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2015 MOBILE SOURCE AIR TOXICS WORKSHOP

Final Report

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COORDINATING RESEARCH COUNCIL, INC.
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The Coordinating Research Council, Inc. (CRC) is a non-profit corporation supported by the petroleum and automotive equipment industries. CRC operates through the committees made up of technical experts from industry and government who voluntarily participate. The four main areas of research within CRC are: air pollution (atmospheric and engineering studies); aviation fuels, lubricants, and equipment performance, heavy-duty vehicle fuels, lubricants, and equipment performance (e.g., diesel trucks); and light-duty vehicle fuels, lubricants, and equipment performance (e.g., passenger cars). CRC's function is to provide the mechanism for joint research conducted by the two industries that will help in determining the optimum combination of petroleum products and automotive equipment. CRC's work is limited to research that is mutually beneficial to the two industries involved, and all information is available to the public.

CRC Project A-92

2015 Mobile Source Air Toxics Workshop

Coordinating Research Council, Inc.

Sacramento, California

February 17-19, 2015

Co-Sponsors:

California Air Resources Board

Health Effects Institute

South Coast Air Quality Management District

Toyota

U.S. Environmental Protection Agency

The Coordinating Research Council (CRC) held its seventh Mobile Source Air Toxics (MSAT) Workshop on February 17-19, 2015. The Workshop consisted of seven oral sessions and one poster session. It included thirty-five oral presentations, seven poster presentations, and one panel discussion. These presentations reviewed the current state-of-knowledge regarding MSAT emission measurements, exposure, air quality and modeling, as well as the effectiveness of regulatory control measures. There were approximately 100 attendees. This report provides brief summaries of all the Workshop presentations.

The summaries included here attempt to reflect the information presented at the Workshop, but do not represent the opinions of CRC, the Workshop organizers, or the Workshop co-sponsors.

Abbreviations and Acronyms

1,3-BD	1,3-Butadiene
ACES	Advanced Collaborative Emissions Study
AERMOD	Atmospheric dispersion modeling system
AMS	Aerosol Mass Spectrometer
AQMP	Air Quality Management Plan
ARB	(California) Air Resources Board
AURAMS	A Unified Regional Air-quality Modeling System
B20	Blend of 20% biodiesel with petroleum diesel
BC	Black Carbon
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CAMx	Comprehensive Air Quality Model with Extensions
CARB	California Air Resources Board
CB05	Carbon Bond 2005 (chemical mechanism)
CMAQ	Community Multi-Scale Air Quality Model
CMB	Chemical Mass Balance
CNG	Compressed Natural Gas
CO	Carbon monoxide
COPD	Chronic Obstructive Pulmonary Disease
CRC	Coordinating Research Council
CSN	Chemical Speciation Network
DALY	Disability Adjusted Life Years
DOE	U.S. Department of Energy
DPF	Diesel Particulate Filter
DPM	Diesel Particulate Matter
E85	Gasoline blend containing 85% ethanol
EC	Elemental Carbon
EC	Environment Canada
EGR	Exhaust Gas Recirculation
EGU	Electric Generating Unit
EI	Electron Impact (ionization)
EPA	U.S. Environmental Protection Agency
FCV	Fuel Cell Vehicle
FFV	Flex-Fuel Vehicle
FTIR	Fourier Transform Infra-Red (spectroscopy)
FTP	Federal Test Procedure
GBD	Global Burden of Disease
GC-MS	Gas Chromatography-Mass Spectrometry
GDI	Gasoline Direct Injection
GEM-MACH	Global Environmental Multiscale – Modeling Air quality and Chemistry
GHG	Greenhouse Gas

GPS	Global Positioning System
HAP	Hazardous Air Pollutant
HAPEM	Hazardous Air Pollutant Exposure Model
HD	Heavy-Duty
HECA	High Efficiency Cabin Air (filter)
HEI	Health Effects Institute
HPDI	High Pressure Direct Injection
HP-PF	High Performance-Panel Filter
ICPMS	Inductively Coupled Plasma Mass Spectrometry
IHD	Ischemic Heart Disease
LAX	Los Angeles International Airport
LBNL	Lawrence Berkeley National Laboratory
LCFS	Low Carbon Fuel Standards
LD	Light-Duty
LDV	Light-Duty Vehicle
LEV	Low Emission Vehicle
LPG	Liquefied Petroleum Gas
MATES	Multiple Air Toxics Exposure Study
MEGAN	Model of Emissions of Gases and Aerosols from Nature
MERV	Maximum Efficiency Rating Value
MOVES	Motor Vehicle Emission Simulator
MSAT	Mobile Source Air Toxic
N_2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standard
NAC	NOx Adsorber Catalyst
NATA	National-Scale Air Toxics Assessment
NEI	National Emissions Inventory
NG	Natural Gas
NH_3	Ammonia
NMHC	Non-Methane Hydrocarbon
NMOG	Non-Methane Organic Gases
NOx	Oxides of nitrogen
O_3	Ozone
OA	Organic Aerosol
OC	Organic Carbon
OEHHA	(California) Office of Environmental Health Hazard Assessment
OS	Oxidative Stress
PAH	Polycyclic Aromatic Hydrocarbon
PAM	Potential Aerosol Mass (reactor)
PAMS	Photochemical Assessment Monitoring Station
PFI	Port Fuel Injection
PIM	Path Integral Method (for source apportionment)
PM	Particulate Matter

$PM_{2.5}$	Fine Particulate Matter (diameter < 2.5 μm)
PMF	Positive Matrix Factorization
PN	Particle Number
POA	Primary Organic Aerosol
PSD	Particle Size Distribution
PUF	Poly-urethane Foam
PZEV	Partial Zero Emission Vehicle
RfC	Reference Concentration (exposure for carcinogenicity)
RFG	Reformulated gasoline
RFS2	Renewable Fuel Standard
ROS	Reactive Oxygen Species
SAPRC	Statewide Air Pollution Research Center
SCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District
SCR	Selective Catalytic Reduction
SEARCH	Southeastern Aerosol Research and Characterization
SMR	Steam Methane Reforming
SO_4	Sulfate
SOA	Secondary Organic Aerosol
SOx	Oxides of sulfur
SP-AMS	Soot Particle-Aerosol Mass Spectrometer
SULEV	Super Ultra-Low Emissions Vehicle
SVOC	Semi-Volatile Organic Compound
TAC	Toxic Air Contaminant
THC	Total Hydrocarbons
TOA	Thermal Optical Analyzer
TWC	Three-Way Catalyst
UDDS	Urban Dynamometer Driving Cycle
UFP	Ultra-Fine Particle
UFPM	Ultra-Fine Particulate Matter
ULEV	Ultra-Low Emissions Vehicle
ULSD	Ultra Low Sulfur Diesel
VOC	Volatile Organic Compound
VUV	Vacuum Ultra-Violet (ionization)
WHO	World Health Organization
WRF	Weather Research and Forecasting model

Overview of the 2015 Mobile Source Air Toxics (MSAT) Workshop

Plenary Session. This session consisted of four presentations that helped introduce the topic of MSAT, provided overviews of MSAT trends, and identified on-going areas of concern. A presentation by the California Air Resources Board (ARB) summarized the history of air pollution problems and solutions in the State. By adopting numerous regulatory measures since the 1980's, cleaner fuels and vehicles have been introduced, resulting in dramatic reductions of MSAT emissions. Estimates of lifetime cancer risk for ambient MSAT concentrations in California continue to be dominated by diesel particulate matter (DPM), although significant progress is being made to reduce these values. The California Office of Environmental Health Hazard Assessment (OEHHA) has recently updated its guidance for estimating human health risks associated with air toxics, including MSATs. With methodological changes that improve exposure estimates and better account for differences between children and adults, the resultant cancer risk values for most MSAT species are higher by a factor of 2-3.

Another presentation described measurement and characterization of non-methane hydrocarbons (NMHC) in urban areas of Saudi Arabia, Pakistan, and Singapore. These results showed that extremely high levels of NMHC (including MSAT) still occur in some locations, and confirm that control measures can be very effective in reducing ambient concentrations. The final talk described the Global Burden of Disease (GBD) study, which attempts to link health loss throughout the world to 76 specific risk factors. While MSAT are not treated explicitly, $PM_{2.5}$ can be considered an imperfect surrogate. In many developing countries, $PM_{2.5}$ is believed to be a significant (and growing) cause of health burden.

Session 1: Regulatory Needs. This session consisted of presentations given by representatives of four regulatory agencies: U.S. EPA, Environment Canada, ARB, and California's South Coast Air Quality Management District (SCAQMD). These regulators were asked to discuss the MSAT issues of greatest concern to them, and suggest additional work required to address these issues. EPA reported that on a U.S. national scale, MSAT emissions have been reduced from 2.9 million tons in 1990 to 1.5 million tons in 2008. Further reductions to 0.5 million tons are projected, due to fleet turnover and continued phase-in of new standards. MSAT species of greatest concern include benzene, 1,3-butadiene, aldehydes, and DPM. Of growing concern are emissions of lead from piston-engine aircraft, which operate at approximately 2000 general aviation airports in the U.S.

Vehicle emissions regulations overseen by Environment Canada closely parallel those in the U.S. Emissions reductions and air quality improvements are now being seen in Canada. In California, considerable efforts have been taken to reduce MSAT emissions and health risks associated with freight operations. It is believed that these operations – which include seaports, rail yards, trucking distribution centers, and high-traffic roadways – are responsible for 38% of the State's air toxic risk. Implementation of a variety of "freight rules," is reducing these risks dramatically. Future planned efforts include zero tailpipe emissions from certain components of the freight system, use of biofuels in other components, and lower emissions overall. The SCAQMD is continuing to address MSAT issues in California's South Coast Air Basin (SCAB). It

is estimated that MSAT are responsible for over 90% of the total lifetime air toxics risk, with DPM alone being responsible for 68% of this risk. The SCAQMD is promoting various initiatives to accelerate deployment of advanced vehicle technologies into the marketplace.

