CRC Project A-104

8th CRC Mobile Source Air Toxics Workshop

Coordinating Research Council, Inc.

Sacramento, California

February 13-15, 2017

Co-Sponsors:

American Petroleum Institute (API)

California Air Resources Board (CARB)

Health Effects Institute (HEI)

South Coast Air Quality Management District (SCAQMD)

Toyota

U.S. Environmental Protection Agency (EPA)

The Coordinating Research Council (CRC) held its 8th Mobile Source Air Toxics (MSAT) Workshop in Sacramento, California, on February 13-15, 2017. The Workshop consisted of six oral sessions and one poster session. It included 30 oral presentations and 10 poster presentations. 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 accurately 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
AERMOD	Atmospheric dispersion modeling system
AC	Air Conditioning
AMS	Aerosol Mass Spectrometer
AQMP	Air Quality Management Plan
AQ-SPEC	Air Quality Sensor Performance Evaluation Center
ARB	(California) Air Resources Board
AURAMS	A Unified Regional Air-quality Modeling System
BAU	Business as Usual
BC	Black Carbon
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CAIR	Clean Air Interstate Rule
CAMx	Comprehensive Air Quality Model with Extensions
CARB	California Air Resources Board
CB05	Carbon Bond 2005 (chemical mechanism)
CEPA	Canadian Environmental Protection Act
CFD	Computational Fluid Dynamics
CHS	Children's Health Study
CI	Compression Ignition
CMAQ	Community Multi-Scale Air Quality Model
CMB	Chemical Mass Balance
CMC	Control Monitor Concentration
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRC	Coordinating Research Council
CRUISER	Canadian Regional and Urban Inventory System for Environmental Research
CSN	Chemical Speciation Network
CVD	Cardiovascular Disease
CVS	Constant Volume Sampling
DBE	Double Bond Equivalent
DEF	Diesel Exhaust Fluid
DOC	Diesel Oxidation Catalyst
DOE	U.S. Department of Energy
DPF	Diesel Particulate Filter
DPM	Diesel Particulate Matter
E85	Gasoline blend containing 85% ethanol
EC	Elemental Carbon
ECCC	Environment and Climate Change Canada
ED	(Hospital) Emergency Department

EGR	Exhaust Gas Recirculation
EGU	Electric Generating Unit
EI	Electron Impact (ionization)
EJ	Environmental Justice
EPA	U.S. Environmental Protection Agency
EV	Electric Vehicle
FEM	Federal Equivalent Method
FEV1	Forced Expiratory Volume
FFV	Flex-Fuel Vehicle
FRM	Federal Reference Method
FTIR	Fourier Transform Infra-Red (spectroscopy)
FTP	Federal Test Procedure
FVC	Forced Vital Capacity
GC-MS	Gas Chromatography-Mass Spectrometry
GDI	Gasoline Direct Injection
GEM-MACH	Global Environmental Multiscale – Modeling Air quality and Chemistry
GHG	Greenhouse Gas
GMC	Goods Movement Corridor
GPS	Global Positioning System
GREET	Greenhouse gases, Regulatory Emissions and Energy use in Transportation (model)
HAP	Hazardous Air Pollutant
HAPEM	Hazardous Air Pollutant Exposure Model
HD	Heavy-Duty
HDDV	Heavy-Duty Diesel Vehicle
HEI	Health Effects Institute
HNCO	Isocyanic acid (chemical formula)
HOV	Heat of Vaporization
HPDI	High Pressure Direct Injection
ICPMS	Inductively Coupled Plasma Mass Spectrometry
I/M	Inspection and Maintenance
InMAP	Intervention Model for Air Pollution
I/O	Indoor/Outdoor ratio
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
LTO	Landing and Take-Off (airport activity)
MATES	Multiple Air Toxics Exposure Study
MOVES	Motor Vehicle Emission Simulator (EPA vehicle emissions model)

MSAT	Mobile Source Air Toxic
N_2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standard
NAC	NOx Adsorber Catalyst
NAPS	(Canadian) National Air Pollution Surveillance
NATA	National-Scale Air Toxics Assessment
NATTS	National Air Toxics Test Site
NEI	National Emissions Inventory
NG	Natural Gas
NH_3	Ammonia
NMHC	Non-Methane Hydrocarbon
NMIM	National Mobile Inventory Model
NMNEHC	Non-Methane Non-Ethane Hydrocarbon
NMOG	Non-Methane Organic Gases
NOx	Oxides of nitrogen
NPRI	(Canadian) National Pollutant Release Inventory
O_3	Ozone
OA	Organic Aerosol
OAQPS	(EPA) Office of Air Quality Planning and Standards
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
PM	Particulate Matter
$PM_{2.5}$	Fine Particulate Matter (diameter < 2.5 μm)
PMF	Positive Matrix Factorization
PMI	Particulate Matter Index
PN	Particle Number
PNC	Particle Number Concentration
POA	Primary Organic Aerosol
POLA	Port of Los Angeles
POLB	Port of Long Beach
PZEV	Partial Zero Emission Vehicle
RfC	Reference Concentration (exposure for carcinogenicity)
RFG	Reformulated gasoline
RFS2	Renewable Fuel Standard
RON	Research Octane Number
ROS	Reactive Oxygen Species
SCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District

SCR	Selective Catalytic Reduction
SEARCH	Southeastern Aerosol Research and Characterization
SO_4	Sulfate
SI	Spark Ignition
SLAMS	State/Local Air Monitoring Stations
SOA	Secondary Organic Aerosol
SOx	Oxides of sulfur
SULEV	Super Ultra-Low Emissions Vehicle
SVOC	Semi-Volatile Organic Compound
TAC	Toxic Air Contaminant
THC	Total Hydrocarbons
TOA	Thermal Optical Analyzer
TRL	Technology Readiness Level
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
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
WHO	World Health Organization
WRF	Weather Research and Forecasting model

Overview of the 2017 Mobile Source Air Toxics (MSAT) Workshop

Plenary Session. This session consisted of four presentations that helped introduce the topic of MSATs, provide overviews of MSAT trends, and identify on-going areas of concern. A keynote presentation by EPA highlighted the progress that has been made on a national basis with respect to monitoring, inventories, and ambient modeling of MSATs. Over the past 15 years, average ambient concentrations of most air toxics, including MSATs, have declined dramatically. Some analytical challenges remain regarding collection of reactive species and detection limits for numerous trace species. Onroad and nonroad mobile sources contribute nearly equally to total MSAT emissions. Significant improvements have been made to the modeling approaches and databases used to assess the impacts of air toxics on human health. EPA's most recent assessments indicate that the largest driver for cancer risk is formaldehyde, with mobile sources being responsible for about 25% of this risk.

A presentation by CARB showed similarly dramatic reductions of MSATs in California. Based on the methodology used to assess statewide cancer risk from exposure to all toxic air contaminants (TACs), the improvement between 1990 and 2012 has resulted in a risk reduction from 3000 to 730 per million people. Diesel PM is the largest driver of this risk. Much of this improvement is attributed to implementation of cleaner vehicles and fuels. Concerns still remain about disproportionate exposure to MSATs in high traffic areas and near shipping ports, railroads, and airports.

R&D efforts are underway by DOE Laboratories and partners to optimize next generation fuels and engines together, thereby developing combinations having improved performance, efficiency, and sustainability. This "Co-Optima" program was described in a presentation by NREL. One area of investigation is focused on improved understanding of the various chemical and physical effects of ethanol-blended fuels, and their impacts on combustion and emissions. Considerable work is also being done to understand relationships between fuel composition and operation of advanced-technology emissions control systems.

A final presentation in this session summarized a laboratory testing program involving over 20 light-duty vehicles covering model years 1990 to 2014. As vehicle technology advanced, exhaust emissions (including MSATs) decreased substantially. For the most advanced gasoline vehicles, almost all VOC emissions occur during the first 45-seconds of cold start operation.

Session 1: Regulatory Needs. This session consisted of presentations given by representatives of four regulatory agencies: U.S. EPA, CARB, Environment and Climate Change Canada (ECCC), and California's South Coast Air Quality Management District (SCAQMD). These regulators were asked to discuss the MSAT issues of greatest concern to them, regulatory approaches towards advancing these concerns, and what additional work is needed in this area. EPA reported that total, nationwide MSAT emissions had been reduced 50% between 1990 and 2008, and that another 50% reduction was expected by 2030. This progress was attributed to fleet turnover and a series of vehicle and fuel regulatory programs. EPA is also focusing efforts on local and regional-scale situations where higher MSAT exposures are possible, such as communities in proximity to high traffic corridors and other major emissions sources. The regulatory approaches applied to vehicular emissions by ECCC closely parallel those by EPA. As in the U.S., long-term monitoring, modeling, and inventory development in Canada also show dramatic, nationwide emissions reductions.

CARB expressed concern about excessive NOx emissions from segments if the HD fleet that operate under low speed/low load conditions, such that the SCR catalyst is not constantly maintained at a high enough temperature to be fully effective. The agency is exploring technology improvements to address this situation, and may develop specific driving profiles to simulate these problematic conditions. With respect to future HD regulations, CARB is considering adopting more stringent NOx certification standards than currently exist, more stringent in-use compliance standards, and improved detection and repair of high emitting engines/vehicles.

Through a series of Multiple Air Toxics Exposure Studies (MATES), the SCAQMD has demonstrated significant improvement in air quality. Yet, the remaining health risks associated with current levels of MSATs are considered unacceptable. Over 90% of health effects attributed to total air toxics is thought to arise from MSATs, with diesel PM being the single largest contributor. To address this, the SCAQMD has established a variety of local initiatives and incentives to accelerate introduction of advanced technology vehicles into the fleet.

Session 2. Measurement and Modeling of Vehicle Emission MSATs. Seven presentations were given in this session, which focused on characterizing emissions from modern vehicles, the effectiveness of vehicle emissions control systems, the utilization of emissions data in modeling applications, and related topics. A presentation by ECCC described the use of a mobile laboratory to characterize pollutant patterns and observe “hot spots” in the greater Toronto area. CARB also reported on the use of a mobile laboratory, which sampled and characterized real-time emissions from several HD truck tractors used to tow a trailer containing the mobile lab. The focus of this effort was on measuring formaldehyde and isocyanic acid while the trucks were driven over a series of routes. While some variation was seen under different driving conditions, overall emission rates were very low. Similarly, engine dynamometer testing by Colorado State University showed extremely low emission rates of isocyanic acid from a modern heavy-duty diesel (HDD) engine, even with excess ammonia dosing in the SCR emissions control unit.

EPA reported on chassis dynamometer testing of three, modern GDI vehicles under both the standard FTP test cycle and the more aggressive US06 cycle. Real-time measurements showed that most of the NMHC emissions occurred within the first minutes of the cold-start phase. The sum of 11 MSAT species constituted about 1/3 of the total speciated VOC emissions. CARB reported on the relative toxicity of PM from a range of vehicle technologies, as determined by simple laboratory toxicity screening methods. Because of their higher PM emission rates, old diesel vehicles have much higher toxicity rates when expressed on a bhp-hr (or mile traveled) basis, but old and new technologies have similar PM toxicities when expressed on a per gram basis.

