VI Health Impacts

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

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Objectives

The Watt Road Environmental Laboratory (WREL) is an active real-world laboratory devoted to:

- Understanding the actual emissions of in-use heavy-duty diesel vehicles.
- Defining the impact of these vehicles on local and regional air quality.

Approach

Combine field measurements of emissions sources, air quality, and meteorological and geographical data to develop and validate air quality models and understand the contributions of various sources to local and regional air quality.

- Measure and characterize emissions from mobile sources by developing and applying remote sensing techniques for oxides of nitrogen (NOx, an ozone precursor), particulate matter (PM), and toxic air contaminant pollutants.
- Measure and characterize ambient air quality at specific sites in the Watt Road corridor corresponding with mobile sources, idling trucks, and background sources.
- Perform simulations of the Watt Road corridor using fine-scale modeling to simulate the evolution of mobile source pollutants into the local area for varying meteorological conditions and source strengths.

Accomplishments

- Completed study for the Knox County Municipal Planning Organization on ambient air quality in truck travel centers.
- Incorporated shorter wavelength laser into remote PM measurement instrument for better resolution of small particles.
- Demonstrated high sensitivity of ultraviolet (UV) method for remote NOx measurement.
- Demonstrated audio signature analysis of passing trucks and cars.

Future Directions

- Continued deployment of the remote sensing instrumentation. Field instrumentation focus will be on weigh-station vehicles to get weight and emissions under known speed and acceleration.
- Linkage of field measurements to air quality models and health impacts.
- Applying higher time resolution measurements of air toxics in order to understand mobile source impacts.

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. The unique laboratory is located near Oak Ridge National Laboratory (ORNL), where approximately 20,000 heavy-duty trucks per day pass by an interstate interchange that also contains multiple travel center facilities. Figure 1 is an aerial view of the site. 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 do the conditions of 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 Road site from multiple stakeholders, there have been a variety of sponsors, including the Knox Co. Municipal Planning Organization and the Federal Highways Administration as well as the DOE Office of FreedomCAR and Vehicle Technologies (OFCVT).

The OFCVT project 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, we can develop and validate air quality models and understand the contributions of various mobile sources to local and regional air quality, and its impact on human populations.

Figure 1. Topographical View of the Watt Road Environmental Laboratory Corridor Reconstructed from Satellite Images

Three main areas of interest are:

- **Mobile Source Characterization:** Measure and characterize emissions from mobile sources by developing and applying remote sensing techniques for NOx (an ozone precursor), PM, and toxic air contaminant pollutants. FY 2005 progress included increased sensitivity and a hundred-fold increase in speed of PM detection.
- **Ambient Air Quality Characterization:** Measure and characterize ambient air quality at specific sites in the Watt Road corridor corresponding with mobile sources, idling trucks, and background sources. Three non-DOE sponsored projects were completed in FY 2005.
- **Simulation and Understanding of Source Contributions to Air Quality:** Model the Watt Road corridor with fine-scale modeling to simulate the evolution of mobile source pollutants into the local area for varying meteorological conditions and source strengths.

Peer-reviewed posters and presentations were given on the remote-sensing work at the 15th Coordinating Research Council (CRC) On-Road Vehicle Emissions Workshop (San Diego, CA, April 2005) and the International Instrumentation Symposium of the Instrumentation, Systems, and Automation Society (Knoxville, TN, May 2005). A peer-reviewed presentation on the measurements of mobile source air toxics in the travel center area was presented at the CRC Mobile Source Air Toxics Workshop (Scottsdale, AZ, December 2004).

Approach

Our approach has been to implement inexpensive, robust instrumentation for remotely sensing NOx and PM emissions of trucks as they pass on the road, and to relate those measurements to engine and vehicle parameters, also measured remotely, so that mass emissions can be estimated. Specifically, we have applied LIght Detection And Ranging (LIDAR) [1] and UV absorption technologies to determine PM and NOx concentrations, respectively, in the exhaust plumes of passing trucks. We couple these measurements with remote sensing of vehicle speed, acceleration, weight, and parameters of engine operation via acoustic signature analysis. This will then lead to a reconciling of exhaust concentration measurements to the vehicle/engine parameters to produce values of emissions in vehicle-specific units, such as grams per mile results. By examining trucks at the nearby weigh station, it is possible to extract power information since weight and acceleration are known. Because it is possible to measure hundreds of trucks in one day, a clearer understanding of the overall fleet emissions is expected. Earlier, more detailed, chassis dynamometer emissions work with a small selection of in-use trucks [2] will be complemented by this information.