Session 2: Vehicle Emission Measurements of MSATs. This session consisted of six presentations focused on measurement and characterization of MSAT from modern vehicles and fuels. EPA laboratory testing of post-2010 diesel trucks using both diesel and biodiesel fuels showed that aldehydes were the dominant MSAT emission species. While these modern vehicles had lower overall MSAT emissions compared to older technology vehicles, aldehyde emissions were similar. Heavy-duty (HD) natural gas engines have also advanced in recent years. Compared to older, lean-burn engines, modern technologies utilizing stoichiometric engines and 3-way catalysts provide lower emissions of organic carbon (OC), BTEX (benzene, toluene, ethylbenzene, xylenes), and carbonyls. Dynamometer testing of several LD vehicle types was conducted by ARB to examine the toxicological effects of emitted PM by quantifying reactive oxygen species (ROS) in PM extracts using a biological assay test. From all vehicles, ROS amounts per mass of PM varied considerably with driving cycle. On an ROS/mile basis, diesel and biodiesel vehicles gave higher results than gasoline or natural gas vehicles.

In a LD dynamometer study by U.C. Riverside, various alcohol-blended fuels were tested in port fuel injection (PFI) and gasoline direct injection (GDI) vehicles. In general, BTEX emissions decreased and aldehydes increased with increasing levels of alcohol in the fuel. When using an isobutanol fuel blend, emissions of butyraldehyde increased. Ratios of organic carbon to elemental carbon (OC/EC) in PM emissions differed significantly between PFI and GDI technologies. With E10 fuel, EC dominated over OC in GDI engines, while the opposite was seen from PFI vehicles. Finally, in a presentation by Ford, it was explained that blending of ethanol into gasoline affects many fuel properties besides oxygen level, with these changes potentially influencing emissions from flex-fuel vehicles (FFVs). Changes in fuel chemistry are largely responsible for increased emissions of ethanol, formaldehyde, and acetaldehyde with increasing ethanol fuel content. Other emissions impacts, such as NOx effects, are driven more by engine calibration strategies, which vary by manufacturer and vehicle model.

Session 3: Air Quality and Exposure Measurement of MSATs. Five presentations were given in this session, which focused on understanding exposure to MSATs and mitigation measures to reduce exposures. SCAQMD's most recent Multiple Air Toxics Exposure Study (MATES IV) showed dramatic reductions of ambient MSAT concentrations in the SCAB over the past decade. Total cancer risk from air toxics is dominated by DPM. Estimated basin-wide average concentrations of DPM have been reduced from 3.5 $\mu g/m^3$ in MATES III (2004-2006) to 1.0 $\mu g/m^3$ in MATES IV (2012-2013). Aircraft emissions during landing operations at LAX are of increasing concern. Using real-time particle number measurements on the ground, UCLA researchers defined an area of impact as far as 16 km away from LAX. These aircraft-related particles have size distributions consistent with fresh combustion sources.

A study by Lawrence Berkeley National Laboratory (LBNL) has demonstrated that various ventilation and filtration strategies are effective in reducing indoor levels of ultra-fine particles (UFP) that originate from outdoor sources. Similarly, a UCLA study demonstrated that

retrofitting school buses with high efficiency cabin air filtration systems was very effective in reducing in-cabin levels of UFP. Finally, retrofitting air filtration systems in portable school buildings has been shown effective in reducing indoor air toxics. One successful product is now being deployed at 47 schools throughout the SCAB.

Session 4: Atmospheric Modeling and Measurements of MSAT Chemistry and Physics. This session included seven presentations, covering topics such as measurement of reactive MSAT species, treatment of MSAT in chemical mechanisms used for air quality modeling, and incorporation of MSATs into mobile source emissions models. Acrolein is a highly toxic specie believed to be responsible for significant adverse health effects. However, it also has numerous other sources – both anthropogenic and natural – making it difficult to accurately allocate ambient acrolein to individual sources. A new modeling approach, called Path-Integral Method (PIM) has been developed and was used to allocate ambient aldehydes (which are also reactive MSATs) to various sources. Results showed that mobile sources are estimated to be very minor contributors to total aldehyde concentrations in the year 2030.

Source apportionment and source characterization work is being done in California to better understand ambient UFP (here defined as $PM_{0.1}$). Established source apportionment methodologies, such as chemical mass balance (CMB) and positive matrix factorization (PMF), have been adapted for this application by U.C. Davis researcher, and regional transport models are being used to estimate UFP exposures. On-going research to characterize organic aerosol emissions from in-use vehicles has been aided by application of two new analytical approaches: (1) soot particle aerosol mass spectrometry (SP-AMS) and (2) soft ionization GC/MS. U.C. Berkeley used these techniques to show that the organic fractions from gasoline and diesel vehicles are very similar, consisting primarily of lube oil-derived material. Laboratory photochemical experimental research is being conducted by Carnegie Mellon University (and others) to investigate the potential of LD vehicle emissions to produce secondary organic aerosol (SOA). There is some concern that while total emissions are greatly reduced with newer technology vehicles, the potential for SOA formation is not being reduced to the same extent.

EPA's Motor Vehicle Emissions Simulator (MOVES) model has been updated to incorporate $PM_{2.5}$ and VOC speciation within the model itself. Thus, MOVES 2014 now includes MSAT species in both the gas-phase and particle-phase. Total gas-phase MSAT (benzene, 1,3-BD, and aldehydes) are dominated by gasoline vehicles, while polycyclic aromatic hydrocarbons (PAH) are more evenly distributed between gasoline and diesel vehicles. Finally, EPA's National Air Toxic Assessment (NATA) is now incorporating a hybrid modeling approach. This combination of dispersion modeling and Eulerian grid modeling provides finer spatial resolution and more accurate estimates of exposure to air toxics.

Session 5: Air Quality and Exposure Modeling of MSATs. Six presentations were given in this session, which dealt mainly with modeling approaches used to estimate MSAT exposures. Updates to EPA's NATA were described in more detail. The 2011 NATA [so-called because it is based on the 2011 National Emissions Inventory (NEI)] is expected to be released this summer. It combines emissions inventory data with exposure modeling, and then applies health risk factors to estimate air toxics inhalation risks with census tract resolution.

Environment Canada is developing a regional air quality modeling approach to estimate mobile source contributions to ambient PAH in urban areas. In this work, it was discovered that mobile source PAH emission factors reported in the literature are highly variable (by several orders of magnitude). Implications of this variability upon modeled results are being investigated.

A small experimental study by U.C. Berkeley researchers investigated bicyclists' exposure to traffic-related air pollutants. It was shown that the cyclists' choice of route can significantly impact their exposure. Lung function results did not show any difference between high- and low-exposure routes for the healthy subjects who participated in this study. To investigate multi-pollutant impacts from increased use of ethanol in LD vehicles, EPA performed a one-year modeling simulation over the entire contiguous U.S. for various scenarios. Applying VOC profiles associated with increasing ethanol resulted in reduced ambient concentrations of xylene (and other NMHC), but increased acetaldehyde – especially during winter months. Effects on ozone concentrations were very small. Finally, detailed CMAQ modeling was conducted by Univ. of Houston researchers to investigate ambient levels of 1,3-BD in the Houston area. Besides the usual mobile source contribution, there are significant industrial sources of 1,3-BD near Houston. The episodic nature of these industrial emissions creates modeling difficulties. Peak ambient concentrations of 1,3-BD are typically underestimated by the model.

Session 6: Accountability. This session consisted of four presentations that addressed the effectiveness of past emissions control measures in reducing MSAT. The Southeastern Aerosol Research and Characterization (SEARCH) study provides a long-term (15+ years) continuous record of air quality measurements. Combining these data with meteorological data enables investigation of the effectiveness of control measures implemented over this time period. This has confirmed dramatic reductions in most air pollutants, including MSAT. On-road emissions measurements made by U.C. Berkeley at the Port of Oakland have demonstrated the effectiveness of California's special "fleet rules" in reducing emissions from drayage trucks. As a consequence of after-treatment retrofits and introduction of new technology engines, emissions of black carbon (BC) and NOx have been reduced drastically. However, there are indications that NO_2 emissions have increased from modern engines equipped with catalytic diesel particulate filters (DPF).

To examine long-term MSAT trends, EPA modeled the entire contiguous U.S. over a 20-year period (1990-2010) using WRF-CMAQ simulations with the CB05 chemical mechanism. Results showed reasonable agreement with monitoring station measurements for many pollutants - including toluene, ethylbenzene, styrene, and NOx - but poorer agreement for CO and EC. For most pollutants, emissions, observations, and modeled concentrations all showed substantial decreases over this 20-year period. Finally, it was discussed how a combination of modeling and observational approaches taken together can provide greater certainty in linking specific control measures to changes in ambient pollutant concentrations, human exposures, and health impacts. To understand impacts on a day-specific basis, it is important to remove the influence of meteorology, which otherwise would strongly affect the results. Similarly, to understand the influence of a specific control measure, it is important to estimate pollutant concentrations that would exist if the measure had not been implemented.

SUMMARIES OF INDIVIDUAL PRESENTATIONS

Plenary Session

Ambient trends of Selected Mobile Source Air Toxics in California: *Bart Croes, California Air Resources Board (ARB)*

This presentation described the history of air pollution problems in California, and the regulatory measures that have been implemented to address them. Since the 1980's, ARB has utilized a statewide air toxics monitoring network, consisting of 17 stations located throughout the state. These monitoring data are used to establish values for statewide exposures to 21 toxic air contaminants (TACs), including several MSATs, such as benzene, 1,3-butadiene (1,3-BD), formaldehyde, and acetaldehyde. In addition, ARB determines ambient concentrations of diesel particulate matter (DPM) based upon measured NOx concentrations and inventory ratios of DPM/NOx. During the past 20+ years of monitoring, dramatic reductions in average ambient concentrations of MSATs have been observed, despite significant increases in statewide population and vehicle usage. These reductions are attributed to a combination of fuel controls and engine/vehicle controls.

