VI. HEALTH IMPACTS

VI.1 Health Effects from Heavy-Duty Diesel Emissions at the Watt Road Environmental Laboratory

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Objectives

- Improve understanding of "real-world" mobile source evolution as a function of meteorology, geography, and traffic at unique site near Knoxville, TN with high volume of heavy-duty truck traffic (>20,000 trucks per day on Interstates 40&75).
- Understand potential impact of developing fuel, combustion, and aftertreatment technologies on air quality and, thereby, human health.

Accomplishments

- Three remote sensing techniques were deployed in two field campaigns at the I-40/75 weigh station. Ultraviolet (UV), light detection and ranging (LIDAR) and acoustic techniques measured NOx, PM, and engine parameters, respectively, to obtain emission distributions as a function of truck weight, speed, and other parameters.
- In cooperation with the Federal Highway Administration (FHWA), a project concentrating on ambient air quality near the Watt Road-I-40/75 interchange was completed. The project showed that idling trucks typically dominate the air quality near the roadway despite the large number of trucks traveling on I-40/75 per day.
- Presented results to and interacted with stakeholders at four conferences.

Future Directions

- Characterization of mobile source air toxics (MSATs) from advanced engine and aftertreatment systems.
- Measurement of MSATs at higher time resolution measurements in order to understand mobile source impacts.
- Continued deployment of the remote sensing instrumentation for evaluation of end use emissions.

Introduction

The Watt Road Environmental Laboratory (WREL) is an active real-world laboratory devoted to (1) the study of actual in-use emissions of heavy trucks and (2) defining their impact on local air quality and thereby on human health. This unique laboratory is located near Oak Ridge National Laboratory where approximately 20,000 heavy-duty trucks per day pass by an interstate interchange that also contains multiple travel center facilities. The mid-south location means that the atmospheric conditions, in particular relative humidity, more accurately reflect the climate in which 75% of the U.S. population lives than the desert southwest, where most air quality studies are performed. This real-world laboratory serves as a national resource for studies of the impact of mobile emissions on local and regional air quality and the health effects from those emissions. Because of interest in the Watt Rd. site from multiple stakeholders, there have been a variety of sponsors including the Knox Co. Municipal Planning Organization (MPO), the Federal Highway Administration (FHWA) as well as DOE.

This project, under the direction of Dr. James Eberhardt, has focused on the health effects of in-use diesel truck emissions. By combining field measurements of emissions sources with air quality, meteorological and geographical data, air quality models are developed and validated so that contributions of mobile sources to local and regional air quality can be defined. The link between mobile sources and air quality must be understood to determine the health impacts on the human population by mobile sources.

Approach

The emphasis of the Watt Road Environmental Laboratory project has been on real-world measurement of emissions and air quality. In general, the approaches involved can be categorized into three areas: (1) mobile source characterization, (2) ambient air quality characterization, and (3) simulation and understanding of source contributions to air quality. Remote sensing has enabled the mobile source characterization, and various analyzers have been employed for ambient air quality studies. The tasks for simulation and understanding of source contributions to air quality have involved multiple techniques, but in general, efforts have centered on analyzing the data obtained from remote sensing and ambient air quality studies to compare the data with models. The comparison of data and model outputs allows further interpretation of the environmental chemistry of mobile source impacts on ambient air quality; in addition, the data allows validation and databases for models. A particular focus of the analysis and modeling has been fine-scale modeling. This report will present FY 2006 results from remote sensing campaigns to characterize mobile source emissions from heavy-duty trucks.

Results

Two remote sensing field campaigns were conducted in FY 2006 to measure the emissions from heavy-duty trucks. Both campaigns were conducted at the eastbound weigh station on I-40/75 just west of Knoxville, TN. The campaign was conducted in cooperation with the Tennessee Department of Safety which operates the weigh station, and we are grateful for their support of the project. Emissions from heavy-duty trucks accelerating away from the weigh scales were measured with several remote sensing techniques. Truck weights and other general truck information were recorded as well.

The remote sensing techniques employed were ultraviolet (UV) differential adsorption spectroscopy, acoustic analysis, and LIDAR. The UV technique was deployed to measure NO emissions. The acoustic technique allowed measurement of several engine and truck operational parameters such as vehicle speed, engine speed, and turbo speed. LIDAR was employed to measure particulate matter (PM) emissions.

The UV spectroscopic technique measured NO concentration over a light beam path by measuring the absorbance of NO in the 226 nm spectral region. Essentially, the remote sensing was performed by passing a UV light beam through the air across the roadway above the height of the trucks. The UV light was actually passed across the truck lane then returned along the same path with a retroreflector mirror. The returning light was collected and analyzed with a UV spectrometer. A picture of the setup is shown in Figure 1. With this arrangement, the emissions from one truck at a time were measured. The height of the beam path above the exhaust pipe of the truck was varied in position between one and five feet above the regulation height for 18-wheeler trucks.

An example of the NO emissions as a function of time during the campaign is shown in Figure 2; here the presence of a truck pulling away from the weigh scales is noted by a yellow circle. Spikes in NO concentration occur in conjunction with the trucks accelerating away from the weigh scales, but the amount of NO and general profile vs. time varies for the trucks due to differences in truck weight, engine type, engine operation, and acceleration speed, etc. The NO emission peaks for each truck were analyzed and combined with other data obtained in the campaign for analysis.

An acoustic-based technique allowed characterization of truck engine operating parameters from data obtained by placing microphones near the truck lane. The detection equipment for the acoustic technique is simple and low cost; the strength of the technique lies in the analysis of the spectrogram which contains a wealth of information. Detailed analysis of the spectrogram for each truck allowed measurement of the engine speed and acceleration, the turbo speed and acceleration, and the vehicle speed and acceleration (via audible indicators on the road). An example spectrogram is shown in Figure 3; here the higher frequency curves represent turbo speed and the lower frequency streaks of data represent engine speed. Based

FIGURE 1. Picture of the UV remote sensing technique being deployed during a field campaign at the I-40/75 weigh station.

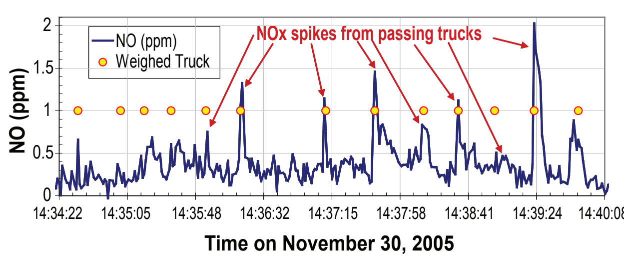

FIGURE 2. Example UV remote sensing data from a weigh station field campaign showing NOx emissions as a function of time. Yellow circles note occurrences of passing trucks.

on assumptions for engine displacement and number of cylinders, a mass flow of exhaust from the truck was computed; this mass flow was combined with the NO concentration data to determine NO mass emissions.