Conventional and unconventional instrumentation has been implemented for air quality studies within the Watt Road environment. Standard analyzers for $PM_{2.5}$ and ambient gases, as well as PM_1 and PM_{10}, are used to distinguish between combustion emissions and other sources of fine particulates. Real-time sulfate and nitrate $PM_{2.5}$ analyzers are used to identify background influences of fossil fuel combustion. Integrated sampling of air toxics such as formaldehyde, acetaldehyde, and polycyclic organic matter is performed to identify potential influences of mobile source emissions. When combined with traffic counting and vehicle identification techniques, these ambient measurements can identify vehicle influences on local air quality.

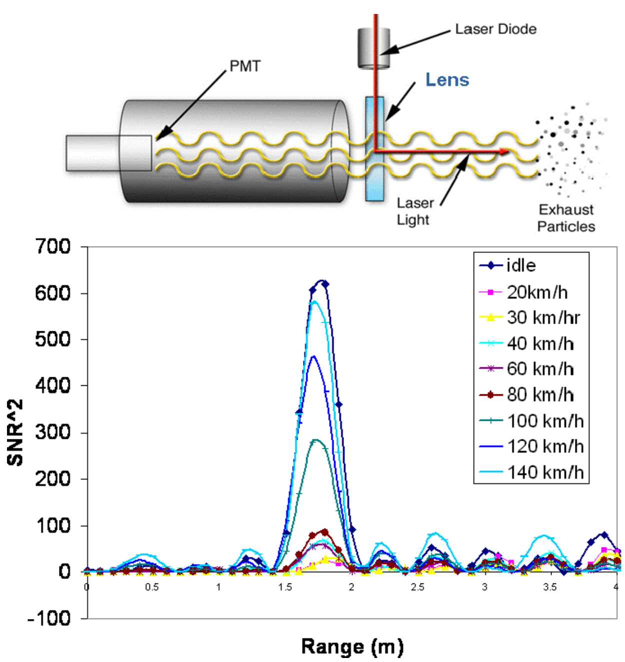

Figure 2. LIDAR System Schematic and Results for Exhaust Plume Measurement (1999 Mercedes A170 diesel on chassis dynamometer)

Ultimately, understanding hot spots like Watt Road will lead to the ability to model traffic influence on air quality. Large-scale eddy simulation (LES) models [3] can be used to translate ground-based emissions up to 1-2 km into the troposphere with high accuracy. Thus, our approach will be to develop these models for Watt Road, such that the finer-resolution modeling can feed into the larger, regional-scale air-quality models. Air quality has proven to be the key link between mobile source emissions and health impacts. A deeper understanding of the effects of new diesel technology and emissions regulations on local air quality is critical to guiding efforts to mitigate transportation's impact on human health.

Results

We have completed significant instrument development efforts and deployed the LIDAR (PM sensing), the ultraviolet differential optical absorption spectroscopy instrument (NOx sensing), and an acoustic instrument for vehicle sensing. Figure 2 illustrates the LIDAR signal from the exhaust plume of a light-duty diesel vehicle being driven on a chassis dynamometer. The highest signals are at idle and at 140 km/hr, which is typical for this type of engine. Figure 3 shows the NOx