Using cancer risk factors determined by the California Office of Environmental Health Hazard Assessment (OEHHA), ARB also assess the cancer risks associated with exposure to airborne toxics. The cumulative lifetime cancer risk attributed to TACs has decreased from about 3000 per million in 1990 to 730 per million in 2012. Over this period, the cancer risk associated with three key MSATs – benzene, 1,3-BD, and diesel PM – have decreased by 89%, 86%, and 82%, respectively. Yet, it is estimated that MSATs account for more than 75% of total cancer risks from all TACs, with diesel PM being the single largest contributor.

An ambient sampling program in Riverside, CA has shown 91% reduction in dioxin concentrations between the 1970's and 2000's. This is attributed to phase-out of leaded gasoline, including the lead scavengers, 1,2-dichloroehane and 1,2-dibromoethane, which are halogen sources of dioxins

Characterization of Non-Methane Hydrocarbons at Three Urban Sites in Western Saudi Arabia, in Lahore (Pakistan), and in Singapore: *Barbara Barletta; U.C. Irvine*

Measurements of non-methane hydrocarbons (NMHC) collected by ambient sampling in western Saudi Arabia (Jeddah, Mecca, and Medina), Lahore, and Singapore were described. In all three geographic regions, the profiles of individual NMHC species were quite similar. These NMHC were largely attributed to gasoline combustion sources, with most species showing good correlation with carbon monoxide (CO), which is commonly used as a tracer for combustion. However, two of the sites in Saudi Arabia (Jeddah and Mecca) also showed strong signatures of light hydrocarbons from natural gas, liquid petroleum gas (LPG), and gasoline evaporative emissions.

The NMHC concentrations in Singapore were quite low. For example, benzene concentrations were measured at approximately 0.5 ppb. (This is comparable to current ambient

levels in California, as reported in the previous presentation by Bart Croes of ARB.) For most NMHC species, measured concentrations in Saudi Arabia were nearly an order of magnitude higher than in Singapore. Concentrations in Lahore were nearly another order of magnitude higher. An assessment of photochemical reactivity of the ambient NMHCs was also conducted. This showed that alkenes were responsible for 60-73% of the total reactivity (for the Saudi Arabia samples), while they comprised only 18-28% of the total NMHC concentrations.

Risk Assessment Under California's Air Toxics Program – Recent Updates: *Melanie Marty; California Office of Environmental Health Hazard Assessment (OEHHA)*

CalEPA's Office of Environmental Health Hazard Assessment (OEHHA) is responsible for establishing human health risk assessments of toxics legislated under California's Air Toxics Hot Spots program. This includes determination of risk factors for both cancer and noncancer endpoints. In 2014, OEHHA completed a major revision to the risk assessment guidelines that had been in place since 2008. These revised guidelines include several changes that impact the final risk factors for MSATs. The most significant changes are the following:

- Uncertainty factors for noncancer reference levels were increased to provide greater protection of infants and young children.
- Cancer risk values were adjusted to account for greater sensitivity at early ages.
- Toxic intake rates were adjusted to account for higher exposures by young children.
- A spatial averaging approach was utilized to provide better estimates of exposure near small point sources.

As a consequence of these changes, some cancer risk values increased while others decreased – as compared to the 2008 values. [Note: based upon information provided by later speakers, it appears that the cancer risk values for most MSATs increased by a factor of 2-3.]

Global Health Burden of Particulate Matter (PM2.5) Air Pollution – An Update from the Global Burden for Diseases, Injuries, and Risk Factor (GBD) 2013 Study: *Mohammad Forouzanfar; Univ. of Washington*

The Global Burden of Disease (GBD) study is an on-going, systematic effort to quantify the comparative magnitude of health loss from all major diseases, injuries, and risk factors by age, sex, and population. GBD includes information from 188 countries from 1990 to present. Health burden is expressed in terms of disease prevalence, cause-specific mortality, disability adjusted life years (DALY), and other metrics. In all, 76 risk factors are considered. The factor most relevant to MSATs is $PM_{2.5}$, although it is recognized that there are also many non-mobile source emitters of $PM_{2.5}$. Annual average exposures to $PM_{2.5}$ are estimated using a combination of ground monitoring and satellite measurements, producing a spatial resolution of 10 x 10 km. Disease outcomes linked to $PM_{2.5}$ exposure include ischemic heart disease (IHD), stroke, lower respiratory infection, chronic obstructive pulmonary disease (COPD), and lung cancer. Population distribution maps are matched with spatial distributions of $PM_{2.5}$ to determine total incidences of particular health outcomes.

GBD results can be graphically displayed in many ways – including geographically, by risk factor, by health outcome, by year, etc. In 2013, it was determined that 3.0% of total burden (expressed as DALY) was attributable to $PM_{2.5}$. In addition, 14.6% of cardiovascular deaths and 4.0% of COPD were attributed to $PM_{2.5}$ exposures above a threshold of 8.8 $\mu g/m^3$. In many developing countries, $PM_{2.5}$ is a significant (and growing) cause of health burden.

Session 1. Regulatory Needs

Mobile Source Air Toxics – EPA Programs and Perspectives: *Marion Hoyer; EPA*

EPA uses the National-scale Air Toxics Assessment (NATA) with inputs from the Motor Vehicle Emissions Simulator (MOVES) model to assess the contribution of mobile sources to cancer and noncancer risks from air toxics in the U.S. The species of greatest concern include benzene, diesel PM, 1,3-BD, naphthalene, formaldehyde, acetaldehyde, acrolein, and polycyclic aromatic hydrocarbons (PAH). Dramatic reductions in these MSATs have been achieved by a combination of regulatory and voluntary actions. Total MSAT emissions have been reduced from approximately 2.9 million tons in 1990 to 1.5 million tons in 2008, with further reduction to 0.5 million tons being projected in 2030. Ambient benzene levels decreased sharply following implementation of the RFS2 regulations, which include controls on gasoline benzene levels. Implementation of Tier 3 light-duty vehicle emissions standards will further reduce MSAT emissions, although this requires many years to realize full benefit, due to the slow turnover of the fleet.

Diesel PM is an area of high priority for EPA. Implementation of stricter heavy-duty engine emissions standards (which began in 2007 for on-highway vehicles and 2012 for non-road vehicles) will be very helpful, but require a long time for full fleet turnover. To achieve emissions reductions from older technology engines, EPA has introduced the National Clean Diesel Campaign. Experimental results from the Advanced Collaborative Emissions Study (ACES), which was conducted by the Health Effects Institute (HEI) and the Coordinating Research Council (CRC) have shown 98% reduction in PM from a 2007 heavy-duty engine, as compared to typical pre-2007 engines. Furthermore, animal studies showed no adverse health effects from lifetime exposure to the exhaust from this 2007 engine.

Lead emissions are of growing concern, resulting mostly from piston-engine aircraft, which typically operate out of small, general aviation airports. In the U.S., there are approximately 2000 general aviation airports, as compared to only 500 commercial airports. The health concerns are greatest for the 10 million people who live within 500 m of general aviation airports. EPA is likely to propose an endangerment finding in 2017, to indicate that lead emissions from piston-engine aircraft may reasonably be anticipated to endanger public health and welfare.

Mobile Source – Environment Canada Regulatory Program: *Josée Lavergne; Environment Canada*

In Canada, mobile source emissions regulations are under the auspices of Environment Canada (EC). The *Canadian Environmental Protection Act of 1999* provides the legal framework

for regulating air pollutant emissions from on- and off-road mobile sources. These regulations are well aligned with U.S. EPA's regulations, although there are some differences in administrative requirements between EC and EPA. Current light-duty (LD) vehicle emission standards are equivalent to U.S. Tier 2 standards. More stringent Tier 3 standards will be implemented later this year.

Trends in LD and heavy-duty (HD) mobile source emissions in Canada were presented, covering the period from 1985 to 2012. Significant reductions were shown for most pollutants and mobile source categories – except for NOx and VOCs from off-road engines/vehicles, which had rather flat profiles over this period. (Presumably, this is because increased usage counteracted the reductions from stricter tailpipe standards.) EC uses EPA's mobile source emissions models (MOVES for on-road; NONROAD for off-road) to determine fleet-wide emissions; although Canadian-specific inputs are used for fleet composition and meteorology.

EC has conducted limited engine/vehicle tests to characterize MSAT emissions, but primarily, they rely upon EPA and other's data. In 2011, a federal-provincial-territorial Mobile Sources Working Group was established to address emissions from the mobile source sector by sharing information and identifying areas of joint interest among jurisdictions. This Working Group has adopted an action plan that includes support for advanced transportation technologies, encourages proper vehicle maintenance, and encourages emissions reduction from the in-use legacy diesel fleet.

Characterizing and Reducing the Health Risks from Freight Operations: *Cynthia Marvin; California Air Resources Board (ARB)*

Freight operations contribute a significant fraction of emissions in California, and are estimated to be responsible for 38% of the State's total air toxics cancer risk. These operations include not only the well-recognized rail yards and seaports, but also distribution centers, warehouses, high traffic roadways, and border crossings. Over the past decade, ARB has conducted several health risk assessments in freight operation "hot spots," – including the Ports of Los Angeles and Long Beach, the West Oakland area, and several major rail yards. In all cases, unacceptably high cancer risks have been calculated. For example, excess cancer risk from freight operations in the West Oakland area was estimated to be 10-1200 per million.