Based on newer data, nonroad toxics emissions have been updated in the current version of EPA’s mobile source emissions model, MOVES2014a. With these changes, the total amount of gaseous hazardous air pollutants (HAPs) attributed to nonroad sources has increased, particularly formaldehyde, acetaldehyde, and naphthalene. However, two metals of concern (arsenic and chromium-6) and dioxins have decreased substantially.

A life-cycle assessment (LCA) presented by the University of Washington compared relative benefits of several alternative light-duty (LD) vehicle technologies. Cradle-to-grave emissions were processed with a chemical transport model to estimate pollutant concentrations, which were combined with health risk factors to calculate human mortalities and other damages. Results showed that all fossil fuel vehicles

(gasoline, diesel, and natural gas) had similar externality costs of $0.4-0.5/gallon. Similar costs were also estimated for cellulosic ethanol scenarios, while the costs associated with corn ethanol and EVs were considerably higher.

Session 3. Air Quality and Exposure Measurements of MSATs. This session included six presentations regarding measurement of ambient MSATs in "hot spots," mitigation of MSAT exposures in certain settings, use of low-cost sensors for pollutant measurements, and other related topics. Remote sensing measurement techniques were used by FluxSense to quantify emissions from over 100 individual marine vessels at the Port of Los Angeles and Port of Long Beach. Results showed overall NOx emissions to be much lower than assumed in current inventories.

An experimental study conducted by UCLA demonstrated the benefits of sound walls and vegetative barriers in reducing PM concentrations downwind of major roadways. However, the mitigation effectiveness is quite variable, depending upon roadway configurations and meteorological conditions.

The SCAQMD has established an Air Quality Sensor Performance Evaluation Center (AQ-SPEC) to characterize the performance of new, low-cost air pollutant sensors, and compare results with those obtained using established instruments and methods. Such sensors are increasingly being used to create monitoring networks for R&D and regulatory purposes.

Research reported by Tufts University indicated particulate emissions from aircraft near Boston's Logan International Airport could be detected as far as 6-7 km downwind of the airport, despite the complexity of wind patterns and contributions of other emissions sources. These results are largely supportive of similar findings from other airports. CARB reported on how commuters' exposures to PM, black carbon, and gaseous pollutants vary with mode of transportation. Of the modes studied, train commuters had the highest exposure to PM emissions, due to self-pollution that is drawn into the passenger cabins when doors open at stops. However, many other factors also influence an individual's exposure, such as meteorology, time of day, background pollutant levels, etc.

The company called Aclima discussed their work using a Google Street View car to acquire and map real-time pollutant concentrations (NO, NO_2, BC, and PN) while driving over different roadways and in different communities. This activity provides a wealth of data that can be utilized for various purposes.

Session 4. Air Quality and Exposure Modeling of MSATs. Four presentations were given in this session, covering different modeling approaches and outcomes for assessing exposures to MSATs. EPA reported on the most recent National Air Toxics Assessment (NATA), which is used to determine health risks associated with chronic inhalation of 140 identified toxic species. NATA results are reported with spatial resolution corresponding to census tracts. Overall, mobile sources contribute about 25% of the NATA-calculated cancer risk, with the most significant toxics being benzene (from direct emissions) and formaldehyde/acetaldehyde (largely from secondary formation in the atmosphere).

ECCC reported on regional air quality modeling of toxics throughout Canada, and comparison between measurements and modeling results. Good agreement was found for some species in some locations, but poor agreement in other cases. An important factor is the dominance of emissions from the oil and gas sector in specific locations.

EPA has conducted several experimental and modeling studies to investigate the effectiveness of near-road barriers in reducing MSAT exposures. This work shows that both noise barriers and vegetative

barriers can be effective, although the benefits depend upon the specific location and conditions. Air quality modeling studies were conducted by U.C. Davis to investigate the suitability of a central monitoring station to adequately represent the concentrations of $PM_{2.5}$ and $PM_{0.1}$ in the surrounding areas. As expected, the representativeness of these central station values diminishes as the distance from the station increases. Additionally, the degree of representativeness was not uniform across all central monitoring stations, and it was found to vary seasonally.

Session 5. Accountability. This session included five presentations that addressed the question of how effective past emissions control measures have been in reducing MSATs. Periodic sampling campaigns conducted by U.C. Berkeley at the Port of Oakland showed dramatic reductions in drayage truck emissions between 2009 and 2015. Improvements in PM and PN are attributed largely to widespread adoption of diesel particulate filters (DPFs), while improvements in NOx are attributed to adoption of SCR systems.

Georgia Tech reported on "counterfactual" modeling of the greater Atlanta area in which the air quality outcomes of various regulatory interventions were compared to outcomes that would have occurred if these regulations had not been implemented. The regulatory measures considered included the Acid Rain Program, the Clean Air Interstate Rule (CAIR), the Tier 2 gasoline program, and vehicle inspection and maintenance (I/M) programs. Modeled differences in air quality between the real scenario and the counterfactual scenarios were coupled with a health effects model to estimate the benefits of the implemented regulations in terms of emergency department (ED) visits between 1999 and 2013. Results showed that the Acid Rain Program provided the largest benefit in terms of asthma-related ED visits, while the CAIR was most beneficial in terms of ED visits related to cardiovascular disease.

The Southern California Children's Health Study (CHS) was begun in 1992, at which time air pollutant concentrations were considerably higher than today. In a presentation by the University of Southern California, it was shown that lung function growth in a cohort of children identified in 2007 was markedly improved compared to a similar cohort identified in 1994. The researchers concluded that reductions in air pollutants over this period of time are associated with measurable improvements in children's health.

A study by U.C. Berkeley was done to assess the effectiveness of California's goods movement regulations that were implemented in 2006. Based on saturation sampling in Goods Movement Corridors (GMCs) before and after implementation, as well as complementary measurements in non-GMC area, it was concluded that these regulations are effective in achieving their desired benefits.

Finally, a presentation by HEI introduced the concept of a "chain of accountability" to describe the numerous steps that occur between implementing a regulatory action and detecting an effect on human health. Due to the influence of many other intervening factors, a clear health signal is often difficult to discern.

SUMMARIES OF INDIVIDUAL PRESENTATIONS

Plenary Session

Achievements and Challenges in Mobile Source Air Toxics Emissions, Modeling and Observations: *Madeleine Strum, US EPA - OAQPS*

In this Keynote Address, Strum reviewed the achievements and remaining challenges associated with MSATs from a national perspective. She focused on three broad air toxics areas: monitoring data, emissions inventories, and ambient modeling. Most air toxics monitoring in the U.S. is conducted by state and local agencies as part of the State/Local Air Monitoring Stations (SLAMS) network. However, 27 sites – designated as National Air Toxics Test Sites (NATTS) – provide the 'gold standard' of air toxics monitoring as they have employed a consistent methodology in monitoring a large set of hazardous air pollutants (HAPs) over many years. NATTS data show that between 2003 and 2014, average ambient concentrations of MSATs (including benzene, toluene, ethylbenzene, and 1,3-butadiene) have consistently declined in most urban areas, but not in rural or remote areas. In recent years, EPA has supported several community scale grants to provide monitoring and document improvements in mobile source-related pollutants. One example was a study conducted in Anchorage, AK where a 70% reduction in gasoline benzene levels was shown to reduce ambient benzene concentrations by 51%. While significant improvements in monitoring of air toxics have occurred, challenges remain with respect to collection and analysis methods (especially for acrolein) and method sensitivity for many pollutants.

The 2014 National Emission Inventory (NEI) is now available on the EPA website at www.epa.gov/air-emissions-inventories. Mobile source contributions to the inventory (both onroad and nonroad are determined using the MOVES emissions model. The 2014 NEI is improved compared to the previous inventory due to inclusion of newer emissions data for nonroad engines and advanced technology onroad vehicles. In addition, spatial allocation of some emissions has been improved. Onroad and nonroad mobile sources contribute nearly equally to total MSATs. While mobile sources are significant contributors to some MSATs, such as BTEX (benzene, toluene, ethylbenzene, and xylenes), their contributions to overall emissions of aldehydes (formaldehyde and acetaldehyde) are quite small, as these secondarily-formed pollutants are dominated by biogenic sources.

In modeling work to support the National Air Toxics Assessment (NATA), EPA uses a hybrid approach in which photochemical grid modeling is combined with dispersion modeling, and is applied to the entire contiguous U.S. using a 12-km grid. The Community Multi-scale Air Quality (CMAQ) photochemical model is used along with the AERMOD dispersion model. Significant modeling improvements have been made, including incorporation of HAPs into CMAQ, updated chemical mechanisms, and improved treatment of boundary conditions. Overall NATA results show that the largest driver for cancer risk is formaldehyde, with mobile sources being responsible for about 25% of this risk. The largest driver for non-cancer risk is acrolein, with mobile sources being responsible for about one-half of this risk.

Exposure to MSATs in California Communities: *Linda Smith; CARB*

This presentation began with a brief discussion of adverse health effects associated with air pollution in California, with a focus on traffic-related pollutants. Proximity to traffic has been shown to correlate with decreased lung function in children. Also, there is now evidence that traffic pollution increases the risk of children developing asthma, not just exacerbating existing asthma conditions. Other health

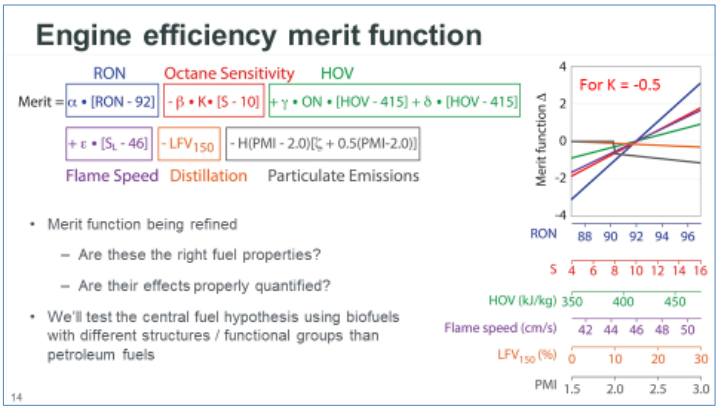
impacts associated with traffic pollution include adverse birth outcomes, obesity, behavioral effects, leukemia, and cardiovascular effects. Over the past 25 years, California communities have experienced significant reductions in ambient concentrations of toxic air contaminants (TACs), with much of this improvement due to reduced MSATs. As a consequence, the estimated cumulative cancer rates due to TACs in California have been reduced from 3000 per million in 1990 to 730 in 2012. Further reductions are expected in the future as existing regulations come into full effect, and new regulations are implemented. The largest driver of this cancer risk is diesel PM (DPM) emissions, which are attributed with about 70% of the total risk in 2012.

CARB has developed a program called CalEnviroScreen to help identify communities that are disproportionately affected by the impacts of pollution. This program is being used to compare long-term trends in traffic pollutant concentrations in so-called Environmental Justice (EJ) communities with non-EJ communities. During the past 25 years, average DPM and CO concentrations have declined significantly, in both EJ and non-EJ communities, with a faster rate of decline in EJ communities. However, pollutant exposures in communities located near mobile sources continue to be of concern. This includes areas near busy roadways, shipping ports, railroads, and airports. In addition, CARB is investigating personal exposures of individuals while traveling using various modes of transportation. Infiltration of outdoor MSATs into personal vehicles is highly variable, with indoor/outdoor (I/O) ratios ranging from 0.05 to 0.95. Excessive buildup of CO_2 (from exhaled breath) has been observed in some situations. CARB is also developing a Technical Advisory document that will provide urban planners with strategies for reducing exposures to pollutants near high-volume roadways. These strategies include urban design, roadside features, traffic management, and use of high efficiency filtration.