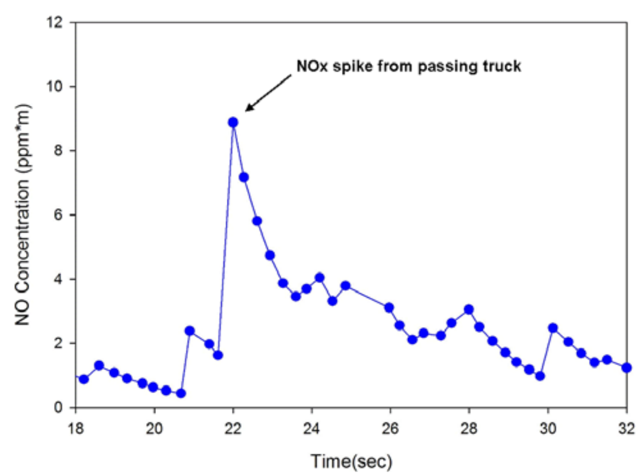

Figure 3. NOx Emission Spike Generated from a Passing Diesel Heavy-Duty Class 8 Truck Measured with the Ultraviolet System

signal for a Class 8 truck driving by the UV system. In this case, the sensor is able to see the increase in NOx concentration from the vehicle's exhaust plume. Figure 4 illustrates the acoustic measurement of engine properties for a diesel truck. The frequency analysis can identify the turbo speed as well as the engine speed. By knowing how those parameters correlate to exhaust flow for typical Class 8 engines, it will be possible to measure exhaust flow from passing vehicles. By combining exhaust flow with concentration measurements, it will then be possible to quantify mass emissions rates for NOx, PM and, in the future, other pollutants.

The impact of idling trucks on local air quality has been characterized with ambient air sampling at truck stops at the Watt Road interchange site. Two studies have been completed, with results showing that the influence of the travel centers is very important due to the high concentration of idling trucks. Figure 5 shows results for formaldehyde, a toxic air contaminant, measured in the travel center. The highest values in winter are thought to occur during overnight periods of inversion, in which the cold air is trapped in the valley. The lowest values occur during rain events. While there are fewer periods of inversion during the summer, photochemistry can produce formaldehyde, and thus the minimum level is likely representative of background levels.

Figure 6 shows an example model calculation of NOx transport into the troposphere from a surface source such as an interstate highway. The model can incorporate turbulence, diffusion as well as chemistry effects. The ultimate objective of this project is to be able to produce data and

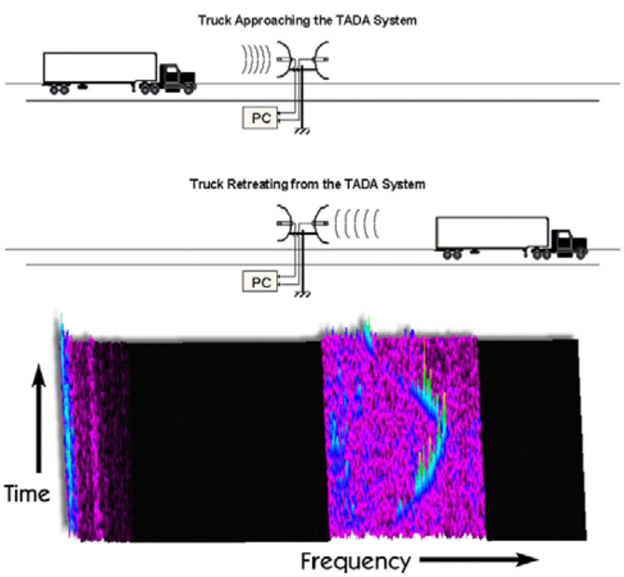

Figure 4. Truck Acoustic Data Analyzer (TADA) Shows Frequency Change of Turbo During Steady-Speed Climb on a Grade (Left side frequencies are engine speed remaining constant with time. Right side frequencies are turbo speed, increasing and decreasing as necessary to ascend the hill.)