To reduce these risks, ARB has implemented a series of "freight rules," which include use of cleaner fuels, stricter tailpipe controls, accelerated phase-out of old engines and vehicles, engine idling rules, and other measures. As a consequence, freight-related emissions of $PM_{2.5}$, NOx, and SOx have all been reduced dramatically since 2005. Also over this time period, it is estimated that freight-related cancer risks have been reduced by 80% at California's largest seaports, and by 40-70% at rail yards.

Efforts for further toxics reductions are underway. In 2014, ARB launched the California Sustainable Freight Initiative to simultaneously address three goals: (1) further reduction in toxics health risks, (2) attain California's ambient air quality standards, and (3) mitigate climate change. Through these initiatives, zero tailpipe emissions are targeted wherever possible, and use of clean-combustion with renewable fuels will be pursued elsewhere.

Drivers to Further Reduce Air Toxic Emissions from Mobile Sources: A Local Perspective: *Henry Hogo (for Philip Fine); South Coast Air Quality Management District (SCAQMD)*

California's South Coast Air Basin (SCAB) is a 4-county region with a population exceeding 16 million. While substantial air quality progress has been achieved in recent decades, the remaining health risk associated with MSATs is still considered unacceptable. Over the years, SCAQMD has undertaken several large measurement and modeling studies to assess the population exposure to air toxics throughout the SCAB. The most recent of these Multiple Air Toxics Exposure Studies (MATES) was conducted in 2012. This so-called MATES-IV study confirmed that considerable progress in reducing air toxics risk was made since the previous MATES-III study of 2005. Total basin wide lifetime air toxics risk was estimated to be 418 per million, which represents a 65% reduction from the MATES-III result. Over 90% of this total risk is attributed to MSATs, with diesel PM alone being responsible for 68% of that risk. (It was pointed out that application of OEHHA's new risk factors would increase these total air toxic risk values by a factor of 2.7.)

To address the on-going air quality concerns in the SCAB, SCAQMD is promoting several initiatives and incentives to accelerate deployment of advanced vehicle technologies and advanced combustion engines. This includes engine replacement and vehicle scrappage programs, clean fleet rules, promotion of future technology vehicles (fuel cells, electrics, etc.), and other measures. Many of these programs will be included in the 2016 Air Quality Management Plan (AQMP) that SCAQMD is now developing to achieve attainment of ambient air quality standards.

Session 2. Vehicle Emission Measurement of MSATs

Biodiesel and Cold Temperature Effects on Speciated Mobile Source Air Toxics from Modern Diesel Trucks: *Ingrid George; EPA*

EPA recently conducted a laboratory experimental program to investigate the emissions effects of operating modern (post 2010) trucks under cold temperature conditions while using diesel and biodiesel fuels. A soy-based biodiesel (B20) was used along with standard ULSD. Testing was conducted on a chassis dynamometer at ambient temperatures of -7 °C and 20 °C. Three light and medium HD vehicles were tested (Class 2B, Class 5, and Class 6), using the urban dynamometer driving cycle (UDDS).

Results showed that carbonyls (particularly formaldehyde and acetaldehyde) were dominant emissions species, comprising over 70% of all VOCs measured. Use of B20 led to small and inconsistent changes in carbonyls. As expected, substantially higher VOC emission rates were seen when testing was conducted at low temperature. This was particularly true for carbonyls. These modern vehicles were equipped with advanced catalytic aftertreatment technologies, which were found to affect MSAT emissions during catalyst regeneration events. Regeneration of both diesel particulate filters (DPF) and NOx adsorber catalysts (NAC) increased VOC emissions, but in different ways. DPF regeneration especially increased

carbonyls, while NAC regeneration increased BTEX (benzene, toluene, ethylbenzene, and xylenes), 1,3-BD, and propylene.

In comparing emission measurements from this test program with literature results of other programs, it was observed that total MSATs are reduced with these modern truck technologies – particularly due to reduced emissions of aromatics. However, carbonyl emissions were not reduced compared to older diesel vehicles.

Semi-volatile Organic Compound Emissions from Heavy-Duty Trucks Operating on Diesel and Bio-Diesel Fuel Blends: *Ingrid George (for Mike Hays); EPA*

This presentation was a continuation of the previous one, in which three modern trucks were tested on a dynamometer at -7 °C and 20 °C while using B20 and ULSD fuels. The focus of this presentation was on aerosol emissions and characterization of semi-volatile organic compounds (SVOCs). The vehicle exhaust sampling system configuration included quartz fiber filters followed by poly-urethane foam (PUF) filters, which allowed for separation of particle-phase and gas-phase SVOCs. Analyses of both fractions revealed that the SVOCs were predominantly in the gas phase. As expected, much higher SVOC emission rates were observed under cold test conditions. The fuel effects were very slight, with little difference seen in SVOC emissions when using B20 compared to ULSD. Based on thermal optical analysis (TOA) of the quartz filters, it was determined that use of B20 resulted in slight decreases in elemental carbon (EC). SVOC emissions increased during periods of regeneration of the vehicles' DPFs.

Unregulated, GHG and Ammonia Emissions from Heavy-Duty Natural Gas Vehicles – Past and Present: *Arvind Thiruvengadam; West Virginia University (WVU)*

This presentation described measurement of MSATs, ammonia (NH_3), and GHG emissions from a variety of natural gas (NG) and diesel HD vehicles tested in-use and on a chassis dynamometer under various driving cycles. Several different engine/emissions control technologies were represented, covering pre-2004, 2004, 2007, and 2010 certification standards. The NG technologies included stoichiometric engines equipped with three-way catalyst (TWC), as well as high pressure direct injection (HPDI) engines with exhaust gas recirculation (EGR), DPF, and selective catalytic reduction (SCR). [Note: the HPDI engines utilized a fueling system that provides simultaneous injection of NG and diesel fuel.]

The large variety of HD engine technologies tested under somewhat different conditions over a period of about a decade makes direct comparisons of emissions results complicated. Nevertheless, some trends/differences are clearly discernable. Older technology NG engines employing lean-burn combustion along with an oxidation catalyst exhibited higher levels of both organic carbon (OC) and elemental carbon (EC) as compared to modern engines that employ stoichiometric combustion and use TWC. However, EC emissions are very low from all NG vehicles. Higher OC emissions were observed from a 2011 diesel engine equipped with DPF and SCR as compared to a 2009 engine equipped only with a DPF. It is thought that the SCR catalyst stores VOC emissions under certain conditions, then releases them under other conditions, thereby contributing to increased OC emissions.

BTEX and carbonyl emissions were much lower with modern, stoichiometric NG engines compared to older, lean-burn NG engines. Up to a 10-fold increase in formaldehyde was seen in modern dual-fueled HPDI engines (NG + diesel fuel) as compared to modern stoichiometric NG engines. Most of the formaldehyde is generated during low-temperature, warm-up conditions. Ammonia emissions of about 1 g/mi were measured from modern NG vehicles equipped with TWC. [Presumably, NH_3 is produced by the TWC, although this was not discussed.] Reduced GHG emissions (CO_2) are observed with NG – 7% lower from modern stoichiometric NG engines compared to 2010 diesel with SCR. However, use of dual-fueled HPDI technology increases CO_2 compared to NG alone, which is attributed to the diesel component of the diesel fuel mixture.

Oxidative Stress from PM Emitted by Various Light-Duty Vehicle Engine Technologies and Fuel: *Chris Ruehl, ARB*

Dynamometer testing of 5 different light-duty vehicle (LDV) types with a total of 5 fuels was conducted to investigate the toxicological effects of the emitted PM. The vehicles included a 1998 Mercedes 420 SEL (high emitter vehicle), 2008 Chevrolet Impala (FFV), 2010 VW Jetta GDI, 2007 Honda Civic CNG, and 2012 Chevrolet Silverado (diesel). By using multiple fuels in some vehicles (e.g., both diesel and biodiesel in the Silverado) a total of 8 vehicle/fuel configurations were tested. From 10 to 29 replicate tests were conducted with each configuration. Average PM emission rates were highest for the “high emitter” vehicle, the gasoline direct injection (GDI) and gasoline port fuel injection (PFI) configurations. The lowest PM emissions were from the diesel, biodiesel, and CNG configurations. It was noted that very high PM emission rates were measured from a few diesel and biodiesel tests. This was attributed to sporadic regeneration events that occurred with this DPF-equipped vehicle.

In vitro assays using rat macrophage cells were used to quantify the reactive oxygen species (ROS) in water extracts obtained from diesel exhaust samples. The amount of ROS per mg of PM was highest (and most variable) from the diesel and biodiesel samples, and lowest for the CNG and high emitter vehicle. The results for E85 and GDI samples were somewhat higher than for the standard PFI gasoline case. In all configurations, ROS/mg PM was much lower for samples collected under highway cruise conditions than under driving modes that included cold or warm start conditions.

When normalizing the ROS results by distance traveled, the assay responses were still highest for the diesel and biodiesel samples. However, on this basis, the E85 and GDI cases were lower than the standard PFI gasoline. Additional experiments were done to determine ROS values before and after filtering the PM extracted samples, using a 0.2 μm filter. Filtering reduced the ROS response in all cases, but had the smallest effect on the E85 samples, and largest effect on the gasoline samples. In the GDI case, filtering reduced the ROS response by 99%. Elemental analysis (by ICPMS) suggested that the filtering effect was related to removal of six specific elements: S, Cu, Ba, Cr, Sb, and Sr.