Overview of the DOE Co-Optima Program and Emission Control: *John Farrell; NREL*

The Co-Optima Program is a large, multi-year R&D effort involving nine national laboratories along with several industry and academic partners. The FY2017 budget is about $25 million for the national labs, and an additional $7 million for university engagement. The main goal of Co-Optima is to optimize fuels and engines together, thereby developing combinations having improved performance, efficiency, and sustainability. This is meant to overcome the current situation whereby the availability of existing fuels constrains future engine design. Parallel efforts are underway involving work with both spark ignition (SI) and advanced compression ignition (CI) engine technologies suitable for applications in light-, medium-, and heavy-duty vehicles. One area of focus in the SI area is identification of bio-blendstocks that could be mixed with petroleum blendstocks to produce high performance fuels. However, Co-Optima is focused on identifying fuel properties that optimize engine performance, independent of composition.

Co-Optima has defined an 'engine efficiency merit function' for rating the overall performance of a candidate blendstock. As shown in the chart, this function is a mathematical equation that includes terms for research octane number (RON), octane sensitivity, heat of vaporization (HOV), flame speed, distillation, and PM emissions. Investigations have also been undertaken to explore use of the

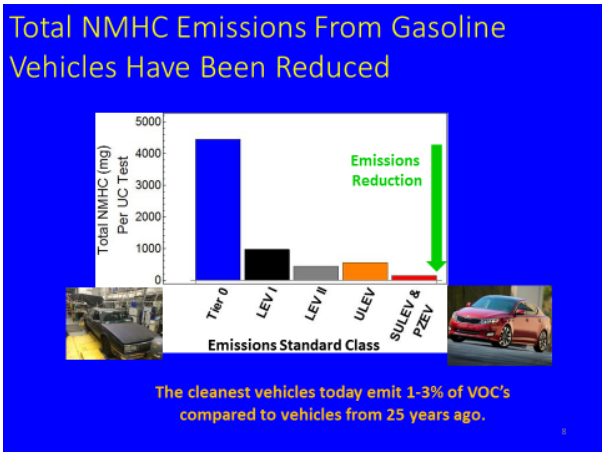


Particulate Matter Index (PMI) as a predictor of PM emissions from SI engines, based upon vapor pressure and double bond equivalent (DBE) values of individual molecular species comprising the fuel. For conventional (hydrocarbon) fuels, PMI provides a reasonably accurate estimate of the fuel's tendency to produce PM/PN emissions. However, there is evidence that the PMI method may not be universally applicable across a range of ethanol blend levels in modern, gasoline direct injection (GDI) engines. Some studies have shown PM reduction with mid-level ethanol blends, while others show increases. The situation is complicated by competition between ethanol's chemical and physical effects. Soot forming tendency would be expected to decrease with increasing ethanol levels, due to oxygenate chemistry that prevents development of graphitic structures. On the other hand, the strong cooling effect that ethanol has upon injection into the combustion chamber may be expected to increase sooting tendency. The overall balance between the chemical and physical effects likely varies with injection geometry, operating conditions, ethanol blend level, and other factors. The Co-Optima program has conducted studies indicating that in some situations, ethanol-blended fuels show interactions between aromatic levels and HOV, such that PM emissions are higher than predicted by the PMI equation. In addition, aromatic oxygenates lead to higher PM emissions than predicted.

Considerable work is also being done involving vehicular emissions control. In SI engines, the focus is on new bio-blendstocks that could reduce emissions associated with cold start and transient operating conditions. In CI engines, the focus is on advanced technologies in which particular fuels could be enablers for improved emissions control systems. To determine optimization in the real-world, other factors besides the engine efficiency merit function must be considered. These include technology readiness level (TRL), sustainability, life-cycle GHG impacts, economics, market situation, and other factors.

Time Resolved Measurements and Cold Start Effects for Mobile Source Air Toxic Emissions from Diesel and Gasoline Vehicles: Impacts of Emissions Controls and Implications for Future Fleet Emissions: *Greg Drozd; U.C. Berkeley*

This presentation described a comprehensive vehicle exhaust sampling and analysis project conducted at CARB's Haagen-Smit Laboratory. Twenty LD gasoline vehicles were tested, along with three LD diesel trucks. The vehicles encompassed model years 1990 – 2014, and included emission technology levels Tier 0, LEV, LEV2, ULEV, SULEV, and PZEV. All vehicles were tested using the California Unified Driving Cycle. This dynamometer drive cycle consists of three phases, with Phase 1 and Phase 3 being identical except for a cold start in Phase 1 and a hot start in Phase 3. As shown in the chart, total NMHC emissions declined dramatically from the oldest to newest vehicle technologies. Similar emission reduction patterns were seen for BTEX species. Nearly all emissions occur during the cold start phase of the driving cycle, with a slight exception for the oldest technology vehicles (Tier 0), where a significant (but still minor) fraction of total BTEX emissions occurred during the hot start phase. Similarly, emissions of acetaldehyde, acetonitrile, and 1,3-BD showed sharp reductions with more advanced emissions control technology. However,



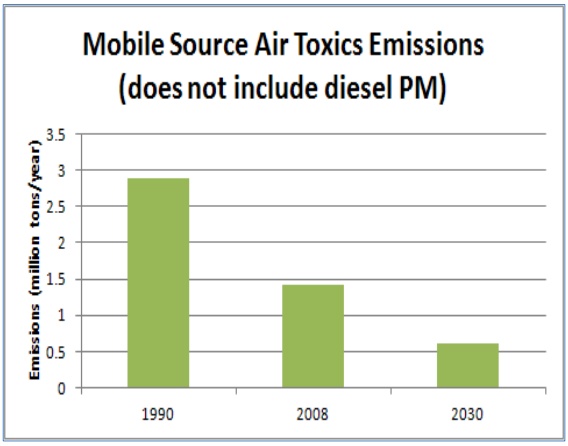
formaldehyde and naphthalene emissions reductions were less pronounced, indicating that to some degree, reductions in MSAT emissions are species dependent.

Time-resolved mass spectrometry measurements indicated that all classes of VOCs showed similar response to emissions controls. These measurements also showed that with the most advanced gasoline vehicles, emissions were primarily restricted to the first 45 seconds of cold-start operation. In contrast, older, Tier 0 vehicles gave measureable emissions over about 150 seconds of both cold-start and hot-start operations. While still higher under cold start, diesel vehicles produced measureable emissions throughout the entire drive cycle, and showed strong response to acceleration events. Based on the emissions tests conducted in this project, a metric was defined to express the distance a vehicle must travel (under hot-running conditions) to provide an equivalent amount of MSAT emissions as produced during a single cold-start phase. This distance was determined to be dependent upon species and vehicle technology, but generally varied from 50 to 150 miles. This suggests that for many commuters, their daily MSAT emissions are dominated by the one or two cold start events they encounter each day, regardless of the distance they travel.

Session 1. Regulatory Needs

Mobile Source Air Toxics – Recent EPA Programs and Future Opportunities: *Catherine Yanca; EPA, Office of Transportation and Air Quality*

EPA defines MSATs as compounds emitted by mobile sources that have the potential for serious adverse health effects. While onroad and nonroad mobile sources are large contributors to overall risks as determined by the National Air Toxics Assessment (NATA), the total amount of MSAT emissions is declining significantly. As shown in the chart, total MSAT emissions were reduced by 50% between 1990 and 2008, and are expected to be reduced by another 50% by 2030, due to fleet turnover and phase-in of new emission reduction programs. Specific EPA regulatory programs that will reduce MSATs include the Tier 3 LD vehicle and fuel standards, the MSAT2 fuel and LD vehicle standards, and several diesel emissions reduction programs. In addition, large reductions in local-scale $PM_{2.5}$ levels are occurring due to implementation of reduced fuel sulfur for marine vessels operating in coastal waters.



Of particular concern with respect to MSATs are local- and regional-scale issues, such as communities in close proximity to high emissions sources, children's exposures and health, and environmental justice. EPA is currently conducting work to understand exposures near roadways and ports, and to explore mitigation methods in these situations. They are also continuing to update vehicle exhaust speciation profiles to better represent the current fleet in modeling of secondary PM. Several further research needs were identified – including investigating impacts of advanced technologies (such as GDI engines), improving speciated air toxic emissions data for large marine engines, improving analytical methods to measure increasingly low levels of MSATs, and collection of additional data to improve spatial allocation of onroad and nonroad MSATs.

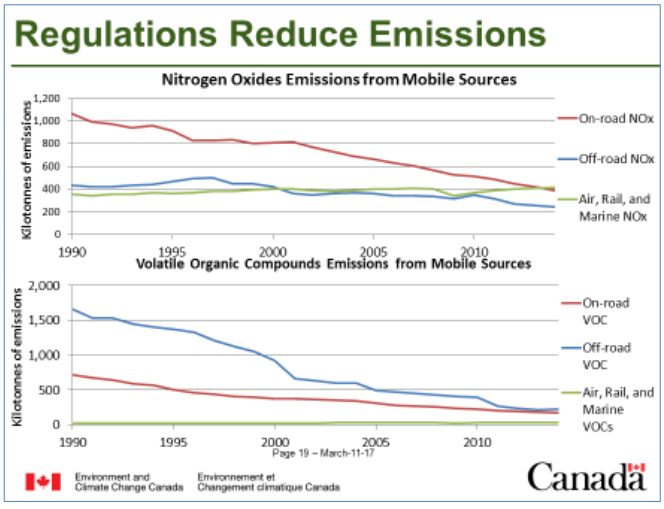
Heavy Duty Engine Program Update: On-Road Plans and Off-Road Opportunities *Bill Robertson; CARB*

Significant reductions of NOx emissions from HD engines (both on-road and off-road) are necessary for California to attain ozone air quality standards. This is made more difficult by the increasing vehicle miles traveled (VMT) by the HD fleet, and the increasing fraction of NOx emissions produced under low speed conditions. There is concern that with low speed operation, the temperature of the SCR catalyst, which is employed on nearly all modern on-road engines, may be too low to ensure maximum NOx control. Based on information obtained from vocational activity data logging, CARB has shown that some vehicle applications result in low SCR temperatures for a significant fraction of their usage time. This is especially problematic for drayage trucks, utility/repair vehicles, and shuttle vehicles. CARB is exploring technology improvements to ensure that low NOx performance is maintained even under these challenging operational conditions. Various approaches are being investigated – such as faster heating of the aftertreatment system, improved delivery of diesel exhaust fluid (DEF) at lower temperatures, and improvements in SCR catalyst formulation. In the future, CARB plans to develop specific vocational driving profiles, and may propose a new 'low load cycle' for use in engine certification.

With respect to future on-road HD regulations, CARB is focused on three areas: (1) introduction of cleaner engines having lower NOx emissions than the current 2010-technology engines, (2) more stringent in-use compliance programs and standards to ensure satisfactory emissions control over the entire lifetime, and (3) identifying and fixing high emitting vehicles – possibly through introduction of a HD inspection and maintenance (I/M) program. In the off-road area, CARB has noted that many Tier 4 engines are able to meet PM emissions certification levels without use of a diesel particulate filter (DPF). This is of concern because inclusion of a DPF would give even greater PM reductions, and would provide protection against high emission episodes resulting from off-cycle operation. Finally, CARB is considering how to align their regulations with the federal Phase 2 GHG regulations for gaseous-fueled engines.

