehicles to those of some recent testing of LPG heavy-duty vehicles conducted at UC Riverside. It would also be useful to provide the reference of the original source data from which the 3 light-duty LPG vehicles was derived. In the absence of data for PAHs, metals, and dioxins and furans, utilizing estimates based on the CNG engines seems reasonable.

Section 6

Toxics measurements of evaporative emissions are relatively limited. The EPA was a part of the most recent E-77-2b test program on permeation emissions. For the permeation emissions, there is a good discussion of some of the limitations that tank and hose permeation are not differentiated in the onroad portion of MOVES. For section 6.1 on the vapor venting and refueling emissions, the data date back to the early 1990s. It would be useful to reference the original Auto/Oil source materials as well as the Environ study. I thought that studies of evaporative emission toxics were also conducted by EPA in a similar timeframe, although these are quite old as well. I have included a list of some of these older references at the end of this document.

Section 7

The approach for developing the crankcase running exhaust emissions from the onroad gasoline and diesel engines profiles seems to be a reasonable methodology. In terms of explanation, some of the details are provided in Sections 2.1 and 3.1. The crankcase to exhaust ratios are the other key piece of information in developing these emissions factors. Although these are included in this document by reference, it really would be useful to have some values for the ratios for at least THC in this document as well, as this provides an important context for understanding the air toxic emission factors in this report.

Some clarifications could be added to the PAH section. It seems reasonable to use the gaseous phase PAH fractions from Table 7 and 12. One question about this methodology is how the distribution of gaseous VOCs might change between gaseous exhaust emissions and vapor from lubricant oil.

It seems unlikely that there would be significant metal or dioxin/furan emissions from the lubricant oil, so the assumption that these emissions would be negligible in comparison with exhaust emissions seems reasonable.

Charge Questions

1. Does the presentation describe the selected data sources sufficiently to allow the reader to form a general view of the quantity, quality and representativeness of data to be used in the development of emission rates? Are you able to recommend alternate data sources that might better allow the model to estimate national or regional default values?

   Overall, speciation data from nonroad sources are pretty limited, so the data sets identified and utilized appear to be good selections in terms of developing the speciation profiles. Two other questions of importance are how representative are these data, and what areas should EPA be looking to collect data in the future.

   In terms of the representativeness of the data, it might be useful to discuss in the document how representative the data are in describing the data sources. For example, for the NRMC and ATVs, the data set did not include any 4-stroke NDMC/ATVs. While 4-stroke represent a smaller percentage of the overall sales, it would be useful to provide or obtain information on what percentage of these vehicles are actually 4-stroke, and as such not accounted for. This could be more important for the nonroad compared to onroad sources because there is such a diverse mix of engines in the nonroad category compared to onroad vehicles.

   In terms of characterizing NRMCs and their use, it appears that EPA has done some work in this area, and may have other resources at its disposal.
   http://www.epa.gov/nonroad/proposal/r01046.pdf
   The California Air Resources Board (CARB) is also in the process of evaluating the respective populations of 2-stroke and 4-stroke NRMC. Cassie Lopina, 916-322-2411, is working to compile this information, which should be available shortly.

   Similarly, for other spark-ignited SORE engines, the test matrix included only 4-stroke engines with the mowers, generators, and blower. A large percentage of smaller hand held and other equipment are equipped with 2-stroke engines, however. Some discussion of how prevalent 2-stroke engines are in these applications would be useful to the reader in determining how representative these data actually are.

   It is worth noting that CARB is in the process of conducting speciation measurements on a small subset of NRMCs. This data collection effort is scheduled to begin shortly, and should be considered by EPA in future updates of nonroad speciation profiles. The contact would be Sherry Zhang, 916-350-6400.

2. Is the description of analytic methods and procedures clear and detailed enough to allow the reader to develop an adequate understanding of the steps taken and the assumptions made by EPA in developing the model inputs? Are examples selected for tables and figures well chosen and do they assist the reader in understanding the intended approaches and methods?

   Most of the recommendations related to this question are included above. The discussion of getting VOCs from Equation 2 in section 2.1 and getting NMHC from equation 1 in section 3.1. In section 2.3, the origin of the 17 mpg fuel economy estimate used in the conversion. Including information on the applicable studies in Table 13. Also, in the Appendix, section 2.1.3, providing more information on the Auto-Oil methods utilized. Zeroing out the acetylene values before averaging is also something that could use some consideration. In sections 4, 5, and 6, references to the original source material where data is derived from should be added. In section 7, more information on the crankcase to exhaust ratios should be added, since this is key to understanding this section.

3. Are the methods and procedures employed technically appropriate and reasonable with respect to the relevant disciplines, including physics, chemistry, engineering, mathematics and statistics? Are you able to suggest or recommend alternate approaches that might better achieve the goal of developing accurate and representative model inputs? In making recommendations please distinguish between cases involving reasonable disagreement in adoption of methods as opposed to cases where you conclude that current methods involve specific technical errors.

   Again, most of the recommendations related to this question are included above. One of the bigger ones in this category is using the onroad sources from catalyzed vehicles to make estimates for nonroad sources without catalysts, as discussed in sections 2.3 and 2.4. Also, the subtleties of the differences between the certification levels for the Tier 4 nonroad diesel engines vs. the 2007+ onroad diesel engines should be explained in section 3.1. Also, the zeroing out the acetylene values before averaging.

4. In areas where EPA has concluded that applicable data is meager or unavailable, and consequently has made assumptions to frame approaches and arrive at solutions, do you agree that the assumptions are appropriate and reasonable? If not, and you are so able, please suggest an alternative set(s) of assumptions that might lead to more reasonable or accurate model inputs while allowing a reasonable margin of environmental protection.

   Overall, the estimates and assumptions made appear to be reasonable for cases where little or no data is applicable. In making assumptions, one of the aspects worth noting in the report is where estimates from catalyst equipped vehicles are utilized for nonroad engines that may not be equipped with catalysts. Again, the subtleties of the differences between the certification levels for the Tier 4 nonroad diesel engines vs. the 2007+ onroad diesel engines should be explained in the report.

   In terms of additional data sets, consideration should be given to work that has been carried out in California in terms of testing of natural gas vehicles, as well as upcoming studies that will be carried out in nonroad motorcycles. A listing of references that would be worth considering for MOVES (most of which being onroad) is provided at the end of this document.

5. Are the resulting model inputs appropriate, and to the best of your knowledge and experience, reasonably consistent with physical and chemical processes involved in mobile source emissions formation and control? Are the resulting model inputs empirically consistent with the body of data and literature that has come to your attention?

   The results appear to be consistent with the larger body of literature available on speciation and toxic, including data from onroad vehicles for which data are more readily available.

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