The combined UV NO measurements and acoustic truck operational parameter measurements allowed a database of truck emissions as a function of several parameters to be generated. An example of some of the data is shown in Figure 4; peak NOx emissions in g/minute are shown as a function of truck weight. The distribution of truck emissions obtained provides a database for models; in particular, emissions data from trucks with weights above 60,000 pounds is in relatively short supply since heavy-duty truck dynamometer emission measurements become difficult at higher truck weights.

The LIDAR technique measures PM concentration and physical location based on the backscattered light intensity. A laser diode of similar power to a common laser pointer was the light source for the LIDAR system. The laser diode was modulated at frequencies of 10-200 MHz and launched into the air above the truck exhaust port at the same height as the UV technique beam path. The backscatter laser light was detected by a collection telescope and measured with a photomultiplier tube (PMT) detector. Lock-in amplification of the modulated light and a narrow bandpass filter on the PMT allowed sensitive detection of the backscattered light in the presence of bright daylight. Analysis of the signal magnitude and phase shift for a set of different modulation frequencies results in a plot of PM concentration vs. position. The details of the analysis technique and the relationship between the detector signal-to-noise and PM concentration are given by M. L. Simpson *et al* [1]. To validate the technique, LIDAR measurements of PM from a light-duty diesel vehicle were made during a chassis dynamometer test and compared with results from a scanning mobility particle sizer (SMPS). A schematic of the LIDAR setup is shown in Figure 5. ORNL worked closely with Galt Technologies, a small company specializing in optics and spectroscopic applications, to develop the LIDAR system.

The field campaigns at the weigh station in FY 2006 represented the first deployment for the novel LIDAR technique in this application; thus, the results gave valuable insight into the feasibility of LIDAR for PM remote sensing. Example data from the campaign is shown in Figure 6. The PM concentration signal peaked above noise levels for only a small percentage of the trucks that were remotely sensed. The large signals observed with the LIDAR technique were due to trucks with soot plumes visible to the naked eye. Moderate size peaks are indicative of PM emissions below the visibility

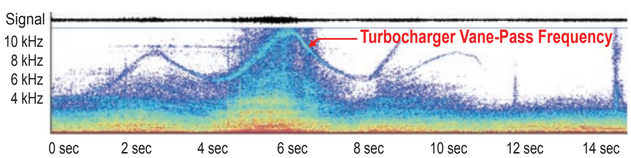

FIGURE 3. Acoustic spectrogram of a heavy-duty truck accelerating away from the weigh scales.

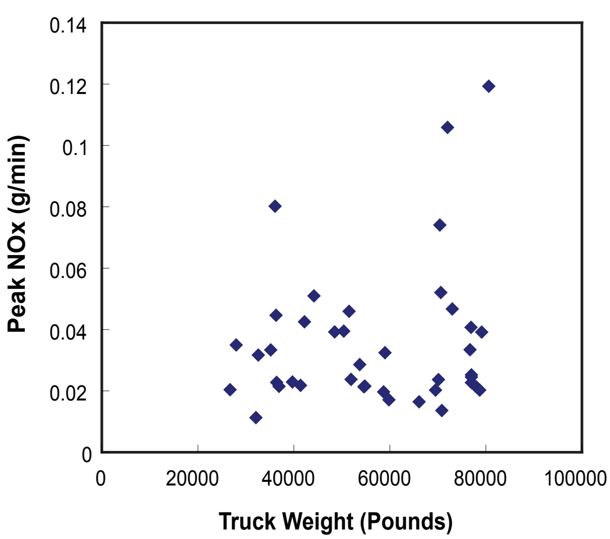

FIGURE 4. Distribution of NOx emissions as a function of truck weight.

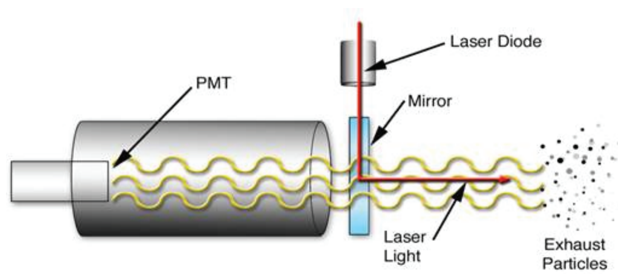

FIGURE 5. Schematic of the LIDAR technique for PM remote sensing.

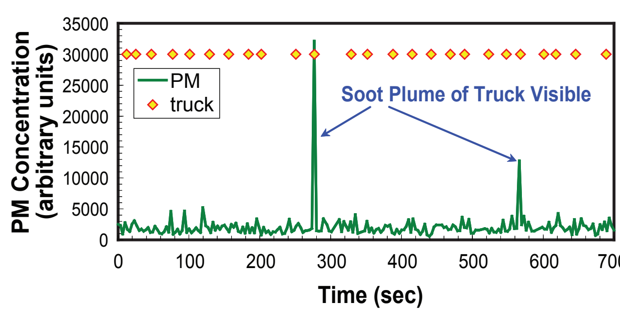

FIGURE 6. Example PM remote sensing data obtained with the LIDAR technique during a weigh station field campaign. Yellow diamonds note occurrences of passing trucks.

threshold. During these initial studies, measurements of PM emissions from heavy-duty trucks with a LIDAR technique were demonstrated for the first time. The results indicate that the technique is feasible, but improvements must be made in the dynamic range of the instrument to be capable of measuring of low PM emission trucks.

Conclusions

Remote sensing techniques have been deployed in the field to measure emissions from heavy-duty trucks at a weigh station on Interstate 40/75. UV spectroscopic measurements of NO emissions were coupled with truck operational data characterized with an acoustic analysis technique to determine mass-based emissions in a non-intrusive manner. The distribution of truck emissions obtained provides a database for models; in particular, the emissions as a function of truck weight at >60,000 pounds are of value. The first deployment of a LIDAR technique for PM measurement from heavy-duty trucks led to a demonstration of the feasibility of the technique and a definition of needed improvements in the technique (specifically dynamic range).

References

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FY 2006 Publications/Presentations

1. Marc Simpson *et al,* "Intensity-modulated, stepped frequency CW lidar for distributed aerosol and hard target measurements," *Applied Optics*, **44**, pp.7210-7217. 2005.

2. Terry Miller *et al*, "Idle Truck Emissions Impact on Air Quality at the Watt Road Environmental Laboratory", Poster presentation at the *2006 Transportation Research Board Meeting* in Washington, DC (January 2006).

3. Jim Parks *et al*, "Impact of Idling Trucks on Nearby Ambient Air Quality: A Study of the Watt Road-I-40/75 Interchange Corridor", Poster presentation at the *16th CRC On-Road Vehicle Emissions Workshop* on March 28-30, 2006 in San Diego, CA.