Transportation Section – Emission Regulations at Environment and Climate Change Canada: *Andrew Giallonardo; Environment and Climate Change Canada (ECCC)*

This presentation provided an overview of mobile source emissions monitoring, modeling, and regulatory control in Canada. The majority of the Canadian population lives in the southern part of the country, near the U.S. boarder; hence, this is where most mobile source emissions occur. The transport sector – including both on-road and off-road – is a major contributor to air pollution throughout the country. Based on legal authority granted under the Canadian Environmental Protection Act (CEPA), ECCC has developed a regulatory strategy very similar to the U.S. EPA, whereby performance-based emissions standards are defined for various classes of on-road and off-road engines and vehicles. ECCC and EPA have a joint work plan that promotes regulatory collaboration on vehicle/engine emissions. Consequently, there is good alignment between Canada and the U.S. in terms of regulatory approach, emissions standards, and fuel standards. As required by CEPA, all



environmental regulations are published in a searchable environmental registry at http:www.ec.gc.ca/lcpe-cepa/.

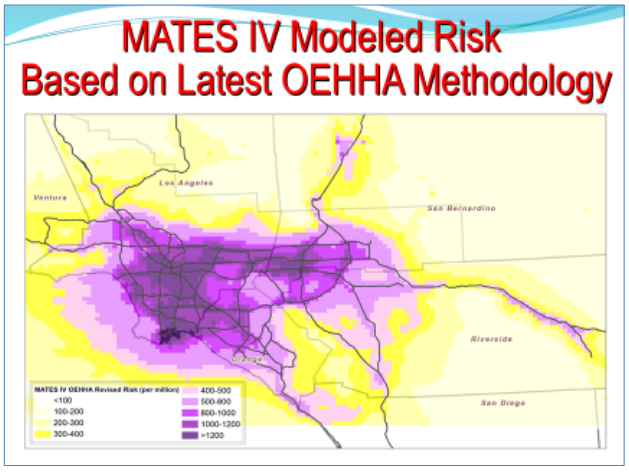
Similar to the U.S. situation, the evolution of regulations has resulted in dramatic reductions of mobile source emissions in Canada over the past 25 years. This is illustrated in the chart, which shows especially large reductions in on-road NOx and off-road VOC emissions. Modeling of on-road and off-road vehicle emissions is done using EPA's MOVES and NONROAD models, respectively; although Canadian-specific inputs are included for fleet distributions, meteorology, and fuel characteristics.

Health Canada has recently completed a human health risk assessment for diesel exhaust emissions in Canada. This involved air quality modeling, which showed that the locations most at risk include large urban areas, trucking routes connecting major cities, and intensive agriculture and mining areas. It is estimated that diesel emissions are associated with 710 premature mortalities (2015 data), with 65% of this due to $PM_{2.5}$, 32% from NO_2, and 3% from O_3. Significant numbers of acute respiratory symptom days, hospital admissions, emergency room visits, and other adverse outcomes were also attributed to diesel emissions. Modeling simulations suggest that on-road and off-road sources contributed approximately equally to these health impacts.

Need for Further Reductions in Air Toxics Exposure from Mobile Sources: *Henry Hogo; 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. Within the basin are over 12 million gasoline vehicles and 260 thousand diesel vehicles. Despite tremendous air quality improvements in recent decades, the remaining health risk associated with MSATs is still considered unacceptable. Air toxics are currently thought to contribute to 4100 premature deaths per year in the SCAB. Besides the traditional health concerns regarding respiratory and cardiovascular conditions, there is growing concern about linkages between air pollutants and other adverse conditions – including autism, ADHD, obesity, and suicide.

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 2012-2013. This so-called MATES-IV study confirmed that considerable progress in reducing air toxics risk was made since the previous MATES-III study of 2004-2006. 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. Air quality modeling based on MATES-IV emissions inventories has shown that the greatest risks due to air toxics occur in traffic-dense areas. As shown in the graph, cancer risk can exceed 1,200 per million in some locations. The main MSATs contributing to these risks are benzene and 1,3-BD from gasoline sources, and $PM_{2.5}$ from diesel sources.



There are already numerous federal and state regulatory and incentive programs to promote accelerated deployment of advanced vehicle technologies and advanced combustion engines. However,

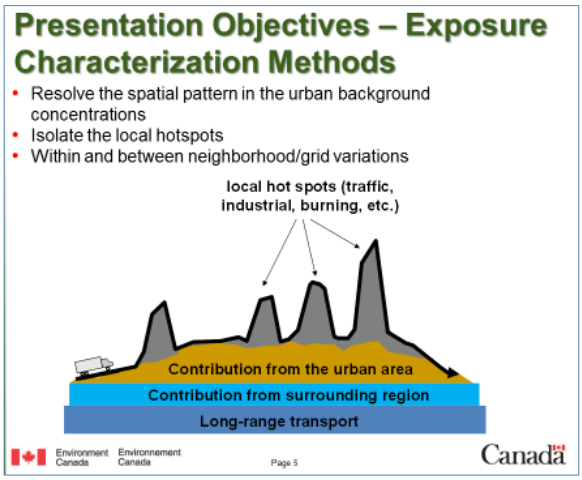
SCAQMD is going beyond this by instituting several local initiatives and incentives. These include engine replacement and vehicle scrappage programs, clean fleet rules, promotion of future technology vehicles (fuel cells, electrics, etc.), and other measures. Many of these programs are included in the 2016 Air Quality Management Plan (AQMP) that SCAQMD is now developing to achieve attainment of ambient air quality standards.

Session 2. Measurement and Modeling of Vehicle Emission MSATs

Mapping VOCs Across a Large Urbanized Region for Exposure Modeling: Neighborhood Scale Variations from the High Traffic Urban Core to the Suburbs: *Jeff Brook; ECCC, Air Quality Research Div.*

This presentation described the deployment of a mobile lab to measure ground-level air pollutants throughout the greater Toronto area. The mobile lab, called the Canadian Regional and Urban Inventory System for Environmental Research (CRUISER) was systematically driven 20 days in summer and winter to repeatedly cover several urban and suburban areas. A large number of pollutants – including NO, NO_2, BC, $PM_{2.5}$, ultrafine particle counts, and VOCs – were continuously measured on a 1-5 sec. time interval. It was determined that approximately 15 independent visits to the same location were required to adequately characterize the pollutant behaviors in that location. The wealth of collected CRUISER data was aggregated, using various processing techniques to properly combine and weight the measurements. From this information, it is possible to construct gridded maps of pollutant concentration, and to identify the location of specific 'hot spots' having unusually high concentrations.

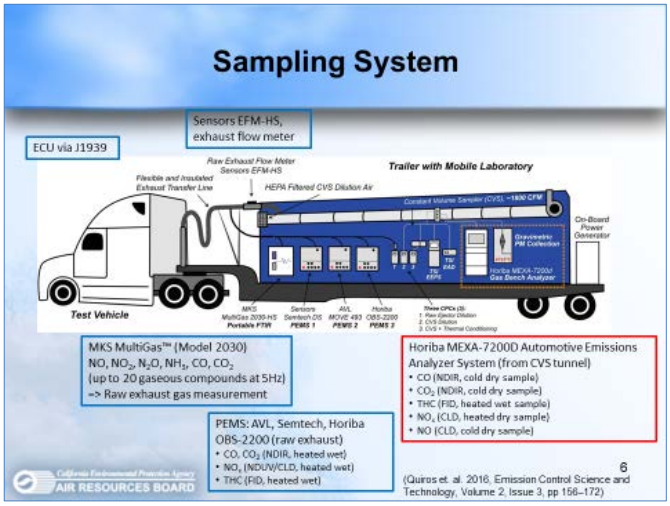
Brooks used the chart shown here to describe the general categories of pollutants that collectively make up air pollutant exposures that individuals experience. One purpose of the CRUISER measurements is to identify and characterize the sharp concentration gradients caused by local hot spots. In the case of benzene, measured concentrations ranged from less than detection limits (<0.1 ppb) to 170 ppb. ECCC is using this highly detailed CRUISER-based information to evaluate and improve their gridded air quality model, called GEM-MACH2.5.



On-Road Emissions of Acetaldehyde and Formaldehyde from Heavy-Duty Vehicles: *Huawei Sun; CARB*

This presentation described an experimental study motivated by interest in determining the extent of toxic air contaminant (TAC) emissions co-benefits resulting from implementation of more restrictive NOx and PM emission standards for HDDVs. The particular focus of was on real-time measurement of two TACs – formaldehyde and isocyanic acid (HNCO) – from HD vehicles while being driven over the road. Six HD test vehicles were used, with one being pre-2010 and the other 5 being post-2010. The older vehicle was equipped with a diesel oxidation catalyst (DOC) and a diesel particulate filter (DPF), but not a selective catalytic reduction (SCR) system. One of the newer vehicles operated on CNG and was equipped with a three-way catalyst (TWC); the four other newer vehicles were all equipped with DOC, DPF, and SCR systems.

As shown in the figure, the sampling system consisted of a mobile laboratory, including a constant volume sampling (CVS) dilution tunnel, on a trailer being towed by the test vehicle. The mobile laboratory contains a variety of sampling and measurement equipment, including a real-time FTIR instrument that was used to measure formaldehyde and HNCO. The validity of this approach was confirmed by demonstrating good agreement between FTIR-based measurements and standard measurement techniques for other regulated pollutants (CO, CO_2, NOx, and THC). The test vehicles were all driven over a series of six prescribed routes, to measure emissions over a variety of real-world operating conditions. Results showed very low emission rates of both formaldehyde and HNCO under most conditions; in fact, instrument detection limits were problematic in some cases. Preliminary route-averaged emission rates from all 6 vehicles were below 0.02 g/mi for formaldehyde, and below 0.10 g/mi for HNCO. However, higher formaldehyde emissions were observed under low temperature operation, and considerable vehicle-to-vehicle variability was seen in emissions of both TACs.



Speciated VOC Emissions from Modern GDI Light-Duty Vehicles: *Ingrid George; EPA, Office of Research and Development*

A laboratory dynamometer-based test program was conducted to investigate speciated VOC emissions (including MSATs) from modern GDI LD vehicles. The three MY2014/MY2015 test vehicles were all certified to Tier 2, Bin 5 levels. The standard FTP driving cycle was used, followed by a portion of the Supplemental FTP, consisting of the US06 driving cycle, which is a more aggressive cycle than the standard FTP. All results reported were based on tests conducted at 72 °F, although further testing is planned at 20 °F.

Results showed significant differences among the three vehicles, with one of the three giving 2-4 times higher emissions for most pollutant species, compared to the other two vehicles. Real-time measurements showed that most NMHC were emitted during the first minute of the cold-start phase of the FTP driving cycle (FTP-1), and that larger emission spikes were seen during the US06 cycle compared to the warmed-up FTP cycle. Through a combination of SUMMA canisters and DNPH cartridges, eleven specific MSAT species were measured. In all cases, the sum of these 11 MSATs was about 1/3 of the total VOC species, suggesting that MSAT emission rates may be approximated by measuring the sum of speciated VOCs. Similar profiles of the top 25 VOCs were observed from each of the three vehicles, although the higher emitting vehicle gave higher emission rates of all species, particularly of species produced by partial combustion, such as propylene.