Gaseous Toxics, Polycyclic Aromatic Hydrocarbons, and Particulate Emissions from GDI and PFI Vehicles on Alcohol Fuels: *Georgios Karavalakis; U.C. Riverside; CE-CERT*

A laboratory dynamometer-based experimental study (using the FTP test) was conducted to investigate the effects of alcohol-blended gasoline on MSAT emissions for three LDVs. Two of the vehicles were equipped with GDI technology (2012 Mazda 3 and 2014 Chevrolet Silverado), while one utilized PFI technology (2013 Ford F150). All vehicles were tested on fuel blends of E10, E15, E20, and Bu16. (Bu16 includes 16% i-butanol, which provides the same oxygen content as E10.) In addition, the Ford F150 and Chevrolet Silverado were FFVs, and were tested with higher alcohol blended fuels: E51, E83, and Bu55.

In all vehicles, emissions of BTEX generally decreased with higher alcohol content, while the effects on 1,3-BD emissions were less clear. The BTEX effects were ascribed to reductions in fuel aromatics level with higher alcohol contents. Carbonyl emissions generally increased with higher alcohol blends. Increased acetaldehyde was particularly noticeable with high ethanol levels, while increased butyraldehyde resulted from high i-butanol levels.

EC/OC results differed significantly among the three vehicles. For both GDI vehicles, the amount of EC dominated over OC when using E10, but EC decreased when going to higher ethanol blends. However, for the PFI vehicle (Ford F150), OC dominated and very little EC was seen with any of the fuels tested. Size distribution measurements indicated that PM emissions from the GDI vehicles resembled typical diesel distributions, being dominated by accumulation mode particles, but also having a significant nucleation mode. For the PFI vehicle, most PM samples were dominated by nucleation mode particles.

Both gas-phase and particle-phase PAHs were measured. In all cases, total PAHs were dominated by the gas-phase portion. The effects of higher alcohol blends varied among the vehicles, with the results showing high variability. However, it appeared that the higher alcohol blends generally resulted in overall lower PAH emissions compared to use of E10.

Ethanol and Air Quality: Influence of Fuel Ethanol Content on Vehicle Emissions: *Tim Wallington; Ford*

Background information was presented about the increasing use of ethanol blends in gasoline, and the potential for further increases in the future. Given this, it is important to understand how fuel ethanol content affects vehicle emissions – both engine-out and at the tailpipe. It was pointed out that increased ethanol content affects numerous fuel properties, and that these changes differ depending upon how the fuel is blended. In particular, there are major differences between “splash blending” and “match blending” of ethanol.

An experimental test program was described in which a single FFV was tested on a chassis dynamometer using splash-blended E0, E10, E20, E30, E40, E55, and E80. Both engine-out and tailpipe emissions were measured under standard FTP test conditions. This vehicle was equipped with a modern emissions control system, which was very effective in reducing all emission species. Tailpipe emission rates of THC and NOx were lower than engine-out by about 2-orders of magnitude, while methane emissions were reduced only 1-order of magnitude (and even less at the highest ethanol blend levels). The lower conversion efficiency for methane was attributed to methane generation in the catalyst, by reaction of precursor species, such as acetaldehyde.

Results showed decreased NOx emissions in going from E0 to E40, then very little change at higher ethanol levels. THC and NMOG had minimum emission rates at mid-range levels of about E30-E40. These results are broadly consistent with other literature reports. Changes in emissions of some compounds are driven mainly by fuel chemistry. This includes ethanol itself, as well as acetaldehyde, formaldehyde, and BTEX. Other emissions (particularly NOx) are influenced more strongly by engine calibration, which differs by manufacturer and vehicle type.

Session 3. Air Quality and Exposure Measurements of MSATs

Results from the Fourth Multiple Air Toxics Exposure Study (MATES IV) in the South Coast Air Basin: *Henry Hogo; SCAQMD*

The SCAQMD has conducted the MATES program since 1987, with periodic intensive sampling periods to characterize toxic exposures and risk in the SCAB. These results are used to evaluate progress in reducing air toxics exposures and to provide direction for future toxics control programs. The MATES IV monitoring program included 24-hour sampling, every 6th day, at 10 fixed sites located throughout the air basin. 37 substances were measured, including several MSATs, such as BTEX, carbonyls, and OC/EC. For the first time, black carbon (BC) and ultrafine particles (UFP) were measured in MATES IV. Besides monitoring, MATES includes development of updated emissions inventories and conduct of air quality modeling.

MATES IV results showed continued reductions in ambient concentrations for most species, compared to MATES III (2004-2006) and earlier programs. Reductions in diesel PM were most dramatic, with the basin-wide average concentration being reduced from 3.5 μg/m^3 in MATES III to 1.0 μg/m^3 in MATES IV. [Note: diesel PM is not measured directly, but is calculated using a ratio of EC/$PM_{2.5}$.] UFP levels averaged around 17,000 particles/cm^3, with higher levels in areas with high traffic density. For example, West Long Beach had the highest UFP concentrations, at around 27,000 particles/cm^3.

On the basis of air toxic risk, the MATES IV results also showed dramatic reductions compared to MATES III. The calculated risk of 1194 per million in MATES III was reduced to 418 per million in MATES IV. (These figures were calculated using the older OEHHA risk factors. Application of the new risk factors would increase both figures.) This risk is driven by diesel PM, which was estimated to account for 84% of the total air toxics risk in MATES III, and 68% of total risk in MATES IV.

International Airport Landing Jet Emissions Results in High Ultrafine Particle Concentrations and Freeway-Like Size Distributions up to 10 km Downwind: *Scott Fruin; USC*

Emissions from aircraft at airports have been a long-standing issue, with most attention focused on take-off emissions and near source impacts. Operations at the Los Angeles International Airport (LAX) are somewhat unusual in that take-offs are generally over water, while landings involve long descending flight paths over highly populated areas. In this study, an

instrumented vehicle conducted numerous N-S transects at varying distances from LAX. These transects crossed the LAX landing patterns, which are predominantly E-W.

Using real-time particle number (PN) measurements, it was possible to define an area of impact as far as 16 km away from LAX, with the impact becoming greater at reduced distance from LAX. It was estimated that at 8 km away, these LAX landings' contribution to PN was 5x background levels; this was reduced to 2x at a distance of 16 km. Based upon similar measurements made near freeways, it was determined that the freeway contribution to these impacts was small.

Particle size characterization was also conducted, and showed that the aircraft-related PM was primarily in the small 20-40 nm range, typically associated with fresh, combustion-related emissions (like diesel PM). Dispersion modeling using AERMOD was conducted to confirm the spatial pattern of impact from these landing operations. It was concluded that LAX should be thought of as a complex, 3-dimensional source of air pollutants that can affect large parts of the Los Angeles area.

Filtration and Air Cleaning to Mitigate Exposures to Vehicle-Related Air Toxics Inside Homes Nearby to Roadways: *Brett Singer; Lawrence Berkeley National Laboratory*

This presentation described an experimental program sampling various air handling strategies and control measures within a modern house to reduce exposures to vehicle-related outdoor air toxics. Although the focus was on UFP and accumulation mode particles, VOCs and their control were also of interest. Continuous, simultaneous measurements were made inside and outside a single home, located near a major freeway in Sacramento, CA. This unoccupied house, built in 2006, is representative of modern California construction, having an airtight envelope, with a maximum efficiency rating value 6 (MERV6) filter on the return of the air distribution blower used for both heating and cooling.

This standard ventilation system configuration provided substantial indoor protection from outdoor air toxics. For example, typical indoor particle numbers were only 40-60% as high as outdoor levels. Even greater protection was provided by modifying the house to include additional ventilation configurations, higher efficiency filters, and several VOC removal technologies. Several configurations were able to achieve >95% particle removal efficiency, with only small, incremental increases in energy costs.

An Exposure Mitigation Strategy for Children in School Buses: High Efficiency Cabin Air Filtration: *Yifang Zhu; UCLA*

It has previously been shown that even relatively short school bus commutes can represent a significant fraction of daily UFP exposures for children. In the study reported here, 12 school buses in Los Angeles were retrofit with high efficiency cabin air (HECA) filters to reduce indoor concentrations of UFP, BC, and $PM_{2.5}$. The test buses included a range of model years, fuel type, cabin volume, tailpipe location, and other parameters. The buses (without children) were driven over typical school bus routes, with simulated pick-up and drop-off events.

During these routes, concurrent real-time measurement of UFP, BC, and $PM_{2.5}$ were made inside and outside the buses.

Results showed that the HECA filtration systems were highly effective in reducing the ratio of in-cabin levels to outside levels of UFP and BC – by about 90% and 85%, respectively. Reductions of $PM_{2.5}$ were smaller (35-75%) but still significant. It was also demonstrated that the effectiveness of the HECA systems were not diminished significantly by frequent opening of the bus doors, as occurs during normal service.

Evaluation and Deployment of High-Performance Air Filtration Systems in California Classrooms: *Andrea Polidori; SCAQMD*

This presentation focused on a pilot study and full testing program to evaluate the effectiveness of air filtration systems in reducing school classroom concentrations of toxics. In the pilot study, three types of filtration systems were investigated: (1) high performance panel filter (HP-PF), (2) register systems, and (3) stand-alone systems. Simultaneous indoor and outdoor measurements of BC, UFC, and PM were made to assess the effectiveness of these systems. All three approaches were quite effective, with the combination of a register system with HP-PF having the highest removal efficiency of ~90%

In the larger testing program, 15 air filtration devices provided by 9 manufacturers were evaluated in a typical classroom setting within a portable school building. Of these 15 systems, only one panel filter and one stand-alone system fully met the performance requirements in terms of removal efficiency, low pressure drops, and low noise levels. One successful product is now being implemented within 47 schools throughout the SCAB.