4. Jim Parks *et al*, "Remote Sensing Instrumentation for Mass-Based NOx and PM Emissions from Heavy-Duty Trucks", Poster presentation at the *16th CRC On-Road Vehicle Emissions Workshop* on March 28-30, 2006 in San Diego, CA

5. Terry Miller *et al*, "Air Monitoring at a PM2.5 Hot Spot Caused by Diesel Truck Emissions", AWMA Paper No. 06-A-290-AWMA, *Air and Waste Management (AWMA) Annual Conference* (June 2006, New Orleans, LA).

6. Jim Parks *et al*, "Mobile Source Air Toxics at the Watt Road Environmental Laboratory" Poster presentation at the *12th Diesel Engine-Efficiency and Emissions Research (DEER) Conference* on August 20-24, 2006, in Detroit, Michigan.

VI.2 Weekend Ozone Effect Studies

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Objectives

- Ambient ozone (O_3) levels in southern California are about 50% higher on Sundays than on mid-week days. The objective of this study is to identify whether this phenomenon exists in other parts of the U.S. that experience violations of the national ambient air quality standard for ozone.
- This project characterized day-of-week differences in:
  - ambient concentrations of primary pollutants, including nitric oxide (NO), oxides of nitrogen (NOx), speciated volatile organic compounds (VOCs), carbon monoxide (CO), and black carbon (BC);
  - ambient concentrations of ozone and particulate matter (PM) nitrate;
  - responses of ozone and PM nitrate concentrations to changes in the ambient concentrations of primary pollutants.

The principal focus is on the gas-phase species NO, NOx, CO, VOCs, ozone, and PM nitrate.

Accomplishments

- Completed analysis of 1998-2002 or 2003 ambient ozone precursor and ozone data from many U.S. monitoring locations.
- Wrote and sent draft report to air quality staff in the regions/states studied for technical comments and peer review. The report was sent to the states of Arizona, Texas, and Colorado; Northeast States for Coordinated Air Use Management; Mid-Atlantic Regional Air Management Association; and the Lake Michigan Air Directors Consortium.
- Submitted paper summarizing study results to the *Journal of the Air & Waste Management Association* for peer review and subsequent publication.

Future Directions

Began proximate ozone modeling study in southeast Michigan region in November 2005, in collaboration with state and local government groups and industry representatives in that area. This project will be completed in FY 2007.

Introduction

The occurrence of generally comparable – or even higher – ambient concentrations of ozone on Saturdays and Sundays than on other days of the week is commonly known as the "weekend effect for ozone," or, simply, the "weekend effect." Because emissions of ozone precursors, including volatile organic compounds (VOC), oxides of nitrogen (NOx), and carbon monoxide (CO), are lower on weekends than on weekdays, the weekend ozone effect is counterintuitive. To provide a better understanding of the implications of the weekend effect, a thorough analysis of weekday and weekend precursor concentrations and composition is needed. Observed in air quality data from the mid-1960s and early 1970s, the weekend effect in California recently has been studied at length. Fujita *et al.* [1] and Lawson [2] conclude that weekend reductions of NO emissions are the most important factor leading to higher weekend ozone, allowing ozone to accumulate earlier in the day and to reach higher concentrations compared with weekdays, and that proposed alternative hypotheses are not supported by ambient data and do not explain the weekend effect in southern California. In contrast, Croes *et al*. [3] considered the available air quality data and photochemical models inadequate to conclusively determine the causes of the weekend ozone effect in southern California.

This study provides further analysis of the weekend ozone effect in areas of the United States outside California. The weekend ozone effect provides air quality managers and scientists the opportunity to make empirical observations of the kind that are so important in testing hypotheses by asking "What if" questions regarding emission reductions that are needed to reduce ambient O_3 levels. Seldom are such opportunities available using ambient data regarding how the atmosphere actually responds to changes in emissions because most air quality regulations provide small incremental benefits and take effect over long periods of time.

Approach

The analyses were carried out at ambient air quality monitoring sites in ozone problem areas in 23 states: the Northeast corridor (including the New York-Northern New Jersey-Long Island, Philadelphia-Wilmington-Trenton, and Baltimore-Washington metropolitan areas); the Gulf of Mexico coast (including the Houston-Galveston-Brazoria and Beaumont-Port Arthur and Baton Rouge metropolitan areas); Dallas-Fort Worth; Phoenix; and the Colorado Front Range area (including Denver, Colorado Springs, Boulder, and Fort Collins). Previous work carried out for the Atlanta area and for six Midwestern states (Ohio, Michigan, Indiana, Illinois, Missouri, and Wisconsin) was also incorporated in this study. The time period analyzed was 1998 through 2002 (or 2003 where data were available).

Results

Ambient air quality monitoring data were analyzed to evaluate the differences between mean day-of-week ambient concentrations of ozone precursors (NO, NOx, CO, and VOC) using 1998-2003 ambient air-pollutant data from monitoring sites in 23 states in New England, the Midwest, the mid-Atlantic, and isolated urban areas in the western and southern U.S. During the months of March through October, median decreases of NO, NOx, and CO at 6 a.m. Sundays compared with 6 a.m. Wednesdays were 71, 58, and 42 percent, respectively, as shown in Figure 1. The median declines of NO, NOx, and CO at 12 noon Sundays compared with 12 noon Wednesdays were 46, 40, and 12 percent, respectively. The Wednesday/Sunday PM nitrate median decline at 69 sites was 2.6%, with the difference statistically significant at only one location.

The large reductions in ambient concentrations of ozone precursors on weekends did not produce meaningful reductions of ambient ozone levels. To the contrary, median 1-hour and 8-hour ozone daily maxima on Sundays increased by 1 and 3 percent, respectively, from their mean peak levels on Wednesdays. When restricted to high-ozone days, the median 8-hour ozone daily maxima were unchanged on Sundays compared with Wednesdays, while the median 1-hour peak ozone levels decreased by 2 percent from Wednesdays to Sundays.