Investigating Diesels and Emissions Controls as an Atmospheric Source of Isocyanic Acid (HNCO): *Shantanu Jathar, Colorado State University*

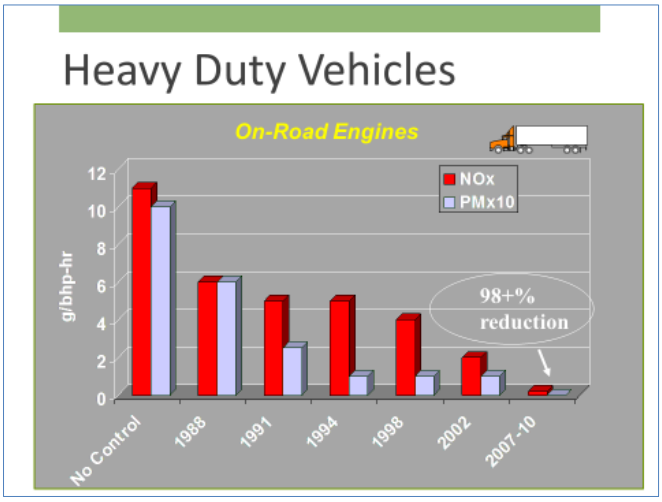
Isocyanic acid (HNCO) is not currently classified as an air toxic (or MSAT), but is thought to be toxic at ambient concentrations >1 ppb. Major primary sources of HNCO are wildfires, although there is some

evidence that diesel exhaust also contains this species. The introduction of SCR emissions control systems has increased interest in investigating diesel exhaust as a source of HNCO – through both primary and secondary formation mechanisms. Because HNCO is produced from urea during normal operation of the SCR system, there is the possibility of an "HNCO slip," analogous to the well-known "ammonia slip" that results from over-dosing of ammonia under certain operating conditions.

An experimental study was undertaken using a single Tier-4 diesel engine operated under several steady state modes, while using both conventional diesel fuel and biodiesel fuel. This engine was equipped with a modern emissions control system that included DOC, DPF, and SCR components. Urea injection was varied from zero to 1.3 times the stoichiometric rate needed to reduce NOx. Measured emission rates of HNCO did not vary with urea injection rate, but was found to be somewhat lower when using biodiesel as compared to conventional diesel fuel. By examining the behavior of diesel exhaust within an oxidation flow reactor, it was shown that the concentration of HNCO can increase by 2-6X when exposed to photochemical aging conditions. Based on these results, chemical transport modeling was conducted to estimate the contribution of diesel exhaust to summertime ambient concentrations of HNCO in Los Angeles. Maximum ambient concentrations were estimated to be 20-110 ppt, which is far below the 1 ppb level of concern.

Relative Toxicity of Old and New Technology Heavy- and Light-Duty Mobile Source PM: *Jorn Herner; CARB*

Transportation is undergoing rapid changes, due to evolving technology, lifestyles, and concerns about air quality and climate. Over the past few decades, dramatic emissions reductions have occurred for both LD and HD vehicles. For example, the chart shown here indicates the evolution of PM and NOx emissions standards for on-road HD vehicles. These vehicle emissions standards, which are meant to protect human health, are set in units of g/mile or g/bhp-hr, but the question remains – Are all grams equal with respect to their health impacts? To help answer this, CARB has conducted a variety of studies to understand how vehicular PM emissions have changed in terms of mass and toxicity. A toxicity screening methodology has been developed and applied to assess the relative toxicity of PM emissions from a set of LD and HD vehicles. Toxicity is expressed in terms of oxidative stress, inflammation, and mutagenicity. The vehicle category "Old Diesel" stands apart from all other vehicle categories depicted here, having a PM emission rate at least 2 orders of magnitude larger than all other categories. ("Old Diesel" is based on testing of a 1998 engine, without PM after-treatment controls.)



Due to its very high mass emission rate, the relative toxicity of Old Diesel per mile is much higher than that of PM from any other vehicle type. Oxidative stress metrics per mile for all other vehicle types were only 5-10% as large as from Old Diesel, while inflammation and mutagenicity outcomes were <2% as large as from Old Diesel. However, on a per mass basis, the toxicity results for PM from all vehicle types, including Old Diesel, were more nearly the same. Herner concluded that the CARB emissions control

programs are effective in reducing toxic emissions, and that the new technologies and fuels tested did not raise any red flags of concern.

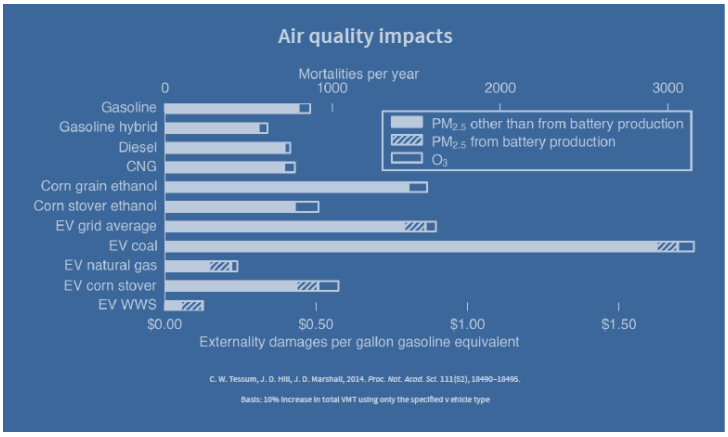
Nonroad Air Toxics in EPA's Mobile Source Emissions Model, MOVES2014a: *Rich Cook; EPA, Office of Transportation and Air Quality*

Nonroad toxics emissions have been updated in the newest version of EPA's mobile source emissions model, MOVES2014a. Previously, nonroad emissions data came from the National Mobile Inventory Model (NMIM), using data and methods developed for the 1999 National Emissions Inventory (NEI). Besides being outdated, there were many other deficiencies in these nonroad data. To improve this situation, EPA identified and analyzed two more recent experimental datasets: one for a 2014 test program involving nonroad spark ignition (SI) vehicles; the other from a 2014 test program of nonroad compression ignition (CI) vehicles. Toxics data in these datasets include VOCs, metals, PAHs, and dioxins.

The updated MOVES2014a model is being used for the first time in developing the 2014 NEI, and will be used in the 2014 NATA. EPA has evaluated the impact of this change in nonroad toxics by comparing nationwide emissions calculated using the old NMIM data and the new MOVES2014a data. With these updates, large increases were seen in most gaseous HAP emissions, especially carbonyls. For example, nonroad formaldehyde emissions increased by 103%; acetaldehyde increased by 63%. PAHs were increased by about 400%, with most of this attributed to naphthalene, a gas-phase PAH that was not included in the older database. Two metals of concern, arsenic and chromium-6, were decreased by a large amount with the new data, while dioxin emissions were reduced to nearly zero. Although these newer emissions data are considered more reliable than in the past, EPA has identified several research needs aimed at further improvement. These include better emissions data from catalyst-equipped nonroad SI engines, Tier 3 CI engines, and CNG/LPG engines.

Spatially Explicit Life Cycle Assessment for Conventional and Alternative Vehicles: *Christopher Tessum; University of Washington*

Life-cycle assessment (LCA) is a tool to estimate emissions and environmental impacts of a vehicle's production and use from 'cradle-to-grave.' This includes impacts associated with upstream processes such as fuel production and transport, which are especially important when considering the relative benefits of alternative vehicle technologies as compared to conventional vehicles. In the work described by Tessum, LCA was conducted to compare the relative impacts of conventional gasoline LDVs with several alternatives, including gasoline hybrid electric, diesel, CNG, corn grain ethanol, corn stover ethanol, and EVs fueled by electricity produced from various sources. The approach utilizes emission factors for most processes as included in the GREET model. These emissions are allocated spatially (throughout the contiguous U.S.) and temporally, and are processed with a chemical transport model called InMAP (Intervention Model for Air Pollution) to estimate pollutant concentrations. Combining this information with health risk factors provides estimates of human mortalities and other damages.



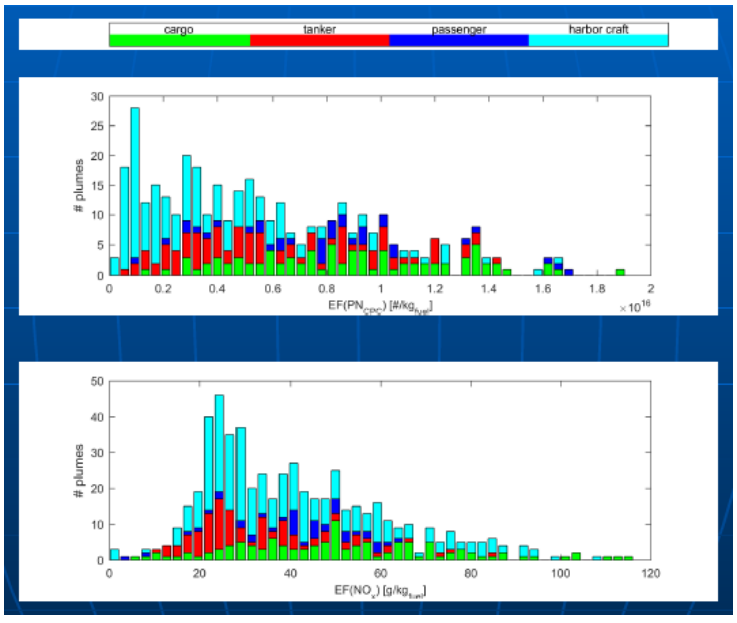
A summary of annual mortality impacts computed using this methodology is shown in the graph. All fossil fuel vehicles have similar mortality impacts, and calculated externality damages of approximately $0.4-0.5/gallon. Corn grain ethanol has significantly higher impacts, largely due to emissions associated with production and use of fertilizers, as well as emissions associated with the utilities used to operate ethanol production plants. EVs can also have substantially higher impacts than conventional vehicles, depending on the source of the electricity. Electricity produced from coal combustion has the highest impacts, while that produced from wind, water, and solar (WWS), has the lowest impacts.

Session 3. Air Quality and Exposure Measurements of MSATs

Remote Quantification of Stack Emissions from Marine Vessels: *Marianne Ericsson; FluxSense*

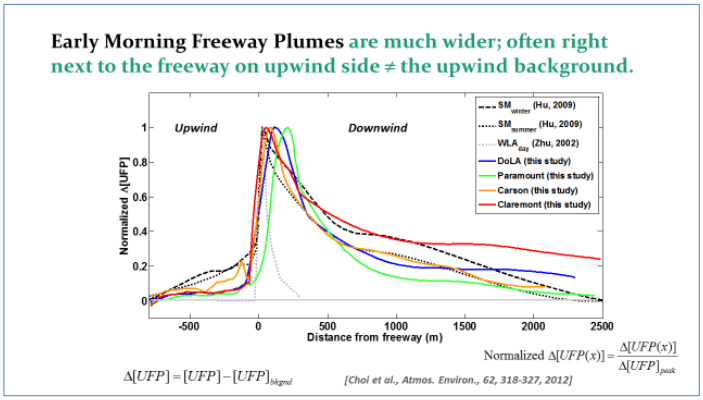
The adjacent ports of Los Angeles (POLA) and Long Beach (POLB) are major sources of air emissions within the SCAB – due to both ships operating in the area and associated ground-based activities. To better understand the influence of ships on air quality, FluxSense, under contract with the SCAQMD, conducted a remote sensing technology demonstration project to measure NOx, SOx, PM, and PN from individual ships while operating near the ports. A combination of sampling techniques (sniffers) and optical techniques were deployed from fixed sites, mobile vans, and aircraft. Emissions concentrations in exhaust plumes were measured relative to CO_2 concentrations, enabling calculation of emission rates in terms of mass per kg of fuel consumed. The vessels being monitored included cargo ships, tankers, passenger ships, and harbor craft.