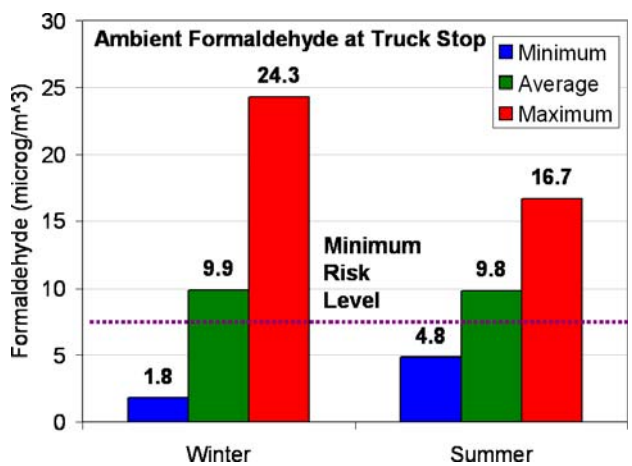

Figure 5. Formaldehyde concentrations measured at a Watt Road travel center. Maximum concentrations are typically associated with periods of atmospheric inversion, which can be persistent in cold weather.

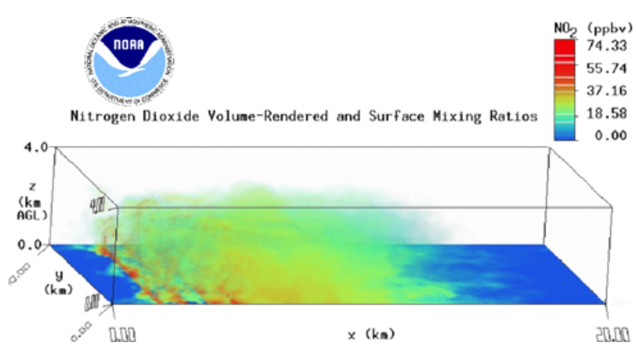

Figure 6. LES Simulation of NO_2 Flux into the Atmosphere from a Dual Line Source such as a Highway (*courtesy of the NOAA Atmospheric Turbulence and Diffusion Division in Oak Ridge)*

measurements that can calibrate and/or validate the meso-scale models such as these. These models have the potential to provide much more accurate input to regional air quality models, and thus help to understand the role of transportation sources and transportation policies in air quality.

Summary

ORNL has established an environmental laboratory for the study of heavy-duty truck emissions and their effects on air quality and therefore human health. Ambient air quality has been characterized to understand the contribution of mobile sources at truck stops (idling) or on the interstate. Furthermore, unique tools have been developed for remote sensing of NOx and PM from mobile sources, and these techniques have been demonstrated in experiments on exhaust from diesel vehicles. The combined approach of source measurement and modeling will develop a better understanding of how major corridors and local hot spots influence and impact regional air quality and the health of the region's population. Future work will continue to emphasize the link between measurements and modeling.

FY 2005 Publications/Presentations

1. Storey, J.M.E. *et al.* "$PM_{2.5}$ speciation and air toxics in the truck stop environment." Presented at the CRC Mobile Sources Air Toxics Workshop, Scottsdale, AZ. December, 2004.
2. Parks, J.E *et al.* "Improved remote sensing instrumentation for NOx and PM emissions from heavy-duty trucks." Presented at the 15th Annual CRC On-Road Emissions Workshop, San Diego, CA. March, 2005.
3. Miller, T.J. *et al.* "Evaluation of emission reductions and air quality impacts of IdleAire truck stop electrification technology." Presented to the Knox County Transportation Planning Organization, Knoxville, TN. October, 2004.
4. Simpson, M.L. *et al.* "Intensity-modulated, stepped frequency CW lidar for distributed aerosol and hard target measurements." *Applied Optics*, **44**, pp.7210-7217. 2005.

References

1. Simpson, M.L. *et al.,* "Intensity-modulated, stepped frequency CW lidar for distributed aerosol and hard target measurements," *Applied Optics*, **44**, pp.7210-7217. 2005.
2. Clark, N.N. *et al.*, "Heavy-duty vehicle chassis dynamometer testing for emissions inventory, air quality modeling, source apportionment and air toxics emissions inventory," CRC E-55 Phase 2 report. Coordinating Research Council, 2005. *available at* http://www.crcao.com/reports/recentstudies2005/ .
3. Zurn-Birkimer, S.M. *et al.*, "Convective structures in a cold air outbreak over Lake Michigan during Lake-ICE," Journal of the Atmospheric Sciences, 62, pp. 2414-2432. 2005.