The changes observed in weekend ozone levels relative to weekday concentrations were the net result of weekday/weekend differences in a number of processes affecting ozone formation, including emissions, ozone transport, and local ozone formation:

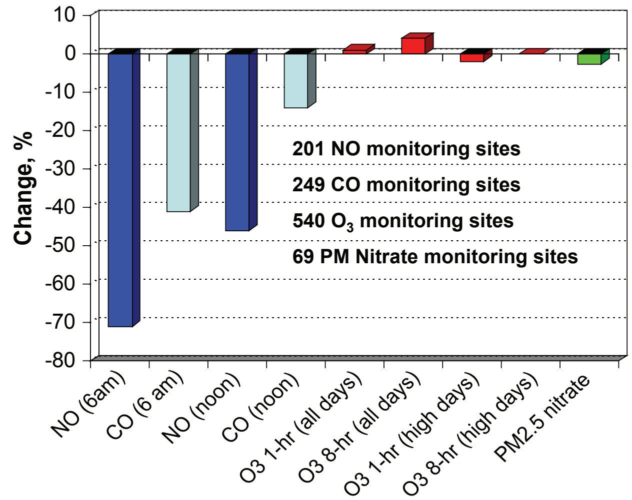

FIGURE 1. Median ambient pollutant concentration changes from Wednesdays to Sundays. Results are shown for morning and noon concentrations of NO, NOx, and CO (March – October), and for 1-hour and 8-hour peak ozone concentrations on all ozone-season days (March – October) and on high-ozone days (top three peak days per day of week per year). PM nitrate levels are obtained from 24-hour sampling periods. Negative values represent higher Wednesday concentrations than on Sundays; positive values indicate that concentrations were higher on Sundays than on Wednesdays. The time period analyzed was 1998 through 2003.

- Ozone accumulation began about one hour earlier on Sundays than on Wednesdays. Ozone can accumulate only after NO concentrations fall to low levels.
- Regional ozone levels contributed the majority of the peak ozone concentrations measured downwind of four urban areas where ozone transport was studied in detail (Atlanta, Chicago, Dallas-Fort Worth, and Phoenix).
- Statistically significant day-of-week differences in ozone levels did not occur at either upwind or downwind locations. Ozone concentrations averaged about 5 to 10 ppbv lower on Sundays than on Wednesdays upwind of Atlanta, Chicago, and Phoenix; none of these differences were statistically significant, and no day-of-week transport differences were observed for Dallas-Fort Worth. Data from the northeastern U.S. are depicted in Figure 2.

Conclusions

The weekend ozone effect provides a natural experiment for understanding how urban ozone and PM nitrate respond to large reductions in ozone precursor emissions. The data suggest that, for ozone problem areas in and downwind of urban U.S. locations, VOC emission reductions reduce ozone, while NOx emission reductions increase ambient ozone levels. Despite large weekend reductions of NO emissions, there is little

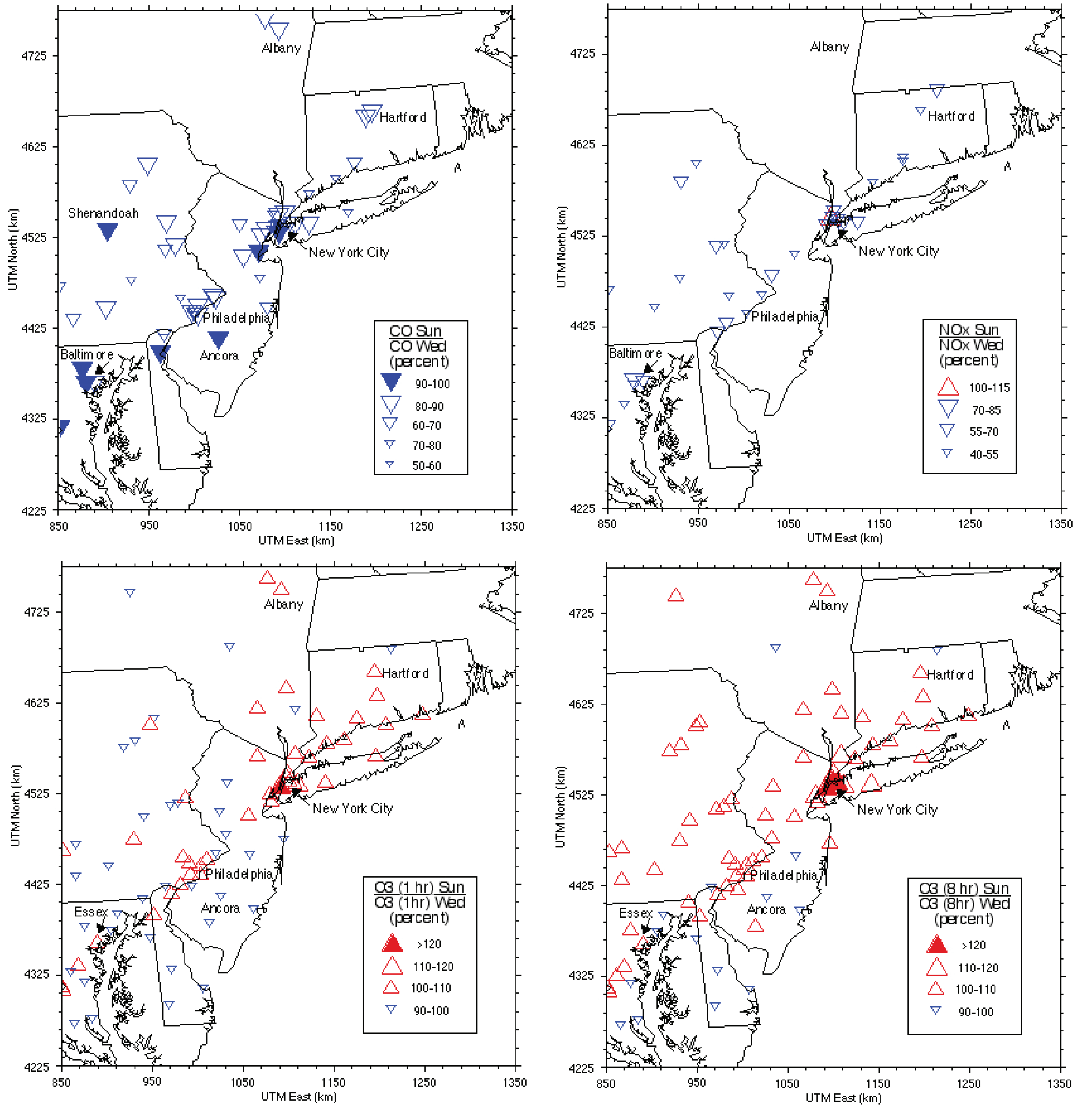

FIGURE 2. Geographical comparisons of mean Sunday to mean Wednesday daytime (6 a.m. through 3 p.m.) concentrations of CO and NOx and mean peak daily one-hour and eight-hour ozone in the Northeast. The differences were determined from all days, March-October 1998-2003.

change in PM nitrate concentrations on weekends. The findings from this study may require a rethinking of present control strategies to reduce urban ozone and PM nitrate exposure and ozone transported downwind of urban locations in the U.S.