Measurements were made of 574 exhaust plumes, coming from 137 individual vessels. Frequency distributions of the PN and NOx emissions results are shown in the chart. The median PN result of the entire dataset is 0.49 x 10^{16} particles/kg fuel; the median NOx result is 36.3 g/kg fuel. The NOx emission rates are considerably lower (by about ½) than assumed in the current emissions inventory. Furthermore, NOx emission rates were found to increase substantially with ship speed. The low speed operation of the ships being monitored may explain this discrepancy, as the inventory does not assume a strong dependence of NOx on speed. Based on airborne measurements, the net NO_2 flux from the port area was determined to be 311 kg/hr, which is about ½ of the current inventory value. The median ship $PM_{2.5}$ emission rate was 0.61 g/kg fuel, with most of this being identified as black carbon (BC). SOx emissions results confirmed very high compliance with the low sulfur fuel requirements that apply near the ports. The disaggregated emissions results, such as those shown in the chart, highlight the significant contribution of harbor craft. These data will be used to improve the emissions inventory for the SCAB.



Effectiveness of Sound Wall-Vegetation Combination Barriers as Near-Roadway Pollutant Mitigation Strategies: *Suzanne Paulson; UCLA*

Because of relatively high mobile source pollutant concentrations near roadways, there is interest in studying the effectiveness of mitigation strategies, including use of sound walls and/or vegetation. It is well known that pollutant concentrations decay downwind of roadways, though the rate of decay varies, depending upon meteorological conditions and differences between peak concentrations and background concentrations of a given pollutant. The chart shown here illustrates decay of ultrafine particle (UFP) concentrations determined in this study and previous studies. Paulson described an on-going experimental study in which an instrumented mobile platform was used to measure a suite of pollutants while driving on various roadways in northern and southern California. A sophisticated data processing approach was followed to ensure that proper weighting of individual sections of each test run was done and reliable data were obtained. It was determined that about 20 repeat runs conducted under similar meteorological conditions and time of day were required to obtain reasonable averages.



Considerable efforts were made to identify suitable roadway sites having both some type of barrier and no barrier (baseline) in close proximity, and where both locations had similar roadway orientation, traffic mix, slope, and meteorology. At a site in Sacramento, the effects of a soundwall without vegetation were compared to the effects of a soundwall with vegetation. At a site in Santa Monica, the effects of a soundwall with vegetation were compared to the effects of vegetation alone. Overall, the results were quite variable, depending to a large degree upon meteorology. However, it is clear that under typical daytime conditions with moderate, perpendicular winds, all barriers provide some benefit in reducing downwind pollutant concentrations. Use of vegetation in combination with a solid barrier results in slightly enhanced effectiveness, probably due to the extended height of the barrier. Under calm conditions, which often occur during nighttime and early morning, the benefits are less clear. Further work is recommended to better understand these effects.

Development and Application of "Low-Cost" Sensor Technology for Measuring Gaseous and Particle Air Pollutants: *Andrea Polidori; SCAQMD*

Due to recent advances in sensor technology and wireless networking, numerous manufacturers have begun to market 'low cost' devices for measuring real-time air pollutant concentrations. These devices have become popular with individuals and organizations who are interested in monitoring air quality in specific locations. To help evaluate the reliability of these low cost sensors, the SCAQMD has established an Air Quality Sensor Performance Evaluation Center (AQ-SPEC). This center aims to thoroughly and systematically characterize the performance of test sensors, as compared to established federal reference methods (FRMs) and federal equivalent methods (FEMs) that operate at fixed sites. AQ-SPEC utilizes both laboratory testing and field testing of candidate devices used for particulate and gaseous pollutants. In the laboratory, temperature and humidity can be controlled in chambers containing known pollutant concentrations. In the field, side-by-side testing is possible with FRM/FEM devices. Thus far, AQ-SPEC has evaluated over 30 particle and gas sensors, with the findings being reported on a

website at: www.aqmd.gov/aq-spec. Broadly speaking, most PM sensors showed minimal down time and good correlation with FRM/FEM. However, PM sensor calibration is needed in many cases, and some sensors are unable to detect very small particles (<0.5 µm). Most gas sensors also showed minimal down time and good correlation with RFMs when measuring CO, NO, and O_3 alone. However, sensors that measure the sum of O_3 and NO_2 were not very reliable, suggesting potential O_3/NO_2 interferences.

The SCAQMD is also exploring greater use of sensors and sensor networks in their own monitoring work. While individual sensors may be quite inexpensive, large networks become much more expensive due to the many support activities that are required, such as calibration, sensor connectivity, maintenance, data logging and management, data validation and analysis, and data visualization and reporting. Nevertheless, small sensor networks can be extremely valuable in monitoring specific facilities, observing differences before and after implementing process or emissions control changes, identifying 'hot spots' that may be missed by fixed monitoring sites, and other purposes. The SCAQMD is currently executing a US EPA-funded project to evaluate candidate sensors, deploy specific sensors in California communities, develop educational materials for community use, and communicate the lessons learned to the public.

Air Pollution Impacts from Aviation Emissions in Two Study Areas Near Logan International Airport in Boston, Massachusetts, USA: *Neelakshi Hudda; Tufts University*

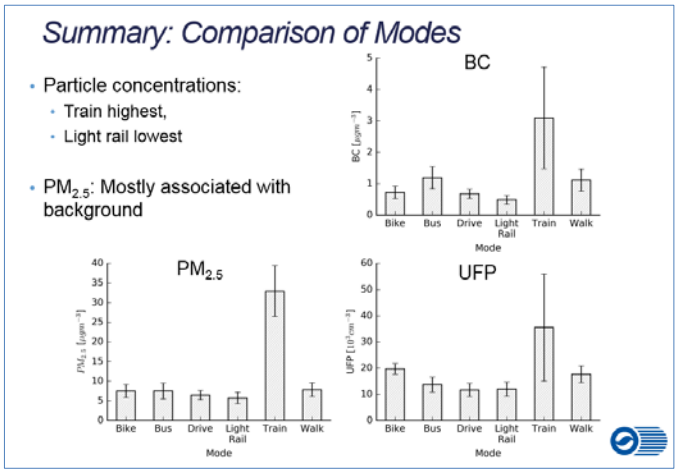
High rates of particle emissions from aircraft have been shown to influence particle number concentrations (PNC) in areas near major airports. For example, impacts have been determined as far as 7 km downwind of Schiphol International Airport in Amsterdam and 20 km downwind of Los Angeles International Airport (LAX). In this study by Tufts University, the impacts of Logan International Airport in Boston upon PNC levels in neighboring areas were assessed. The meteorology at Logan is more complex than at many other airports, having two dominant wind directions: NE-E and SE-S. As shown in the map, during periods of NE-E winds, the Roxbury site is 7.3 km downwind of Logan; during periods of SE-S winds, the Chelsea site is 4 km downwind of Logan. Besides measurements at central monitoring stations, the Tufts team monitored PNC at several residential sites, as noted by the small black dots on the map. Continuous monitoring was conducted for 6 weeks at each of 22 residences. Data analysis showed that PNC levels at Roxbury were 1.3 fold higher when this area was downwind of Logan, while levels at Chelsea were 2 fold higher when this area was downwind. Additionally, there was good correlation between PNC levels and landing & takeoff (LTO) activities at Logan.

It is expected that traffic-related emissions also influence the observed PNC levels at monitoring sites. However, it was still possible to detect the airport signature due to two key differences between the behaviors of traffic emissions and aircraft emissions. First, downwind PNC concentrations from aircraft plumes are not affected much by wind speed, whereas traffic-related concentrations are reduced with increased wind speed. Second, traffic emissions show high correlations between PNC and other pollutants (CO, NO_2, and NOx), whereas aircraft-related plumes show much poorer correlation with these pollutants. The researchers concluded that they could reliably detect the PNC impact of Logan

Airport as far as 6-7 km downwind, despite the complexity of wind patterns and contributions of other emission sources.

Experiments to Determine the Primary Factors that Contribute to Exposure to Traffic Emissions during Commutes: *Nico Schulte; CARB*

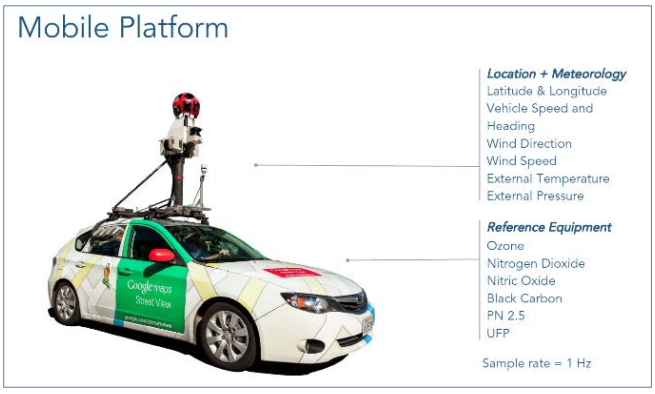
Previous work has shown that relatively high exposures to UFP and BC can occur during commuting activities. However, there is large variability in these results and to-date, no comprehensive study has been conducted to systematically investigate the impact of various factors influencing commute exposures. Schulte's presentation discussed a pilot study conducted in the Sacramento area in which commuters were equipped with portable equipment backpacks to measure BC, UFP, $PM_{2.5}$, CO and GPS location as they underwent their normal commuting activities. The main objective of the study was to develop an understanding of the most important factors that influence in-commute exposures so that practical guidance can be developed to reduce such exposures.



A total of 377 individual commuting trips were monitored, encompassing commuting modes by bicycle, bus, passenger car, light rail, train, and walking. Within a given mode, numerous other factors are important, such as nearby traffic emissions, meteorology, background pollutant levels, routes taken, time of day, ventilation settings, and many others. Schulte briefly summarized BC, UFP, and $PM_{2.5}$ results for several commuting modes. As has been seen before, closing windows and using recirculation AC in passenger cars is quite effective in reducing in-cabin exposures. Commuting by train led to the highest exposures, due to self-pollution that is drawn into the passenger cabins when doors open at stops. Bus cabins also had somewhat elevated BC concentrations, although bus commuters' total exposures were also influenced by their walking/biking to and from the bus stops. Light rail cabins had the lowest levels of BC and UFP, but these commuters' exposures were also significantly affected by their approaching and departing the light rail stations. A comparative summary of average pollutant concentrations measured during 6 different commuting modes is shown in the chart.