Session 4. Atmospheric Modeling and Measurements of MSAT Chemistry and Physics

Remote and Urban Concentrations of Acrolein: Implications for Natural Sources: *Thomas Cahill; Arizona State University*

Based upon animal studies, acrolein is considered a highly toxic air pollutant. Due to its very low reference concentration (RfC = 0.01 ppb, = 20 ng/m^3) acrolein generally ranks high on lists of HAPs (Hazardous Air Pollutants). However, acrolein suffers from analytical problems, as it is highly reactive and quickly degrades if not handled properly, making accurate quantification difficult. In addition, there are numerous sources of acrolein besides mobile sources, making source attribution difficult.

In the experimental study reported here, a new, more reliable analytical methodology was used to sample and quantify acrolein levels at numerous sites throughout California. Approximately 10 sites of 4 different types were sampled: coastal, inland remote, intermediate, and urban. Results showed that summertime background concentrations at the coastal and remote inland locations were about 40 ng/m^3, which is twice as high as the RfC value. The highest concentrations were measured at urban sites in the SCAB, but these were less than an order of magnitude above background levels. Sites located near major roadways did not have

high acrolein concentrations, suggesting that direct vehicular sources do not dominate ambient levels. It has also been shown that indoor acrolein concentrations often exceed outdoor concentrations by a large margin. These observations raise questions about treating acrolein as a standard MSAT. In some ways, acrolein is more similar to ozone. In particular, acrolein is a reactive air pollutant with a low background level. It also has numerous sources, and may be formed in the atmosphere by reaction of precursor species, including vehicle source VOCs.

Determining Source Contributions to Aldehydes Within 3-D Photochemical Models: *Greg Yarwood, ENVIRON*

A new mobile source modeling method was described for allocating ambient aldehyde concentrations to anthropogenic sources. This Path-Integral Method (PIM) relies upon 1st order sensitivities computed by the model to determine the anthropogenic increment to total ambient concentrations above the background case. The PIM approach could be applied to any species in the chemical mechanism that is being used. In this work, the Carbon Bond 2005 (CB05) mechanism was used, within the Comprehensive Air Quality Model with Extensions (CAMx) model to compute source allocations for formaldehyde, acetaldehyde, and higher aldehydes. Modeled scenarios covered the eastern portion of the U.S., using meteorological conditions from July of 2008. Emissions were projected to 2030, with the following approach:

- Mobile source emissions were calculated from MOVES, assuming adoption of LEV III standards and 10 ppmS gasoline
- Area and point source emissions were taken from EPA's 2030 inventory
- Biogenic emissions were taken from MEGAN (Model of Emissions of Gases and Aerosols)

Results were calculated for five receptor locations: New York City, Washington D.C., Cincinnati, Atlanta, and Great Smoky Mountain National Park. At each location, background sources (non-anthropogenic) dominated monthly average aldehyde concentrations, with mobile sources generally contributing <10%. Although direct aldehyde emissions from point sources are comparably small, these sources are still significant due to enhanced secondary aldehyde formation involving NOx emissions. One caveat pointed out in this presentation is that the CB05 mechanism was not designed to predict aldehyde emissions; thus, further work in this area is necessary.

Sources and Chemical Composition of Atmospheric Ultrafine Particles in California: *Mike Kleeman, U.C. Davis*

This presentation discussed source characterization and apportionment of ultrafine particulate (UFP), defined as being $PM_{0.1}$. From previous work, it is known that ambient UFP are toxic (as determined by *in vitro* tests), and that their toxicity varies with sampling location, time of day, and season. UFP source profiles have been determined for several sources, including gasoline vehicles, diesel vehicles, meat cooking, wood smoke, road dust, and others. These profiles have been used in chemical mass balance (CMB) modeling to apportion ambient samples collected throughout California to these sources. This has shown significant changes in UFP source contributions as the sampling location moves from near-roadway, to a community

setting, and to further downwind sites. Also, strong diurnal patterns in UFP source apportionment have been observed.

A year of daily sampling of $PM_{0.1}$ was conducted at a single site near downtown Sacramento. Positive Matrix Factorization (PMF) was used to determine source apportionment over this period. A factor associated with old diesel engines was observed to be significant during the first half of the year, but then declined in importance – perhaps due to implementation of California's Diesel Fleet Rules. Factors associated with regional traffic and residential wood burning were also found to be significant.

Regional chemical transport models have been used to estimate UFP exposure levels throughout much of California. Preliminary epidemiology studies have indicated positive associations between UFP and mortality from Ischemic Heart Disease (IHD). $PM_{0.1}$ exposure values give a better fit of the data than do the corresponding $PM_{2.5}$ data. However, one caveat is that sharp concentration gradients of $PM_{0.1}$ make it difficult to estimate population exposures with a high degree of certainty.

Chemical Composition of Primary Organic Aerosol Emissions from Light- and Heavy-Duty On-Road Vehicles: *Rob Harley; U.C. Berkeley*

Sampling and characterization of vehicle emissions within a highway tunnel (Caldecott Tunnel) in the San Francisco Bay area have been conducted on numerous occasions over the past 20 years. In this presentation, a set of tunnel experiments conducted in 2010 was described. An aerosol mass spectrometer (AMS) instrument was modified to enable characterization of black carbon (BC) in aerosols of 0.1-1.0 μm size, in addition to the normally characterized organic carbon fraction. This so-called soot particle AMS (SP-AMS) utilizes a laser beam and a tungsten vaporizer, which effectively vaporizes both EC and OC, in addition to low-volatility lube oil constituents containing Zn, P, and S.

By operating this SP-AMS in a fast mode, it was possible to capture individual truck plumes. Results showed high EC fractions in aerosols from HD trucks, as compared to gasoline vehicles. However, organic aerosol (OA) compositions from diesel and gasoline vehicles were very similar, and were dominated by cyclo-paraffin compounds (so-called naphthenes), which are major constituents of lube oil. Further evidence supporting a lube oil source of OA is the detection of Zn and P in aerosol samples, in ratios consistent with their lube oil concentrations.

Further characterization of the OA was conducted using a GC-MS technique that utilized "soft ionization" in the form of vacuum ultra-violet (VUV) photo-ionization, in contrast to the more commonly used electron impact (EI) ionization. This mild ionization allowed for greatly improved chemical characterization of the OA constituents, and resulted in a much higher mass closure of >60% for identified species. GC-MS results also confirmed the dominant presence of lube oil in OA from both gasoline and diesel vehicles, with an additional small contribution of unburned fuel in the case of diesel vehicles.

Secondary Organic Aerosol Formation from Ultra-Low, Super Ultra-Low and Partial Zero Emission Vehicle Exhaust: *Yunliang Zhao; Carnegie Mellon Univ.*

In many urban areas, summertime ambient aerosol is dominated by secondary organic aerosol (SOA), as opposed to primary organic aerosol (POA). Major precursors of this SOA are non-methane organic gases (NMOG) from light-duty vehicles. As vehicle emissions standards have been tightened, NMOG emission rates have decreased dramatically. Yet, there is evidence that reductions in SOA have not been commensurate with reductions in NMOG emissions rates. One possible explanation is that although total NMOG has decreased with newer technology vehicles, the NMOG that remains is a more efficient precursor to SOA.

To investigate these issues, a vehicle emissions test program was conducted at ARB's Haagen Smit Laboratory. Several vehicles of increasingly stringent emissions certification were tested on a dynamometer, and the diluted exhaust emissions were introduced into a photochemical smog chamber and a Potential Aerosol Mass (PAM) flow reactor. The vehicle fleet included technologies of the following types: pre-LEV, Low Emission Vehicles (LEV I), LEV II, Ultra-Low Emission Vehicle (ULEV), Super Ultra-Low Emission Vehicle (SULEV), and Partial Zero Emission Vehicle (PZEV).

Emissions measurements confirmed that NMOG emissions decreased in going from older to newer technologies. Smog chamber results showed that substantial concentrations of SOA formed from the pre-LEV, LEV I, LEV II and ULEV vehicles, but not from the SULEV or PZEV vehicles. In the PAM reactor, however, SOA formation was observed from emissions of the SULEV and PZEV vehicles. Reasons for the different results between the smog chamber and the PAM reactor are not fully understood at present.

Air Toxics and Speciation in EPA's Mobile Source Emission Model, MOVES 2014: *Rich Cook, EPA*

The Motor Vehicle Emission Simulator (MOVES) model is used by EPA to estimate mobile source emissions at the national, county, and project level for criteria pollutants, GHGs, and air toxics. This presentation described updates to the 2010b version of MOVES that were made in developing MOVES 2014. Significant changes include: (1) incorporation of recent GHG and fuel economy standards, (2) incorporation of Tier 3 vehicle emissions and fuel standards, and (3) updated activity and emissions data for current in-use vehicles. For the first time, MOVES 2014 incorporates $PM_{2.5}$ and VOC speciation within the model itself. (Previous versions incorporated speciation by means of post-processing routines.) This speciation provides estimates of CB05 mechanism species and PM species needed for aerosol modeling in CMAQ and CAMx. Thus, the output of MOVES modeling can now be used directly in chemical transport modeling.

The air toxics included in MOVES 2014 include gaseous HAPs, PAHs (both gas-phase and particle-phase), dioxins, metals, and fire emissions. The gaseous HAPs (benzene, formaldehyde, acetaldehyde, acrolein, 1,3-BD, and ethanol) are calculated as ratios to total VOCs, which vary with fuel properties and vehicle technology. Comparison with MOVES 2010b showed that MOVES 2014 estimates of total gaseous HAPs were somewhat lower in both 2011

and 2030, for each of three cities modeled. The MOVES 2014 model also estimated small reductions of benzene, but larger reductions of formaldehyde as compared to MOVES 2010b – particularly in the year 2030 (about 50% formaldehyde reduction). The total mass of gaseous HAPs was dominated by gasoline vehicles in both years, being about an order of magnitude higher than diesel vehicles.