We interpret the observed absence of differences between weekday and weekend ozone levels, in combination with significantly lower ambient levels of NOx, as an indication that ozone formation in our study areas is VOC-limited. Our analyses of weekday/weekend differences in ozone precursor emissions show that different emission reductions of ozone precursors than normally take place on weekends will be required before significant reductions in ambient ozone can be achieved. Yet, in relative magnitudes, the emission changes that are projected to occur between now and 2010 more closely resemble the weekend reductions that we report here than the historical emissions trends, in which VOC emission reductions have exceeded reductions of NOx emissions on a relative basis. Our results call into question the rates of future progress in reducing peak ozone levels in major metropolitan areas in the United States.

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VI.3 Health Impacts: Respiratory Response

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Objectives

- Define relative health hazards of competing existing power technologies
- Determine contributions of different fractions of emissions to health hazards
- Evaluate health benefits of emission reduction technologies
- Evaluate emerging technologies for unanticipated health hazards

Accomplishments

- Developed technology to generate nanoparticle aerosols from engine crankcase oil
- Discovered that used diesel crankcase oil nanoparticles have low lung toxicity, but may suppress systemic immune responses
- Completed a comprehensive study of the effects of repeated inhalation exposure to laboratory-generated gasoline emissions
- Discovered that non-particulate emissions from gasoline engines can cause vascular changes in a mouse model of atherosclerosis

Future Directions

- Complete work to clarify health importance of nanoparticle (< 50 nm) components of diesel emissions, and relative importance of black carbon- vs non-solid condensate-based particles
- Complete study testing the hypothesis that artifactual formation of nitro-aromatic compounds on filter samples is responsible for much of the mutagenicity of diesel particle extracts
- Complete analysis and publication of results from study of gasoline emissions, and comparison to effects of diesel emissions

Introduction

This project is the biological evaluation component of the Health Impacts Program, and supports meeting DOE technical targets by: 1) placing in proper context the health hazards of engine emissions relative to other air quality hazards, and the relative hazards of emissions from different fuel, engine, and emission reduction technologies; 2) determining the key toxic components among the hundreds of components of vehicle emissions; and 3) evaluating emissions from emerging technologies to avoid unintended health consequences prior to commercialization and demonstrate that reductions in emissions are paralleled by reductions in health hazards. This project addresses potentially technology-limiting issues that are not addressed in other DOE or non-DOE programs. This project complements other Health Impacts projects that are characterizing emissions, determining the impact of emissions on air quality, and conducting long-term health studies of 2007-2010-compliant diesel systems.

Approach

This project employs a four-tactic strategy to placing the health hazards of vehicle emissions in proper context, identifying the key toxic components, and evaluating new technologies. The first tactic involves laboratory evaluations of emission samples collected from vehicles and environments elsewhere. The second tactic involves animal studies of inhaled whole emissions, separated fractions of emissions, and specialized aerosols generated in the laboratory. Tissue oxidative stress, lung inflammation, cardiovascular effects, and immune responses are evaluated. The third tactic employs multivariate and univariate statistical analyses of data on composition vs. biological response to identify components that cause adverse effects. The fourth tactic involves working with DOE program managers and industry partners to identify advanced technologies having the greatest near-term commercialization potential, and using the above approaches to evaluate those technologies for unintended health consequences.

Work during the past year focused primarily on two issues pertaining to current technologies in order to clarify issues that must be addressed for emerging technologies: 1) the health importance of organic condensate nanoparticles; and 2) the health effects of particulate and non-particulate components of gasoline engine emissions. There has been considerable speculation about the health effects of so-called “nanoparticles” (under 50 nm diameter) from combustion and other sources, and the non-solid condensate species are hypothesized by some to be of concern for future emissions. Such particles have always existed in engine emissions, but no technology has been successful for separating condensate particles from other emissions for health studies. Because crankcase oil is the primary source of this material, this project undertook to develop a method for generating nano-sized aerosols from crankcase oil in the laboratory. Developmental work led to the successful generation of aerosols by a vaporization-condensation method followed by carefully controlled cooling and dilution to produce suitably small particles.

Despite the overwhelming attention to the potential health hazards of diesel emissions, there has been little evaluation of gasoline emissions. Because gasoline emissions contain a greater proportion of mass in the vapor phase, parsing the effects of particulate vs. non-particulate effects can provide important insights into the physical-chemical species responsible for effects of whole emissions. This project collaborated with other federal and non-federal partners (including several major large engine and fuel providers) to conduct a detailed study of the respiratory and cardiovascular effects of inhaled emissions from "fleet average" light-duty gasoline engines. Of special interest in view of recent epidemiological results linking traffic emissions to cardiac mortality and morbidity was the inclusion of an animal model of atherosclerosis and other vascular effects.

Much of the concern for carcinogenicity of diesel emissions stems from the bacterial agenicity of solvent extracts of material collected on filters. There is evidence that the passage of nitrogen oxides through filters during collection increases the formation of nitroaromatic compounds that drive much of the mutagenicity. To determine the extent to which the mutagenicity of diesel particles might result from this artifact, this project began testing the mutagenicity of material collected with and without removal of oxidizing gases by denuders.

Results

The many detailed results of this project are communicated in numerous technical presentations and peer-reviewed scientific publications (FY 2006 products listed below, full listing available on request). Only example key results are summarized here.

After developing and validating the technology to generate nanoparticles, a study of the health implications of oil condensate began this year with an inhalation exposure of mice to an aerosol generated from used crankcase oil from a 2000 model Cummins ISB 5.9 liter 6-cylinder turbocharged engine operated on the EPA heavy-duty certification cycle. The oil was Shell Rotella-T® 15W-40, a diesel lube oil with a high market share. Control mice were exposed to clean air. This was the first of a planned series of exposures to aerosols from new and used oil from diesel and gasoline engines. Mice were exposed six hours/day for seven days to an aerosol of 17 nm particles at a mass concentration of 300 $\mu g/m^3$ and a particle number count of 1 million/cc. Health evaluations included lung inflammation, lung tissue oxidative stress, and the responses of systemic immune cells (spleen lymphocytes).

The exposure did not cause evidence of lung inflammation, either by histopathology or cell and biochemical markers in airway fluid. The only effect observed in the lung was an increase in heme oxygenase-1 in lung tissue, a marker of oxidative stress that is increased by many inhaled pollutants. The exposure caused two indications of a mild disturbance of the systemic (outside the lung) immune system. In a systemic immune response, different types of lymphocytes in the spleen and other lymphoid tissues must divide to produce more cells, and also produce antibody to foreign materials. Two types of lymphocytes, T and B cells, were removed from the spleen and treated with materials that stimulate cell division. In condensate-exposed animals, the cell division responses of both cell types were modestly, but significantly reduced (Figure 1). The T lymphocytes were also challenged with a foreign protein to test for the ability to form antibody, which was also significantly reduced by the exposure (Figure 2).