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 will characterize 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.

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).

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.

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 and 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

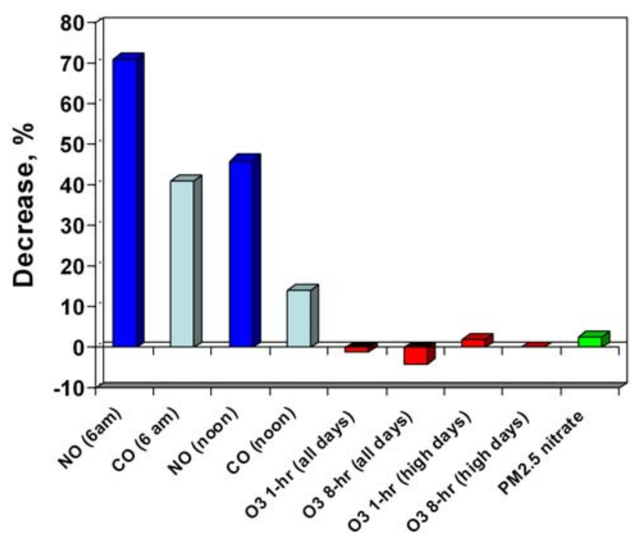

Figure 1. Median ambient pollutant concentration decreases from Wednesdays to Sundays. Results are shown for morning and noon concentrations of NO, NOx, and CO (March – October), and for 1-hour and 8-hour peak ozone concentrations on all ozone-season days (March – October) and on high-ozone days (top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

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:

- 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 Houston area 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 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.

References

1. Fujita, E.M., W.R. Stockwell, D.E. Campbell, R.E. Keislar, D.R. Lawson. Evolution of the magnitude and spatial extent of the weekend ozone effect in California's South Coast Air Basin. J. Air Waste Manage. Assoc., **2003**, 53, 802-815.
2. Lawson, D.R. Forum – the weekend ozone effect – the weekly ambient emissions control experiment. EM, **2003,** July, 17-25.
3. Croes, B.E., L.J. Dolislager, L. Larsen, J.N. Pitts. Forum – the O_3 "weekend effect" and NOx control strategies – scientific and public health findings and their regulatory implications. EM, **2003**, July, 27-35.