Total PAH emissions are more evenly distributed between diesel and gasoline vehicles. For diesel vehicles, MOVES 2014 estimates somewhat lower PAH in both 2011 and 2030. For gasoline vehicles, MOVES 2014 estimates higher PAH in 2011, but lower in 2030. Total metal emissions (Ni, Hg, Mn, Cr, and As) are approximately an order of magnitude higher from gasoline vehicles compared to diesel. For both vehicle types, emissions levels decrease between 2011 and 2030. MOVES 2014 estimates of metals are slightly lower than MOVES 2010, in all cities and years modeled. EPA is currently in the process of incorporating toxics data from nonroad equipment into the MOVES model.

Hybrid Approach for the 2011 National Air Toxics Assessment: *Madeleine Strum; EPA*

This presentation described the development and application of EPA's hybrid modeling approach used in the most recent National Air Toxics Assessment (2011 NATA). With this new approach, dispersion modeling and Eulerian grid modeling systems are merged to estimate fine-scale ambient concentrations within the framework of a multi-pollutant chemical transport model. The Community Multi-Scale Air Quality (CMAQ) regional photochemical model is used to account for complex chemical and physical processes that affect both criterial pollutants and air toxics. The AERMOD dispersion model is used to determine spatial concentration gradients of inert pollutants. The hybrid method combines annual concentrations estimates from both CMAQ and AERMOD.

Advantages of this hybrid approach include improved spatial and temporal concentration gradients of large urban point sources, more appropriate treatment of transport and photochemistry of biogenic and mobile source emissions, and the ability to provide source attribution for fires and biogenic emissions. Two examples were shown to illustrate the improvement in NATA estimates when using the hybrid approach: formaldehyde concentrations in New York City, and benzene concentrations in suburban North Carolina. In both cases, the hybrid approach provided far greater resolution of concentration gradients, as compared to the older, non-hybrid approach.

Session 5. Air Quality and Exposure Modeling of MSATs

The National Air Toxic Assessment (NATA) – Mobile Source Overview: *Ted Palma; EPA*

This presentation provided updates to the data sources and modeling methods used within NATA. The version currently under development is called 2011 NATA, because it is based upon the 2011 National Emissions Inventory (NEI). NATA combines this detailed emissions inventory with atmospheric transport modeling, exposure modeling, and health risk factors to estimate risks associated with chronic inhalation of air toxics. Both cancer and non-cancer risk estimates are generated for about 140 HAPs, with census tract resolution. These

HAPs include numerous MSATS, such as BTEX, formaldehyde, acetaldehyde, acrolein, 1,3-BD, several PAH, and diesel PM. (Note: only non-cancer risks are estimated for diesel PM, as EPA has not adopted a quantitative cancer risk factor for this pollutant.)

Numerous improvements are being incorporated into 2011 NATA, including: (1) use of a new mobile source emissions model (MOVES 2014), (2) use of the hybrid CMAQ/AERMOD approach described above to provide improved temporal and spatial gradients of pollutant concentrations, (3) updated exposure assessment information to account for near roadway exposures, and (4) more detailed emissions data for some high risk categories such as ports and oil/gas production sites. For some pollutants, updated exposure factors were applied, using the Hazardous Air Pollutant Exposure Model (HAPEM7). Besides the numerous output formats used in previous assessments, the 2011 NATA data will be presented on a GeoPlatform to enable visualization of results within an individual census tract. Efforts are also underway to enable display of results on mobile devices. It is expected that the complete 2011 NATA will be released by this summer.

Air Quality Assessment of Alternative Fuels for Low Carbon Fuel Standards: *Donald Dabdub; U.C. Irvine*

This presentation discussed air quality impacts in California of distant scenarios (2050) involving hydrogen fuel cell vehicles (FCVs) and the use of biomass for bio-power vs. biofuel. Both GHG and criteria pollutant impacts were assessed using 3D air quality models. Several different H_2 production approaches were considered for the FCV cases, including steam methane reforming (SMR), coal gasification, and electrolysis using nuclear and renewable sources. H_2 production sites were spatially distributed throughout the SCAB. Modeling results showed greater O_3 and $PM_{2.5}$ benefits for FCVs when using renewably-produced H_2 as compared to fossil based H_2.

California has large biomass resources, especially in the northern and central regions of the State. These resources could be used for electrical power production (by combustion and/or gasification) or for production of transport fuels (bio-CNG and ethanol). By means of various modeling tools, the potential impacts of using these biomass resources for bio-power and biofuels were compared. Modeling results showed significant NOx emissions associated with the collection and transport of the biomass feedstocks. Use of biomass for either bio-power or biofuels gave comparable GHG benefits. However, use of biofuels (CNG) gave O_3 and $PM_{2.5}$ benefits compared to bio-power. Similar modeling assessments could be applied to other MSATs, although no examples were provided.

Using a Regional Air Quality Model to Determine Transportation Contributions to PAH in Urban Air: *Elisabeth Galarneau; Environment Canada*

PAH are classified as toxics under the Canadian Environmental Protection Act, thus requiring efforts to minimize their release into the atmosphere. However, PAH are ubiquitous, arising from numerous natural and anthropogenic combustion sources. Although the overall contribution of mobile sources may be small on a nationwide basis, these sources could dominate exposures in urban areas. Thus, Environment Canada (EC) is developing air quality

modeling methodologies to determine the mobile source contributions to PAH in Canadian cities.

While receptor models are often used to apportion sources of air pollutants, this approach is not suitable for PAH. Major problems are: (1) PAH source signatures are not unique, having considerable overlap among different sources, and (2) some PAH are reactive in the atmosphere, and thus are not conserved between sources and receptors. Because if this, EC is using a forward, grid modeling approach that combines PAH emissions data with meteorology and atmospheric chemistry to estimate PAH concentrations at urban areas of interest. The mobile source contribution to urban PAH is determined by running these models with and without inclusion of mobile source emissions inputs.

Initial work was done with the AURAMS model (A Unified Regional Air quality Modeling System), which has coarse grid spacing (42 km) and incorporates meteorology in an off-line model. Currently, this PAH modeling is being migrated to the on-line GEM-MACH framework (Global Environmental Multi-scale - Modeling Air Quality and Chemistry), which has a much finer grid resolution of 2.5 km. As part of this work, EC has reviewed the literature regarding mobile source emission factors for PAH, and found that the values vary over several orders of magnitude. Further modeling work will investigate the sensitivity of PAH model outputs to this emissions variability.

Cyclist Route Choice, Traffic-Related Air Pollution, and Lung Function: A Scripted Exposure Study: *Michael Jerrett; UCLA*

This presentation described a scripted-activity study in Berkeley, CA, to investigate bicyclists' exposure to air pollutants. Fifteen study participants rode two different routes – one with high traffic, the other with low traffic. Both routes involved approximately 45-min. rides. The high traffic route was on major city streets; the low-traffic route was largely on "Bicycle Boulevards," which are designated residential streets that parallel, but are one block removed from the high traffic city streets.

The bicyclists were equipped with global positioning systems (GPS) devices and instruments for real-time measurement of $PM_{2.5}$, ultrafine particulate matter (UFPM), CO, and BC. Lung function measurements were conducted using spirometry before and after each ride. Results showed that all pollutant measurements were significantly elevated on the high-traffic routes as compared to the low-traffic routes. Using GPS information, spatial variability of each pollutant could be determined. UFPM measurements showed a particularly high degree of variability on the high-traffic route. No statistically significant differences in lung function were noted between the high- and low-traffic routes. This outcome was expected, given the small sample size of healthy subjects (no asthmatics were included). Although much more work is necessary to determine overall health implications, it seems clear that bicyclists can reduce their exposure to traffic-related air pollutants by riding in low-traffic areas.

Modeling of 1,3-Butadiene in Urban and Industrial Areas: *Bernhard Rappenglueck; Univ. Houston*

1,3-BD is of particular interest in the Houston area because of the significant industrial sources located there. Estimated emissions and observed concentrations of 1,3-BD are higher in Houston than in any other major U.S. metropolitan area. Besides its designation as a HAP, 1,3-BD is of concern because of its known influence on O_3 formation and potential role in SOA formation. Air quality modeling simulations were conducted in the Houston area using the CMAQ model with an extended version of the SAPRC99 chemical mechanism, in which the chemistry of 1,3-BD is represented explicitly. Emission inputs include mobile, area, and point sources. Of these, point sources are the largest and most variable. Both 1,3-BD emissions and mixing ratios are higher in industrial areas compared to urban areas. The urban areas are dominated by mobile sources, which are high during daytime, but low at night. The industrial areas are dominated by point sources, which are high during both day and night.

Comparing modeled results with hourly 1,3-BD measurements showed that the model typically underestimated peak concentrations. This discrepancy is most noticeable near industrial locations that are influenced by high episodic emissions of 1,3-BD. Although the CMAQ model is able to capture background concentrations of 1,3-BD quite well, it cannot capture such irregular emission events. This under-prediction of 1,3-BD may also lead to under-prediction of O_3, SOA, and nighttime radicals.

Multipollutant Air Quality Impacts from Ethanol-Fueled Vehicles: Sensitivity to Ethanol Blend and VOC Speciation: *Deborah Luecken; EPA*

The air quality impacts of ethanol usage in LD vehicles have been studied by many researchers, but the reported results are not consistent. EPA has reported that with current low blend levels (satisfying RFS2 requirements) slight increases in O_3 may occur (~0.5 ppb), with little (or no) impact on toxics. Others have reported that with E85, ambient acetaldehyde concentrations may increase, while O_3 and other HAPs may decrease.