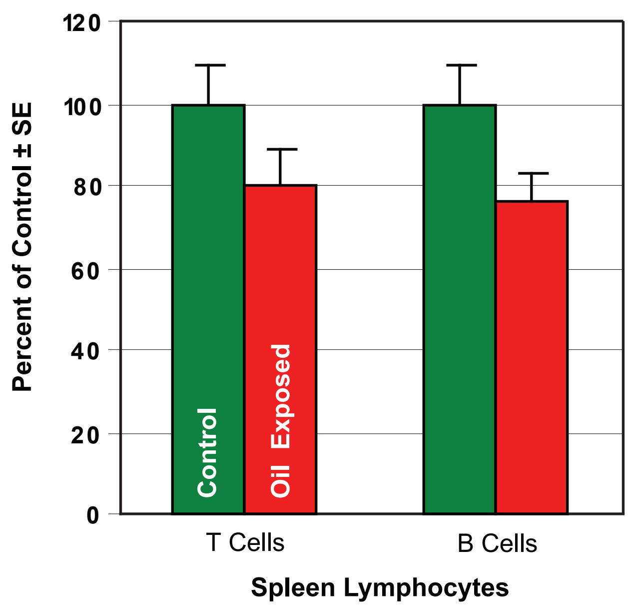

FIGURE 1. Oil nanoparticle exposure-related reduction in response of T and B lymphocytes from the spleen to a proliferative stimulus.

The study of oil condensate nanoparticle aerosols is still underway. The initial finding described above is being compared of the effects of unused diesel lube oil from the same lot, and both new and used gasoline lube oil. We will also explore lower exposures to determine if realistic environmental exposures present a hazard. Parallel studies at Lovelace funded from other sources are providing additional comparisons by evaluating carbon fullerene and nanotube particles.

During the past year, a jointly-funded comprehensive laboratory study of the health hazards of repeated inhalation exposure to "fleet average" gasoline emissions was completed. Animals were exposed daily for up to six months to emissions from 1996 model General Motors 4.3 liter V-6 engines burning national average regular unleaded gasoline and operated on the California Unified Driving Cycle. Animals were exposed to clean air as controls, to whole emissions diluted to particle mass concentrations of 7, 30, or 60 μg/m^3, or to the highest concentration with the particles removed by filtration (particle mass at background level of 2 μg/m^3). Many different respiratory and cardiovascular health indicators were measured, in accordance with a standardized protocol used in companion studies of diesel emissions and wood smoke (www.nercenter.org).

Of special interest concerning both current and future emissions, this study demonstrated for the first time that some health effects were driven primarily by particles, some by the non-particle gases and vapors, and some by both. A concentration-related reduction in the resistance to lung infection with bacteria, for example, was shown to be caused by both fractions, because the effect was reduced approximately by half with particles removed. The new finding most relevant to recent epidemiological results was that non-particle emissions were primarily responsible for changes observed in blood vessels associated with the heart. These changes were of a type that would promote the development of atherosclerosis – the root cause of most myocardial infarctions. A genetic strain of mouse used by cardiologists to study atherosclerosis was exposed for seven weeks, followed by measurement of several indicators of stress and damage in the aorta adjacent to the heart. The results for endothelin-1, a marker of vascular stress, are shown in Figure 3; similar results were shown by other indicators of vascular stress and damage. Endothelin-1 was increased slightly at the lower exposure levels, and markedly at the highest level. The finding of no significant difference between responses to filtered and unfiltered emissions at the high level indicated that the non-particle gas and vapor phases were responsible for the effect. Work is underway to determine the specific gases or organic vapors responsible for the effects, which will point toward emissions to target in evaluating emerging technologies.

Conclusions

Emissions from all technologies evaluated to date are attended by potential adverse health impacts of some nature and degree that need to be understood and mitigated as new technologies develop. Evidence to date indicates that attention to crankcase oil emissions is warranted, and that emissions of non-solid organic condensate nanoparticles should be minimized.

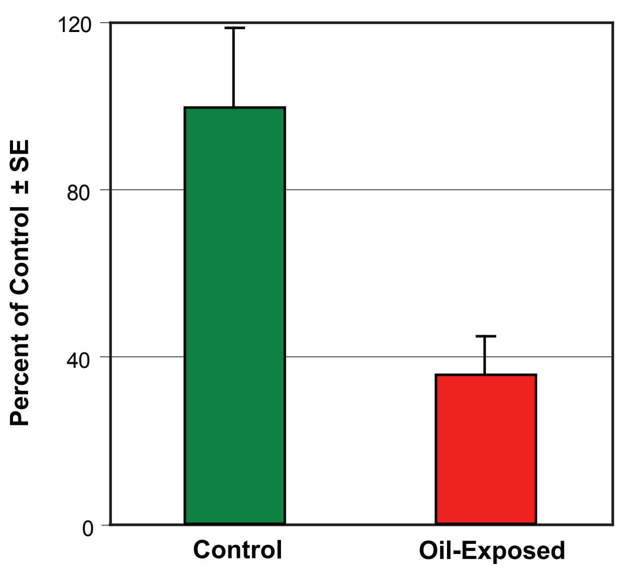

FIGURE 2. Oil nanoparticle exposure-related reduction in ability of spleen T lymphocytes to produce antibody to a foreign protein.

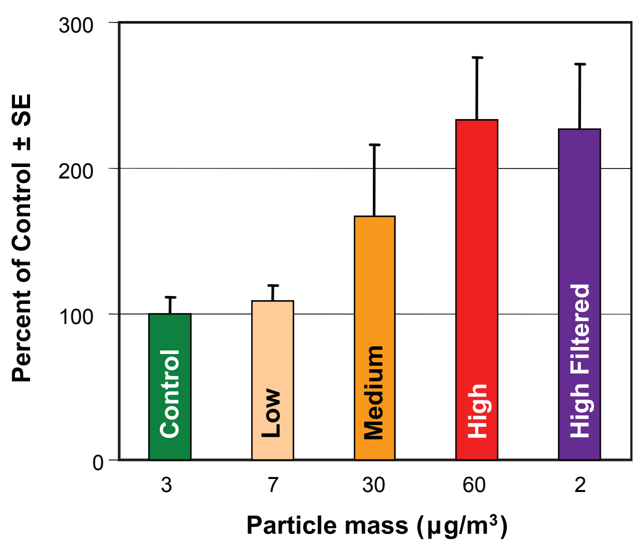

FIGURE 3. Exposure-related increase in endothelin-1in aorta of mice exposed for seven weeks to clean air (control), one of three concentrations of whole gasoline emissions, or to the highest concentration with particles removed by filtration.