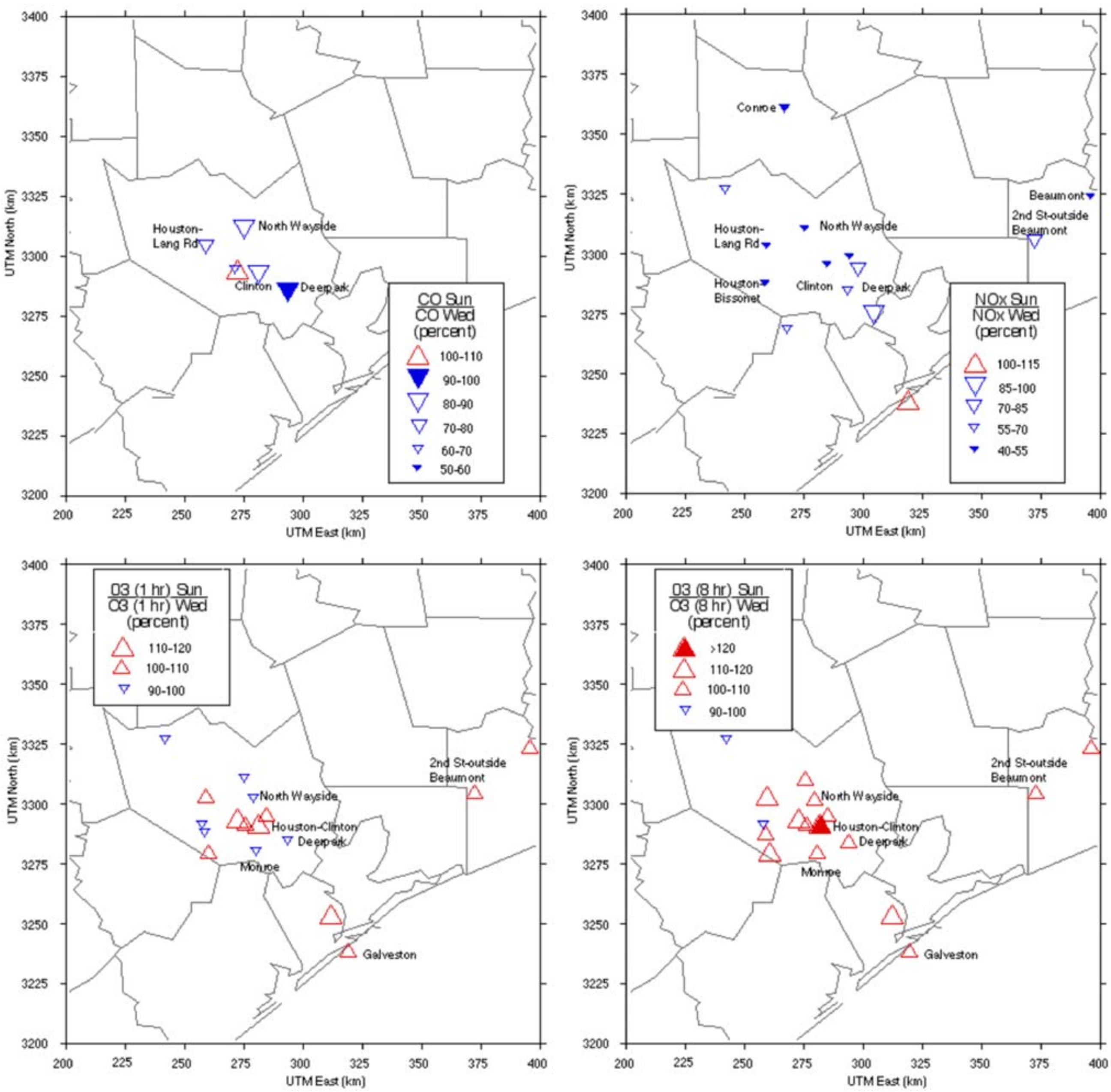

Figure 2. Geographical comparisons of mean Sunday to mean Wednesday daytime (6 a.m. through 3 p.m.) concentrations of CO and NOx and mean peak daily one-hour and eight-hour ozone in southeastern Texas. The differences were determined from all days, March-October 1998-2003.

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

Approach

- Use animal and cell tests to characterize and quantify adverse health effects
- Adapt, optimize, and validate biological test systems for emissions testing
- Test collected samples from vehicles and whole emissions and components from laboratory-operated engines
- Use emissions fractionation, multivariate analysis of whole emissions, and exposures to specific compounds to identify and confirm toxic components
- Examine emerging technologies prior to commercialization

Accomplishments

- Discovered that emissions from malfunctioning gasoline-, diesel-, and compressed natural gas (CNG)-fueled vehicles (high emitters) were up to 5 times more toxic to the lung per unit of mass than normal emissions
- Discovered that crankcase oil emissions can be more toxic to the lung than fuel combustion emissions, and are a primary cause of higher toxicity per unit of mass of emissions from high emitters
- Determined that emissions from normally-functioning 1990s technology gasoline and diesel engines have similar toxicity per unit of mass
- Demonstrated that retrofitting a laboratory-operated conventional diesel engine with low-sulfur fuel and catalyzed particle trap reduced sensitive biological effects 75-100%
- Determined that results from cultured cells exposed by adding emissions components to culture medium do not produce a relative ranking among samples that matches ranking by lung toxicity in animals [Seagrave et al., 2003]
- Determined that although emissions from CNG-fueled heavy-duty vehicles can be more mutagenic per unit mass than diesel and gasoline emissions, CNG emissions are less inflammatory in the lung

Future Directions

- Complete work to confirm or refute health importance of nanoparticle (<50 nm) components of diesel emissions, and relative importance of black carbon- vs. non-solid condensate-based particles
- Complete direct comparison of respiratory and cardiac effects of inhaled diesel and gasoline emissions using contemporary biological assays probing effects implicated by epidemiology