Mapping Mobile Emissions using Aclima-Equipped Google Street View Cars: *Melissa Lunden; Aclima*

In partnership with Google, Aclima is using an instrumented vehicle (a Google Street View car) to acquire real-time measurements of NO_2, NO, BC, $PN_{2.5}$, and UFP in several regions and communities within California. With 1-sec. resolution, it is possible to see large variations in pollutant concentrations over very small distances. As expected, BC measurements showed elevated concentrations on freeways, and lower concentrations on arterials and

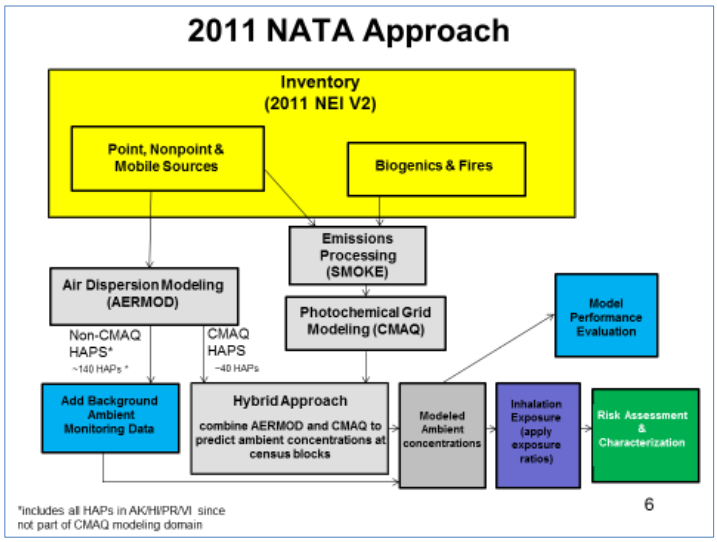


residential streets. One application that was discussed involved measurement of BC concentrations near schools in the Los Angeles and San Francisco areas. Clear differences were seen between more polluted and less polluted school locations in both regions. Aclima plans to publicly launch their California data this year, and to make their database available to scientists and air quality researchers.

Session 4. Air Quality and Exposure Modeling of MSATs

The National Air Toxics Assessment (NATA) – Mobile Source Overview: *Ted Palma; EPA, Air Quality Planning and Standards*

NATA is a modeling assessment that combines a detailed emissions inventory, atmospheric fate and transport modeling, exposure modeling, and health risk criteria to characterize the risks associated with chronic inhalation of outdoor air toxics. Both cancer and non-cancer risk estimates are provided for 140 HAPs, with census tract resolution. The 2011 NATA is the 5th national-scale assessment, which was released to the public in 2015, and represents the current version. Palma cautioned that the 2011 NATA results should not be compared directly with previous versions because not only were emissions updates included, but there were also several changes to modeling approaches and emissions processing techniques. For example, the 2011 NATA improved emission estimates for several sectors, improved dispersion modeling by using a 'hybrid approach' that blends local-scale and long-range air quality models, and improved exposure assessments by using updated human activity data. The overall approach used in the 2011 NATA is summarized in the chart shown here.



Major findings from the 2011 NATA indicate that the national-average cancer risks for air toxics are approximately 40 per million people. This figure is an order of magnitude lower than the value determined by the SCAQMD as part of their MATES-IV Study. One reason for this large discrepancy is that diesel PM, which is a dominant contributor to the SCAQMD's overall risk, is not included in the NATA cancer risk, as EPA has not adopted a unit risk factor for DPM. Overall, mobile sources contribute about 25% of the 2011 NATA cancer risk, and 50% of the non-cancer risk. The pollutants that contribute the most to cancer risks are formaldehyde and acetaldehyde (largely from secondary, photochemical activity) and benzene (from on-road mobile activity). The MSAT with the greatest contribution to non-cancer risk is acrolein. As expected, MSAT-related risks are higher in urban cores than in other areas. In 12 specific urban areas, total cancer risks were estimated to exceed 100 per million people. Much more information about NATA and its results are available on the EPA website at www.epa.gov/national-air-toxics-assessment.

Toxic Volatile Organic Air Pollutants Across Canada: Multi-Year Concentration Trends. Regional Air Quality and Source Apportionment: *Craig Stroud, ECCC*

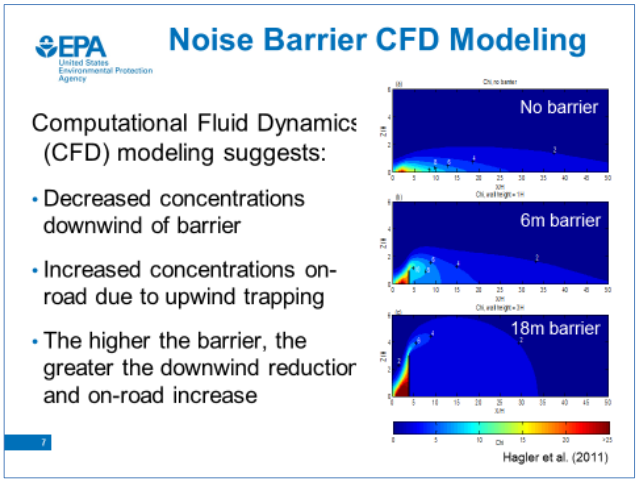
A project was conducted by ECCC to develop air quality modeling for six air toxics: benzene, 1,2,4-trimethylbenzene (1,2,4-TMB), 1,3-BD, formaldehyde, acetaldehyde, and acrolein. A Unified Regional Air Quality Modeling System (AURAMS) was used for this project. Mobile source emissions were generated using the Canadian version of MOBILE6.2; stationary emissions were obtained from the 2006 Canadian National Pollutant Release Inventory (NPRI) and the 2005 U.S. National Emissions Inventory (NEI). Biogenic emissions were modeled using BEIS v3.12, with Canadian-specific inputs. Simulations were performed for both summer and winter seasons, using base year meteorology from 2006.

Air quality modeling simulation results were compared to measurements from Canada's National Air Pollution Surveillance (NAPS) program, which includes speciated VOC measurements from about 50 stations throughout the country. The model predictions showed good agreement with measurements of formaldehyde and acetaldehyde throughout the country, some agreement with benzene and 1,2,4-TMB, but very poor agreement with 1,3-BD and acrolein. Agreement between model predictions and satellite measurements of formaldehyde, NO_2, and CO was excellent, indicating that the model itself performed quite well. Other results from the study showed that mobile source emissions were responsible for 40-60% of benzene in major cities, but much less in rural locations, where oil and gas operations dominated. Similarly, for 1,2,4-TMB, mobile sources dominated in most cities, except in cases where oil and gas operations were prevalent.

Evaluating the Effects of Near-Road Solid and Vegetation Barriers on MSAT Exposures: *Rich Baldauf, EPA, Office of Research and Development*

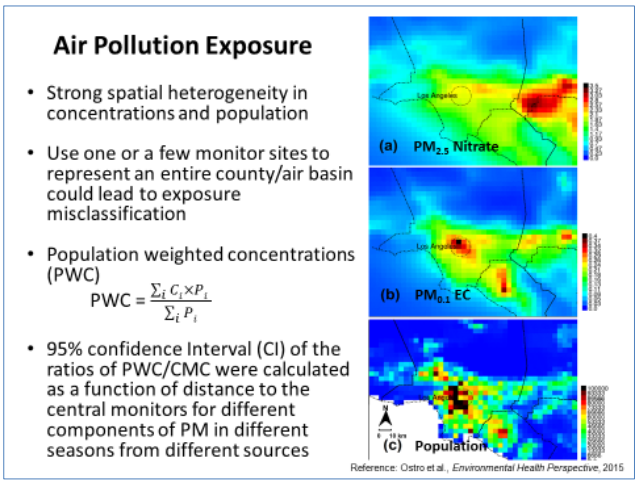
Due to increasing evidence of adverse health risks for populations located near highways and large transportation facilities, there is interest in mitigating near-road exposures. Numerous mitigation options involving transportation planning and/or land use planning are being considered. The options of roadside barriers and vegetation are particularly attractive because they offer immediate benefits, improve other environmental outcomes (e.g. reduce storm water runoff, reduce urban heat island effects, and improve aesthetics and property values), and generally improve community livability and public health. EPA has conducted several studies to examine how roadside features affect near-road air pollutant exposures. This work has included wind tunnel assessments, computational fluid dynamics (CFD) modeling, and field studies.

These efforts have led to development of new model algorithms that evaluate and quantify the pollutant reduction effectiveness of roadside features. An example from CFD modeling of a noise barrier is shown in the figure. Field measurements of UFP concentrations downwind of noise barriers in Phoenix, AZ have provided an independent data set to evaluate these air dispersion model algorithms. Overall, results of this EPA work have shown that both noise barriers and vegetative barriers can be quite effective at reducing downwind pollutant levels. However, the magnitude of the benefit depends upon the specific location and conditions. Also, it should be recognized that pollutants can meander around the edges of such barriers, possibly leading to increased pollutant concentrations in some locations.



Exposure to Fine and Ultrafine Airborne Particulate Matter: Central Site Monitors vs. Regional Chemical Transport Models: *Michael Kleeman; U.C. Davis*

Air pollution health studies generally rely on pollutant measurements made at central monitoring stations. However, there are questions about the representativeness of such central monitor concentrations (CMC) with respect to actual population exposures. Kleeman described work done in California to compare CMC values with model-predicted values for $PM_{2.5}$ and $PM_{0.1}$ at various locations, over the period of 2000-2008. Regional chemical transport models with 4-km spatial resolution were used to estimate mass concentrations of PM and its chemical components in several urban areas throughout the State. Results showed strong spatial heterogeneity in concentration, as seen in the figure, suggesting that use of only a few monitors to represent an entire county or air basin could lead to erroneous conclusions.

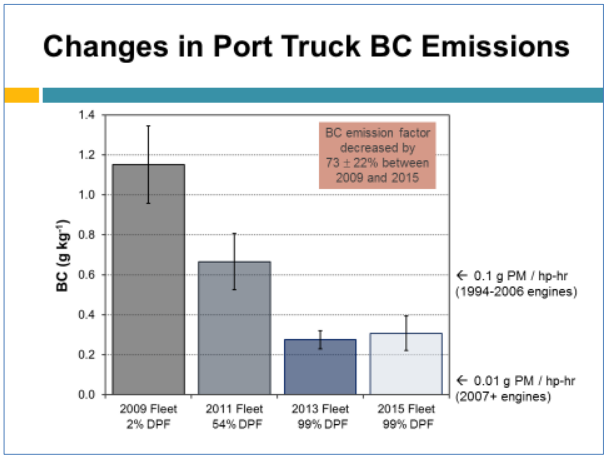


To assess the spatial representativeness of central monitor stations, population-weighted concentrations (PWC) were calculated from the model runs, and compared to CMC values, as a function of distance from the central monitors. As expected, agreement decreased with distance, but not to the same extent for all pollutants and locations. For example, spatial representativeness of CMC values was better in Sacramento, San Jose, Riverside and El Cajon than in Fresno, Bakersfield, and Los Angeles. Also, spatial representativeness was better for secondary PM components (ammonium and nitrate) than for primary components (EC and POA). Furthermore, the CMC representativeness was better during warmer seasons (April-September) than during cooler seasons (October-March), for both primary and secondary PM components.