Evidence also suggests that the non-particle components of emissions require continued attention. Fortunately, the fuel-trap-catalyst technologies required to meet 2010 on-road diesel emission standards will markedly reduce emissions of the organic vapors that condense to form nanoparticles, and constitute the vapor phase of emissions. After completion of the work described above, the project will shift completely to the evaluation of emissions from emerging fuel, engine, lubrication, and after-treatment technologies, with priorities based on the likelihood of commercialization.

FY2006 Publications/Presentations

Publications

1. Mauderly, J.L. and E. Garshick: Diesel Exhaust. Chapter 17 in: *Environmental Toxicants*, Lippmann, Ed., Wiley, New York (submitted).

2. McDonald, J.D., M.D. Reed, E.G. Barrett, M.J. Campen, JC. Seagrave, and J.L. Mauderly: Health Effects of Inhaled Gasoline Engine Emissions. *Inhal. Toxicol.* (in press).

3. Seagrave, JC., S. Dunaway, P. Hayden, J.D. McDonald, C. Stidley, and J.L. Mauderly: Responses of Differentiated Primary Human Lung Epithelial Cells to Exposure to Diesel Exhaust at an Air-Liquid Interface. *Exper. Lung Res.* (in press).

4. McDonald, J. D. and J. Costanzo: Particle Size and Organic Phase Distribution of Four Dilutions of Diesel Engine Emissions. *Atmospheric Environ.* (in press).

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7. Chow, J.C., J. G. Watson, J.L. Mauderly, D.L. Costa, R.E. Wyzga, S. Vedal, G.M. Hidy, S.L. Altshuler, D. Marrack, J.M. Heuss, G.T. Wolff, C. A. Pope, and D.W. Dockery: Health Effects of Fine Particulate Matter Air Pollution: Lines that Connect. *J. Air Waste Man.* 56:1368-1380.

8. Mauderly, J.L.: Health Hazards of Complex Environmental Exposures: A Difficult Challenge to Inhalation Toxicology. *Inhal. Toxicol*. 18: 137-141, 2006.

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1. Mauderly, J.L.: Non-Cancer Health Effects. Conference on Diesel Exhaust: Partnering with Stakeholders to Reduce Emissions. Air & Waste Management Association, Chicago, IL, October 7, 2005.

2. McDonald, J.D., K. Harrod, JC. Seagrave, S.K. Seilkop, and J.L. Mauderly: Effects of Low Sulfur Fuel and a Catalyzed Particle Trap on the Composition and Toxicity of Diesel Emissions. Conference on Diesel Exhaust: Partnering with Stakeholders to Reduce Emissions. Air & Waste Management Association, Chicago, IL, October 7, 2005.

3. Mauderly, J.L.: Recent Developments in Diesel Emissions: Impact on Health Effects and Risk Assessment (introduction to symposium). 31^{st} Annual Winter Toxicology Forum, Washington, DC, January 31, 2006.

4. McDonald, J.D.: Recent Findings with Engine Emission Components and REelation to Older Engine Emissions. 31^{st} Annual Winter Toxicology Forum, Washington, DC, January 31, 2006.

5. Mauderly, J.L., and J.D. McDonald: Health Effects of Gasoline Engine Emissions. Japan Automobile Manufacturers Association, Tokyo, February 8, 2006.

6. Mauderly, J.L.: How Particles Affect Health. American Association for Advancement of Science, Annual Meeting, St. Louis, MO, February 19, 2006.

7. Mauderly, J.L.: Health Effects of Controlled Exposure to Diesel Emissions, Conference on Air Quality and Health, British Columbia Lung Association, Vancouver, BC, March 29, 2006.

8. McDonald, J. D., JC. Seagrave, J. L. Mauderly, and B. Zielinska: Approaches to Characterizing the Toxicity of Atmospheric Transformations of Diesel and Coal Combustion Emissions. Society of Toxicology Annual Meeting, San Diego, CA, March 6, 2006.

9. Reed, M. D., J. A. and Berger: Real Time RT-PCR Assessment of Clearance of Respiratory Syncytial Virus Altered by Exposure to Diesel Exhaust and Hardwood Smoke. Society of Toxicology Annual Meeting, San Diego, CA, March 6, 2006.

10. Seagrave, JC., S. Dunaway, P. Hayden, J. D. McDonald, C. Stidley, and J. L. Mauderly: Responses of Differentiated Primary Human Lung Epithelial Cells to Exposure to Diesel Exhaust at an Air-Liquid Interface. Society of Toxicology Annual Meeting, San Diego, CA, March 7, 2006.

11. Campen, M.J., T. Knuckles, and A.K. Lund: Diesel-Induced Venous Congestion and Vasoconstriction: A Potential Link to Heart Failure Symptoms. HEI Annual Conference, San Francisco, CA, April 10, 2006.

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13. Mauderly, J.L.: Commentary on Health Effects of Fine Particulate Air Pollution: Lines that Connect. Annual Meeting of the Air & Waste Management Association, New Orleans. LA, June 21, 2006.

14. Mauderly, J.L.: Strategies for Disentangling the Causal Components of PM and Contributions of PM and Co-Pollutants, Annual Meeting of the Air & Waste Management Association, New Orleans. LA, June 23, 2006.

15. McDonald, J.D., JC. Seagrave, L. Mitchell, A. Gigliotti, and J.L. Mauderly: Pulmonary and Systemic Immune Response to Inhaled Oil Condensates. 12th Diesel Engine-Efficiency and Emissions Research Conference, Detroit, MI. August 23, 2006.

VI.4 The Advanced Collaborative Emissions Study (ACES)

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Objectives

- **Phase 1:** Extensive emissions characterization (at an existing emissions characterization facility) of four production-intent heavy-duty diesel engine and control systems designed to meet 2007 standards for particulate matter (PM) and nitrogen oxides (NOx). One engine/aftertreatment system will be selected for health testing.
- **Phase 2:** Extensive emissions characterization of a group of production-intent engine and control systems meeting the 2010 standards (including more advanced NOx controls to meet the more stringent 2010 NOx standards).
- **Phase 3:** One selected 2007-compliant engine will be installed in a specially-designed emissions generation and animal exposure facility (Phase 3A) and used in chronic and shorter-term health effects studies to form the basis of the ACES safety assessment (Phases 3B and 3C). This will include periodic emissions characterization during both a core 24-month chronic bioassay of cancer endpoints and shorter term biological screening assays in rats and mice similar to the standard National Toxicology Program (NTP) bioassay (Phase 3B) as well as emission characterization during a set of shorter animal exposures and biological screening using accepted toxicological tests after the end of the chronic bioassay (Phase 3C). (NOTE: Only the emissions characterization and shorter-term biological screening activities at the beginning and during Phase 3 are components of the DOE ACES contract.)