- Complete determination of validity of cultured cells exposed in real-time to whole emissions (aerosols) for predicting lung effects of inhaled emissions
- Test directly whether crankcase oil-derived hopane and sterane compounds associated statistically with toxicity of emissions are actually the causes of toxicity
- Evaluate potential health concerns of emerging power technologies, with priorities based on most likely success and timing of commercialization
- Determine causal components responsible for unanticipated toxicity associated with emerging power technologies

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Introduction

This project is the biological evaluation component of the Health Impacts Program, and it 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 uses short-term cell and animal studies to address specific technology-limiting issues that are not addressed in other DOE or non-DOE programs. This project complements other Health Impacts projects that characterize emissions, determine the impact of emissions on air quality, and conduct long-term carcinogenicity studies of 2007-2010-compliant diesel systems.

Approach

This project employs four fundamental strategies to place the health hazards of vehicle emissions in proper context, identify the key toxic components, and evaluate new technologies. The first strategy involves laboratory evaluations of emission samples collected from vehicles elsewhere. Filters containing particulate emissions and chemical canisters containing vapor-phase emissions are collected from a wide range of vehicles under realistic operating conditions; material is extracted from the collection media in the laboratory and analyzed chemically; and the mutagenic, inflammatory, and other toxic effects are tested using animals and cells. The second strategy uses multivariate statistical analysis of data on composition vs. biological response, step-wise fractionation of whole emissions (e.g., removing particles or denuding vapors), and exposures to specific physical-chemical classes contained in emissions to determine which components cause the toxicity of whole emissions. The third strategy directly compares biological responses to emissions from advanced technologies to responses to a baseline case to confirm reductions of health hazards and provide quantitative evidence of benefit. The fourth strategy involves working with DOE program managers and industry partners to identify advanced technologies (e.g., fuel, engine, emissions reduction) having the greatest near-term (5-10 year) commercialization potential, and then using the above approaches to evaluate those technologies for potential health issues and provide feedback to managers.

This project is highly leveraged by also participating in the larger government-industry National Environmental Respiratory Center program (www.nercenter.org) that is conducting detailed composition and health studies of different source emissions, including diesel, gasoline, coal, and wood. This participation yields information on a broader range of emissions and health effects characterizations and cross-emissions comparisons than can be accomplished solely within this project.

Results

The results of this project are communicated in numerous technical presentations and peer-reviewed scientific publications (FY 2005 products listed below, full listing available on request); only a few example key results are summarized here.

Using samples collected from a traffic tunnel, this project demonstrated for the first time that vapor-

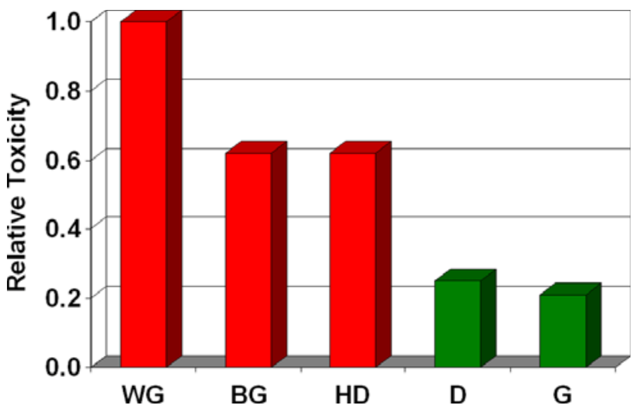

Figure 1. Relative potency of combined PM and SVOC emissions for causing lung inflammation, compared at equal mass doses to animal lungs. The most toxic sample was set at a value of 1.0 for ease of comparison. WG = white smoker gasoline, BG = black smoker gasoline, HD = high-emitting diesel, D = normal diesel, G = normal gasoline.

phase semi-volatile organic compounds (SVOCs) can be equally, or even more, toxic to the lung per unit of mass than particles. Because this poorly-studied class constitutes a significant portion of the mass of emissions from contemporary diesel and gasoline vehicles, this finding identified the need to control organic vapor emissions as well as the stringently-regulated particulate material (PM) and nitrogen oxides (NOx).