Session 5. Accountability

Impacts of Fleet Modernization on Heavy-Duty Diesel Truck Emissions at the Port of Oakland: *Rob Harley; U.C. Berkeley*

Implementation of drayage truck emission regulations in California has resulted in rapid modernization of the Port of Oakland truck fleet. For example, the 2008 fleet consisted of 2% DPF-equipped trucks and 0% SCR-equipped trucks. In 2015, the fleet had 99% DPF and 25% SCR. By conducting periodic sampling campaigns (2009, 2011, 2013, and 2015) Harley was able to monitor the evolution of the fleet composition and the corresponding changes in emission rates, measured on a fuel-specific basis. During each field campaign, BC, PN, NOx, and CO_2 were measured using continuous instruments, while



individual trucks drove through the sampling zone. Information about each vehicle's engine and after-treatment control system was acquired from the drayage truck registry for the Port of Oakland.

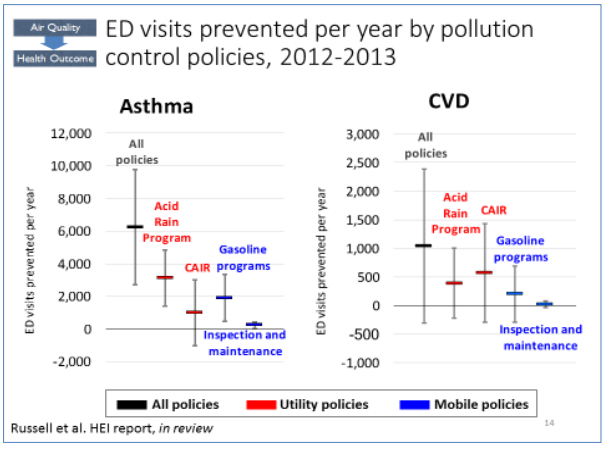
As shown in the chart, BC emission rates have been reduced dramatically since 2009. This is attributed to the near-universal application of DPFs during this time period. The slight uptick in 2015 vs. 2013 is thought to be real, and is attributed to DPF failures. Based on high BC emission rates from individual vehicles, it was estimated that by 2015, 9% of the particle filters installed in the 2007-2008 engines, and 5% installed in the 2009 engines had failed. This suggests that long-term durability of DPF systems is an issue that should be investigated.

Fleet-wide reductions in BC emission rates between 2009 and 2015 were 73 ± 22%. Similar fleet-wide reductions during this time period were measured for PN (74 ± 27%) and NOx (70 ± 9%). For NO_2, however, the emission rate doubled between 2009 and 2015. Much of this increase is attributed to intermediate-technology vehicles that were equipped with only a DPF. More modern vehicles equipped with both DPF and SCR show a smaller increase in NOx emission rates.

Accountability Assessment: The 1990 Clean Air Act Amendments: *Lucas Henneman; Georgia Tech*

A modeling and analysis study was conducted to estimate the effectiveness of emissions reduction programs upon ambient pollutant levels and health outcomes in the Atlanta area. Because multiple regulations were implemented and phased-in contemporaneously, the effects are confounded, making it difficult to assess the benefits of an individual control program. To address these problems, Georgia Tech performed a 'counterfactual' modeling study in which the outcomes of various intervention measures were compared to outcomes that would have occurred (over the same time period) in the absence of these intervention measures. The time period of interest in the study was 1999-2013. The regulatory interventions that were assessed included NOx and SOx reductions for electricity generating units (EGUs) as required under the Acid Rain Program and the Clean Air Interstate Rule (CAIR); and mobile source emissions reductions as required by vehicle inspection and maintenance (I/M) programs, the Tier II gasoline program, and HD diesel programs. Counterfactual emissions cases assumed that none of these regulatory programs took effect, and that a business as usual (BAU) scenario continued since the early 1990's. Actual emissions in 2013 were substantially lower than in the counterfactual case: EGU NOx and SOx emissions decreased by about 80% each; mobile source emissions decreased by 60-90% for NOx, VOC, and $PM_{2.5}$.

Air pollution outcomes were modeled for ozone and $PM_{2.5}$ using the Community Multi-scale Air Quality (CMAQ) model and observation-based statistical methods, with uncertainties derived from Monte Carlo sampling methods. Compared to a counterfactual scenario, actual summertime ozone concentrations were reduced, with most of this reduction attributed to lower emissions from EGU sources. $PM_{2.5}$ reductions were larger, and were dominated by EGU reductions during summer months and mobile source reductions in winter months.

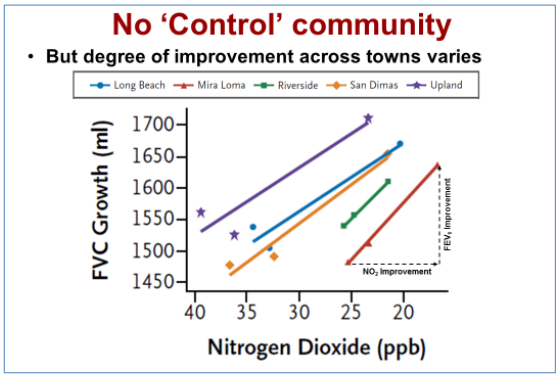


Finally, a multi-pollutant health effects model was used to relate differences in daily air pollution concentrations between actuals and counterfactual scenarios to hospital emergency department (ED)

visits. This model included terms for $PM_{2.5}$, CO, NO_2, O_3, SO_2, NO_3, and OC. Over time (from 1999 to 2013), the benefits of reduced ED visits increased, especially for asthma-related problems. By 2013, the number of asthma-related ED visits in the Atlanta area had decreased by 6,241, which represents a 17% reduction. As shown in the chart, the Acid Rain program was determined to provide the largest benefit in terms of asthma-related ED visits, while the CAIR Program was most beneficial in terms of ED visits related to cardiovascular disease (CVD). The Tier II gasoline program provided modest benefits, while I/M programs were largely ineffective in improving health outcomes.

The Impact of Improved Air Quality on Children's Health: *Jim Gauderman; University of Southern California*

The Children's Health Study (CHS), which began in 1992, was designed to monitor the long-term respiratory health of children living in different communities throughout Southern California. Communities were selected to cover a wide range of pollutant concentrations (O_3, PM_{10}, $PM_{2.5}$, NO_2, EC and acids). Throughout the history of the CHS, five separate cohorts of children have been studied. For each child, lung function development was tracked by annually measuring forced expiratory volume (FEV_1) and forced vital capacity (FVC). Based on results from the early cohorts (followed from 1993 to 2001), it was shown that abnormally low lung function development was more likely to occur in a more polluted community. In particular, associations were seen between low lung function and pollutant levels of PM_{10}, $PM_{2.5}$, NO_2, EC, and acids – but not O_3.



More recently, three separate cohort groups were compared, each of which followed the lung development of children from age 11 to 15. These 5-year time periods were staggered, with the first one beginning in 1994, and the last one in 2007. Over this time period, average ambient concentrations of air pollutants in Southern California decreased dramatically, thus providing the opportunity to assess lung function growth vs. pollutant levels within the same community. In all five communities studied, improvements in lung function growth were observed to correlate with reductions in pollutant levels of NO_2, PM_{10}, and PM $_{2.5}$. As shown in the chart, the degree of improvement varied across the five communities. Gauderman concluded that reductions in air pollutants are associated with measureable improvements in children's health.

Identification of the Effects of Regulatory Actions on Improvements in Air Quality in the Goods Movement Corridors: *Jason Su; U.C. Berkeley*

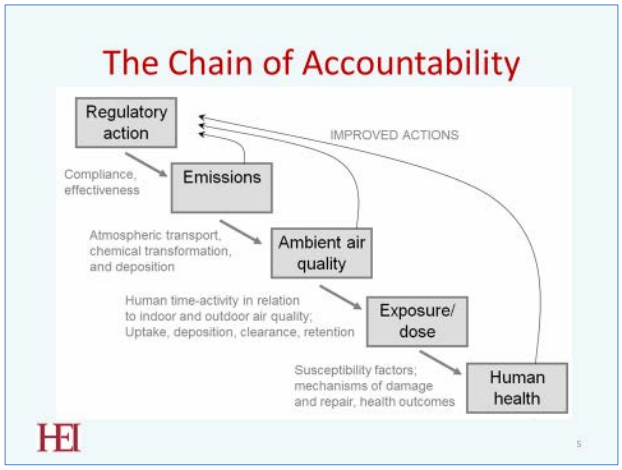
In 2006, CARB and local air quality management districts implemented an "Emissions Reduction Plan for Ports and Goods Movement" to reduce emissions associated with the handling and transport of goods throughout the State. These regulatory actions included requiring cleaner engines for trucks, ships, and locomotives; idling limits for trucks and locomotives; and other measures. Su described an experimental and modeling study that was conducted to assess the effectiveness of these regulatory actions. Two general regions were selected for field sampling: Alameda County (which includes the Port of Oakland) and Los Angeles County (which includes the POLA and POLB). Saturation sampling of NOx and NO_2 was conducted in these areas both before implementation of the Goods Movement policy (2003-2007) and after policy implementation (2008-2012). Inexpensive, passive air monitors were used to collect 2-week

integrated samples at scores of sites in both regions. These Ogawa samplers were deployed in three location categories: (1) goods movement corridors (GMCs), meaning zones within 500m of truck-permitted freeways, ports and railways; (2) non-goods movement corridors (NGMCs), meaning zones within 500m of truck-prohibited freeways; and (3) controls (CTRLs), meaning areas outside of the other two corridors.

To assess the effectiveness of the Goods Movement policies, the monitoring data were used to develop linear mixed effects models to compare pre-policy and post-policy concentrations in each of the three location categories. In every location, average concentrations of NOx and NO_2 were lower during the post-policy period. However, pollutant concentrations decreased by the largest amount in the GMC areas. After controlling for potentially confounding factors due to weather conditions, seasons of sampling, and economic conditions, it was determined that larger emissions reductions in the GMCs were statistically significant. Based on this finding, the researchers concluded that the Goods Movement regulations implemented in 2006 were achieving their desired effect.

Accountability Research: Pitfalls and Opportunities: *Rashid Shaikh; Health Effects Institute (HEI)*

In the air pollution domain, accountability research attempts to evaluate the extent to which specific air quality interventions (i.e. policies or regulations) improve public health. Accountability research is important in evaluating the intended effects of proposed interventions, as well as assessing the actual effects (costs and benefits) after implementation. HEI has developed a framework for accountability research based on the concept of the 'chain of accountability,' as illustrated in the figure. While this concept has proved useful for characterizing research with respect to the specific steps between implementation of a regulatory action and the ultimate health outcome, this chain of accountability is typically confounded by many other factors.



A major challenge – especially for long-term studies – is that many other concurrent changes occur, thereby obscuring the effect of the specific intervention being investigated. As an example of this, Shaikh summarized studies conducted in Ireland to assess the health benefits of banning coal use for residential heating. An initial study by Clancy determined that this coal ban provided clear benefits in terms of reduced total mortality, cardiovascular mortality, and respiratory mortality. However, a later extension of this study by Dockery determined no benefit in terms of total mortality or cardiovascular mortality, although reduced respiratory mortality was still seen. There are many factors that likely contributed to the inconsistent conclusions between these studies, including different locations and time periods of investigation, changes in background pollutant levels, differences in hospital data, changes in economic conditions, and social changes. This example emphasizes the importance, and difficulty, of accounting for the multitude of confounding factors, so that the true effects of a regulatory policy can be determined.