To investigate these differences, and to understand how sensitive the results are to input assumptions, a modeling sensitivity study was conducted. The CMAQ model was used, with the SAPRC07 chemical mechanism and the Weather Research and Forecasting (WRF) meteorological model. One year of simulation over the contiguous U.S. was conducted, representing emissions in 2020. 150 gas-phase and 61 aerosol-phase species were modeled. Multiple scenarios were investigated to explore the effects of changes in emissions upon species of interest in both summer and winter. Scenarios included high NOx, alternative biogenic emissions, E0 for all LDV, and E85 for all LDV. In all scenarios except the alternative biogenics case, total VOC levels were held constant – just the VOC profiles were changed.

Results were depicted for five urban areas: Baltimore, Chicago, Atlanta, Houston, and Los Angeles. Using VOC profiles associated with increasing ethanol fuel resulted in reduced monthly average ambient concentrations of xylene in all cities. On the other hand, use of E85 resulted in increased acetaldehyde concentrations, especially during winter months, when primary emissions are responsible for a larger share of total ambient levels. Very little difference in O_3 levels was seen among all the VOC profiles used in these scenarios.

Session 6. Accountability

Air Quality Improvement Due to Emission Reductions in the Southeastern U.S., 1999-2013: *Charles Blanchard; Envair*

As part of the Southeastern Aerosol Research and Characterization (SEARCH) study, a network of 8 well-instrumented air quality measurement sites has been in constant operation since the late 1990's. This long-term record, coupled with meteorological information and emissions inventories, enables detailed investigation of how emission control measures have affected air pollution in the U.S. Southeast.

Over the past 15 years, emissions in this region have been reduced dramatically: 30-40% reductions of CO, VOCs, $PM_{2.5}$, and EC; 60% reduction of NOx; 75% reduction of SO_2. These emission reduction trends are also reflected in ambient measurements. For example, the very large SO_2 emissions reduction, due mainly to controls on electric generating units (EGUs), is mirrored by measured reductions in ambient SO_2 and SO_4 levels. Similarly, NOx emission reductions during this time period are reflected in measured reductions in NOx and other atmospheric nitrogenous species. EC emissions reductions are attributed in large part to mobile source controls, including introduction of ULSD in the mid- to late-2000's. Evidence of these EC reductions is seen in ambient measurements in both urban and rural areas. However, fires from biomass burning, which is another important EC source in the Southeast, have not decreased.

Carbon isotope measurement is a useful way to distinguish between modern and fossil contributions to total carbonaceous aerosol. Preliminary results were shown from analysis of samples from one urban and one rural area in the Southeast. While too early to draw firm conclusions, it appears that the ratio of fossil/modern carbon has decreased between 2004 and 2014.

On-Road Measurements of Emissions from Heavy-Duty Diesel Engines: Impacts of Regulations on Drayage Trucks: *Rob Harley; U.C. Berkeley*

Operation of drayage trucks at the Port of Oakland provides an opportunity to observe real-world emissions changes as engine technology and after-treatment control technology rapidly evolve. Because of state-mandated retrofit and accelerated replacement rules, DPF deployment on the drayage fleet increased from 2% to 99% between 2008 and 2013. Experimental measurements at the Port were made during several field campaigns between 2008 and 2013. Exhaust plumes of individual port trucks were sampled, and concentrations of NOx, NO_2, BC, UFP, and CO_2 were determined. Based upon license plate images, each truck was identified with respect to engine make/model year and retrofit devices.

Results showed that the fleet composition and emission rates changed drastically over a period of 5 years. In 2008, the fleet contained 2% DPF and 0% SCR; in 2011 it contained 54% DPF and 2% SCR; in 2013 it contained 99% DPF and 9% SCR. Over this same period, BC emission rates decreased from about 1.15 to 0.25 g/kg of fuel; NOx emission rates decreased from 33 to 15 g/kg of fuel; and NO_2 emission rates increased from 1.0 to 2.8 g/kg of fuel.

Inspection of individual classes of vehicles/emissions controls showed that 1994-2006 vehicles equipped with retrofit DPF had quite low emission rates of BC, but high NOx. This confirms the in-use effectiveness of the retrofit technology, which is meant to control PM/BC, without affecting NOx. Newer technology engines certified to 2004-2006 standards without a DPF gave relatively high BC emissions, but lower NOx – and especially low NO_2. Still newer engine technologies equipped with DPF had very low BC emissions and reduced NOx compared to engines without DPF. However, these newest technology engines produced higher NO_2 emissions than engines without DPF.

Examining Long-Term Trends in Mobile Source Related Pollutants through Analysis of Emissions, Observations, and Model Simulations: *Christian Hogrefe; EPA*

This presentation described a long-term, 3D modeling effort to investigate relationships between emissions reduction and air quality outcomes. A 20-year period was evaluated using WRF-CMAQ simulations over the contiguous U.S. The CB05 chemical mechanism was employed and a grid size of 36-km was used. Pollutant species of interest included CO, NOx, EC, and VOCs measured at photochemical assessment monitoring stations (PAMS). A critical aspect of this study was development of a self-consistent, county-level emissions inventory that is appropriate over the 20-year period. Modeling was performed to focus on three types of evaluation: (1) spatial average concentrations over the entire modeled domain, (2) detailed analyses at 5 selected urban areas, and (3) analysis of trends by day-of-week.

Emissions, observations, and CMAQ-estimated pollutant concentrations all showed substantial decreases between 1990 and 2010. There was generally good agreement between modeled and observed results for TOL (includes toluene, ethylbenzene, styrene, isopropyl benzene, and n-propylbenzene) and NOx. However, the model significantly overestimated EC, and underestimated CO. Reasons for this are not entirely clear, although it should be remembered that the 36-km model results are compared to point observations, and that analyses were based on a spatially-limited dataset. Day-of-week trends were used to investigate differences between weekday and weekend pollutant concentrations. The observed difference in weekday-weekend TOL and NOx were greater than predicted by CMAQ, whereas the NOx agreement was quite good.

Investigating the Effects of Air Pollution Controls on Pollutant Concentrations in Atlanta: *Ted Russell; Georgia Tech. Univ.*

It is a difficult problem to link specific emission control measures to changes in ambient pollutant concentrations, human exposures, and health impacts. Direct observations of such effects are not possible, and all models have limitations and uncertainties that can lead to unrealistic results. The approach described here is to utilize a variety of methods (including observation-based, model-based, and hybrids) to provide specific, scale-appropriate exposure measures, and to determine how they relate to control regulations. The Atlanta region, which is the focus of this study, is an excellent testbed due to long-term, detailed air quality data provided by the SEARCH Program and EPA's Chemical Speciation Network (CSN). In addition, Atlanta is heavily impacted by mobile sources, making it more likely to detect the effects of specific mobile source control measures.

The time period of interest in this work is roughly 2000-2012. During this period, clear reductions in mobile source NOx and CO emissions have occurred, with similar trends being observed in the atmosphere. Reductions in mobile source EC are not as clear, and there may be a problem with properly allocating EC to gasoline and diesel vehicles.

Because meteorological fluctuations greatly affect pollutant measurements from day-to-day, it is important to remove this factor when investigating any specific day. Mathematical approaches have been developed to achieve this "meteorological detrending," and calculate "detrended" pollutant concentrations for individual days. (Such detrending is not as important when dealing with annual average pollutant concentrations.)

For health assessments of control measures, it is important to estimate what the pollutant concentrations would have been if the measures had not been implemented. Such "counterfactual" concentrations were estimated using various modeling approaches in which emissions were adjusted to remove control measures (such as Tier 2 vehicle/fuel rules and the 2006 HD Highway rules). Results showed that observed daily O_3 concentration ranges are smaller than the predicted ranges in the absence of these control measures. In other words, counterfactual O_3 maximum values are higher, and minimum values are lower than what are actually observed.

Accountability Panel: *Ted Russell, Georgia Tech. Univ.; Rashid Shaikh, HEI; Madeleine Strum, EPA; Susan Collet, Toyota*

This panel was asked to address four sets of questions in their overall discussion of how effective MSAT control programs have been, and how they could be more effective:

1. What baseline information should be required upfront to help demonstrate the effectiveness of mobile source regulatory programs in producing the intended benefits?

2. What observations and methods are useful for isolating the mobile source signal from other emission sources vs. meteorological forcing?

3. How well are data from the current monitoring programs (e.g., PAMS sites, AQ monitoring network), novel data sources such as OBD, and air quality models being utilized to evaluate the impact of regulatory programs that have been promulgated? How could data from OBD increase the effectiveness of emission I/M programs?

4. To what extent can satellite observations be used to discern the mobile source signal? Are we missing observations of some tracers to properly delineate the impact of controls on mobile sources vs. other sectors? How could data from OBD and I/M programs help in this effort?

Susan Collet explained some limitations of OBD systems and their applications. OBD systems do not measure emissions directly, but monitor and report on the operational behavior of emissions control hardware components. The focus of OBD monitoring is on criteria pollutants, not MSAT. Through advanced technology, large amounts of telemetric data are becoming available, but this is raising concerns about privacy.

Madeleine Strum mentioned the usefulness of long-term NATA network data in documenting the effectiveness of MSAT reduction measures. However, as ambient concentrations are decreasing, measurement sensitivity and detection limits are becoming problematic for some species. Near-roadway measurements of MSAT are now becoming more common, and will provide good documentation of progress in the future.

Ted Russell suggested that the Photochemical Assessment Monitoring Station (PAMS) network could be utilized more extensively to investigate long-term MSAT trends. He also discussed the potential of using satellite-based measurements of NOx and other species to improve understanding of regional MSAT trends, although challenges remain in effective integration of satellite data with ground-based data.

Rashid Shaikh explained a conceptual model for accountability research that includes multiple interactions among: (1) regulatory action, (2) changes in emissions, (3) effects on air quality, (4) effects on human exposure and dose, and (5) human health responses. At each step, research can provide evidence for the effectiveness of policy, and can help set priorities for additional studies.