Accomplishments

- Conducted site visits to potential facilities in Albuquerque, NM, Oak Ridge, TN, and Richland, WA (November 2005).
- Issued a Request for Proposals for Phase 1 (and 2) emissions characterization (CRC February 2006, see *www.crcao.com*) [1].
- Issued a Competitive Solicitation for Phase 3 emissions and health effects assessment, including RFP 06-1 for the emissions characterization and chronic bioassay and RFA 06-2 for shorter term biological screening studies. (HEI May 2006, see *www.healtheffects.org/funding.htm)* [2].
- Reviewed six proposals for Phase 1 and requested revised proposals from the top two contenders (May/June 2006).
- Reviewed two revised proposals for Phase 1 (July 2006).
- Selected Southwest Research Institute (SwRI) to conduct emissions characterization in Phase 1 (August 2006).
- Reviewed one proposal for Phase 3A and B, the core emissions characterization and chronic bioassay, from the Lovelace Respiratory Research Institute (LRRI) and determined that it was responsive to the RFP (August/September 2006).
- Finalized protocols and methods for emissions characterization to be performed in Phase 1 and initiated contract negotiations with SwRI (September/October 2006).
- Discussed details of facility development, emissions characterization, and health effects assessment for Phase 3 with the LRRI principal investigator and the ACES HEI Oversight Committee, specifically regarding cost savings options (September 2006).
- Finalized dates for delivery of test engines to SwRI and degreening procedures to be performed by the engine manufacturers (September 2006).
- Discussed composition of fuel and lubricants and delivery to SwRI for January 2007 (September 2006).
- Planned meetings with the ACES Oversight, Advisory and Steering Committees regarding finalization of emissions generation and characterization, health effects assessment, and cost savings options for Phase 3, and to finalize financial commitments (September 2006).
- Received initial letters of intent for shorter term biological screening studies during Phase 3B (September/October 2006).

Future Directions

Phase 1

- Finalize the contract with SwRI and start preparation of the engine testing facility for Phase 1 (Fall 2006).
- Select fuel and lubricant suppliers and arrange for delivery to both SwRI and LRRI (Fall 2006).
- Start emissions characterization work in Phase 1 (Winter 2007).

Phase 3

- Review cost and project options for emissions characterization and health effects assessment in Phase 3 through meetings with the ACES Oversight, Advisory and Steering Committees; finalize financial commitments (Fall 2006).
- Assuming adequate cost reductions, begin contract negotiations with LRRI (Fall 2006).
- Initiate Phase 3 (Spring 2007).
- Solicit and select shorter term biological screening study contractors for Phase 3B (Spring 2007).

Introduction

The Advanced Collaborative Emissions Study (ACES) is a cooperative, multi-party effort to characterize the emissions and assess the safety of advanced heavy-heavy duty diesel engine and aftertreatment systems and fuels designed to meet the 2007 and 2010 emissions standards for PM and NOx. The ACES project is being carried out by the Health Effects Institute (HEI; contractor) and the Coordinating Research Council (CRC; subcontractor). It is utilizing established emissions characterization and toxicological test methods to assess the overall safety of production-intent engine and control technology combinations that will be introduced into the market during the 2007-2010 time period. This is in direct response to calls in the U.S. Environmental Protection Agency Health Assessment Document for Diesel Engine Exhaust [3] for assessment and reconsideration of diesel emissions and health risk with the advent of new cleaner technologies.

The characterization of emissions from representative, production-intent advanced compression ignition (CI) engine systems will include comprehensive analyses of the gaseous and particulate material, especially those species that have been identified as having potential health significance. The core toxicological study will include detailed emissions characterization at its inception, and periodically throughout a two-year chronic inhalation bioassay similar to the standard National Toxicology Program (NTP) bioassay utilizing two rodent species. Other specific shorter-term biological screening studies also will be undertaken, informed by the emission characterization information, to evaluate these engine systems with respect to carefully selected respiratory, immunologic, and other effects for which there are accepted toxicologic tests. It is anticipated that these emissions characterization and health effects studies will assess the safety of these advanced CI engine systems, will identify and assess any unforeseen changes in the emissions as a result of the technology changes, and will contribute to the development of a database to inform future assessments of these advanced engine and control systems.

Approach

Experimental work under ACES will be performed in three phases, as outlined in the Objectives. Detailed emissions characterization (Phases 1 and 2) will be performed by an existing engine laboratory that meets the U.S. Environmental Protection Agency specifications for 2007 and 2010 engine testing. In Phase 1, emissions from four 2007-compliant engine/control systems will be characterized. One engine will be selected for health testing in Phase 3. In Phase 2, emissions from four 2010-compliant engine/control systems will be characterized. In Phase 3, one selected 2007-compliant engine/control system will be installed in a specially designed emission generation facility connected to a health testing facility to conduct a chronic inhalation bioassay and shorter term biological screening in rats and mice. During the 2-year bioassay, emissions will be characterized at regular intervals throughout the testing.

The emissions characterization work will be overseen by the subcontractor (CRC) and its technological panels. The health effects assessment will be overseen by HEI and its ACES Oversight Committee. Set-up of the emission generation facility at the health effects testing facility (for Phase 3) and establishment of periodic emission characterization throughout Phase 3 will be done with input from the team of investigators selected to conduct emissions characterization in Phase 1 and CRC.

Results

At this time, the engine facility to perform emissions characterization in Phase 1 (and 2) has been selected. Contract negotiations are currently underway. The emissions characterization and health testing facility for conduct of Phase 3 has also been identified. Negotiations are underway to finalize the feasibility set-up, emissions characterization, and health assessment plans to keep them within the available funds by considering various cost saving options.

Conclusions

By identifying the teams for emissions characterization and core chronic bioassay we have made substantial progress towards the implementation of the project. Furthermore, the emissions characterization work for Phase 1 is being finalized in order to be ready to start the work upon delivery of the engines to SwRI early in 2007. Final negotiations for emissions characterization and health effects assessment in Phase 3 are underway.

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1. Coordinating Research Council. February 2006. Request for Proposals: Advanced Collaborative Emissions Study (ACES). Phases 1 and 2: Emissions Characterization. Available at *www.crcao.com*

2. Health Effects Institute. May 2006. Research Solicitations for *Development of a Diesel Exhaust Exposure Facility and Conduct of a Chronic Inhalation Bioassay in Rats and Mice.* Available at *www.healtheffects.org/funding.htm*

3. US Environmental Protection Agency, 2002. Health Assessment Document for Diesel Engine Exhaust. EPA/600/8-90/057F. US Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development, Washington D.C.

FY 2006 Publications/Presentations

1. Poster Presentation at the Diesel Engine Emissions Reduction (DEER) meeting in Detroit MI, August 2006, P-11: “Status of the Advanced Collaborative Emissions Study (ACES)”

2. Platform Presentation at the HEI Annual Conference in San Francisco CA, April 2006, in the session “Hot Topics, Breaking News”