Using samples collected from in-use vehicles, this project demonstrated that per unit of equal mass, 1) the lung toxicities of PM and SVOC emissions from 1990s technology diesel and gasoline engines were approximately equal, and 2) emissions from high-emitting vehicles were more toxic than those from normal emitters, with "white smoke" emissions from gasoline vehicles the most toxic of all (Figure 1). These direct comparisons demonstrated for the first time that the principal difference between the health hazards of diesel and gasoline emissions was their amount, rather than their toxicity; thus, the current marked reductions can make diesel technology competitive with gasoline technology from a health viewpoint. These findings also suggested the substantial health gains achievable by removing smoking vehicles from the fleet.

Using PM and SVOC samples collected from diesel, gasoline, and CNG vehicles, this project identified hopanes and steranes, organic species contained in crankcase oil, as statistically most closely associated with lung toxicity of emissions. Because other oil components (calcium and phosphorus) varied less closely with toxicity, work is now underway to determine whether these classes of organic compounds are the toxic components, rather than just reflecting the toxicity of some other oil emission component. Because all internal combustion engines emit traces of oil emissions (and oil burners emit large amounts), these findings demonstrate for the first time that attention must be given to lubrication oil formulations and emissions.

Using whole diesel emissions generated in the laboratory, this project demonstrated that retrofitting with low-sulfur fuel and a catalyzed ceramic PM trap markedly reduced our most sensitive indicators of biological responses to inhaled emissions. Animals were exposed for seven days to emissions from national average fuel without a PM trap, at a concentration known to produce measurable effects, and to emissions under identical operating conditions and at the same dilution with the retrofit. The retrofit nearly eliminated the reduced clearance of Respiratory Syncytial Virus (RSV), the most common respiratory virus of infants and young children [Harrod et al., 2003]), from the lung; the amount of a pro-inflammatory protein (TNFa); and an indicator of oxidative stress to lung tissue (HO-1) (Figure 2). These findings demonstrate the health benefit of diesel retrofits and offer great encouragement that advanced emissions reduction technologies will be paralleled by marked health benefits.

Conclusions

Because this project is an integral component of a continuing program to facilitate the development of advanced motive power technologies, a single final conclusion is not expected. Several broad conclusions have resulted, in addition to the specific findings exemplified by the above results. First, it is clear that multiple motive power strategies are tenable from a health viewpoint. With proper consideration and mitigation of health concerns, all

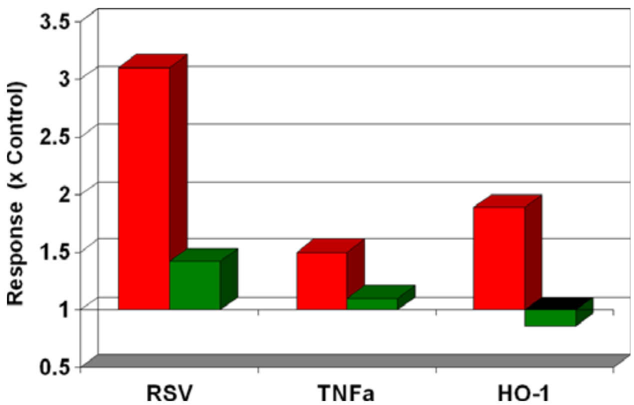

Figure 2. Reductions in health effects by retrofitting diesel engine with low-sulfur fuel and a catalyzed PM trap. Values are relative to control values from sham-exposed animals, which were set at 1.0. Abbreviations are given in text.

current and candidate technologies can fill their niche in the motive power portfolio. Second, all technologies (internal combustion and other) are attended by potential adverse health impacts of some nature and degree that need to be understood and mitigated as the technologies develop. Third, evidence to date indicates that with guidance from efforts such as this project, emissions reduction and other mitigation strategies can indeed markedly reduce, if not eliminate, public health impacts that are sufficient to warrant concern.

FY 2005 Presentations

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