CRC Project A-122

10th CRC MOBILE SOURCE AIR TOXICS WORKSHOP

Trends, Measurements, Modeling, and Impacts

Virtual
February 8-10, 2022

Co-Sponsored by:
California Air Resources Board
EPA- Office of Transportation and Air Quality
South Coast Air Quality Management District
Health Effects Institute

WORKSHOP ORGANIZERS

Sandy Winkler, Co-Chairperson	Ford Motor Company
Seungju Yoon, Co-Chairperson	California Air Resources Board
Chad Bailey	U.S. EPA
Tim French	EMA
Sang-Mi Lee	South Coast AQMD
Matti Maricq	Consultant
Chris Rabideau	Chevron
Jenny Sigelko	Volkswagen Group of America

Introduction

The Coordinating Research Council (CRC) Mobile Source Air Toxics (MSAT) Workshop provides a forum for academic, industry, and government to exchange the latest research in the area of mobile source air pollutants, their measurement, modeling, air quality impact, and health effects implications. It ordinarily takes place every two years, but the 10th workshop was postponed from February 2021 to February 2022, due to the COVID pandemic. Because of concerns over the Omicron variant, the 10th workshop was held virtually. It was extended to three days to accommodate a range of time zones and alleviate attendee computer fatigue. While not the preferred option the virtual format eliminated the need for travel, thus extending the geographical range of speakers and attendees relative to the typical in-person workshop.

The 10th MSAT Workshop followed closely the agendas of its recent predecessors. It featured three keynote speakers, one leading off each day, and five sessions. These addressed the following themes: 1. Regulatory needs, 2. Air quality and exposure modeling, 3. Air quality and exposure measurements, 4. Measuring and modeling vehicle emissions, and 5. Accountability. In addition to the keynote talks, the workshop invited 27 speakers to present their latest work in the five sessions. Given the virtual format, conference attendance varied by session and time of day.

A few themes emerged over the course of the workshop. Several speakers noted that motor vehicle related MSATs have followed the general decline in regulatory pollutant tailpipe emissions over that past few decades. There was increased emphasis on at risk populations, those susceptible to air pollution and those subject to higher exposure, as well as the related issue of environmental justice. The talks encompassed a wide range of measurement approaches from satellites to urban networks and roadside measurements, recognizing that air quality data need to extend from regional to local. Finally, non-traditional topics of brake and tire wear emissions and consumer product emissions conveyed a sense that MSAT sources may change as vehicle technology changes.

Workshop overview

Each day of the workshop began with a keynote talk. The first gave an overview of the new California Air Resources Board (CARB) facility in Riverside, which had been slated to host the workshop prior to the decision to hold it virtually. In addition to describing the design objectives and capabilities of the facility, the talk gave a sense of CARB's future direction in protecting California's air quality. The second keynote gave the current status and future outlook of air quality health effects. Of note was discussion of the interplay between health effects and climate change as the vehicle fleet transforms to battery electric. The third keynote described current technology developments in exhaust aftertreatment, including catalytic converters and particle filters, and how they relate to achieving regulatory requirements in emissions reductions. This provided helpful context to appreciate the observed motor vehicle emissions trends presented in the session talks.

Session 1 was devoted to regulatory needs. This included a California and national perspective and a presentation on the CalEnviroScreen tool. The California Air Toxics program has had good success in identifying and reducing a wide array of pollution sources. Much of this effort has been community oriented and attentive to environmental justice. Current efforts include work to establish community based monitoring to help address local issues and improve education. The CalEnviroScreen tool combines information on the pollution burden and population characteristics of individual communities into a score that allows identification of those most in need. This can then be used by state and local agencies to prioritize actions and inform environmental justice decisions.

The national perspective describes successes in reducing MSAT emissions over the past few decades. Work continues to update the National Emissions Inventory and air toxics screening assessments. New efforts are looking at air quality impacts of airports, the impact of requirements for zero emissions vehicle sales, and brake and tire wear emissions.

Session 2 addressed MSAT and air quality modeling. A wide array of modeling applications was presented. Two talks discussed air toxics and diesel PM in the South Coast Air Basin. The results showed reductions in both diesel PM and air toxics from 2012 and 1998, respectively. The diesel PM reductions were attributed to the success of CARB's Diesel Risk Reduction plan, but this pollutant remains a major California health risk. Two talks examined the impacts of shifts in the vehicle fleet. The shift from port fuel injection to direct injection gasoline vehicles reduces fuel consumption but has increased black carbon emissions; thus, there are costs and benefits to this shift. Lower CO_2 emissions benefit climate change, but black carbon emissions can offset this benefit and poses a health concern. The change to electric vehicles represents a shift that could benefit public health. Model simulations show decreases in ozone and PM2.5 that support this.

The remaining talks in Session 2 discussed the National Emissions Inventory (NEI), the size and demographics of people living near truck routes, and volatile chemical products emissions. EPA provided an overview of its work on the 2017 and 2020 inventories. The road proximity study found that large fractions of the population, associated with non-whites and lower income, lived near truck routes. Volatile chemical products are not air toxics, but their emissions are increasing. In urban areas they are starting to have a major impact on ozone and need to be considered in inventories and models.

Session 3 examined air quality and MSAT exposure measurement. One aspect of this was a look at different air quality monitoring tools ranging from sensors to satellites. Dense networks of sensor-based monitoring stations can improve coverage across urban environments relative to standard air quality monitoring stations. This provides community level resolution to help address local air quality issues and guide policy. Satellite data give a complementary global view of pollutants that shows their transport between regions. NASA has a program to apply satellite data to address questions of air quality and health.

Other talks in this session continued the theme of near roadway air quality. One approach to mitigating the dispersion of roadway pollution is through noise barriers and roadside vegetation. Though each helps, together the benefit is better. EPA has a developed several recommendations and best practices to mitigate traffic related pollution. On the other hand, another presentation examined trends in air toxic concentrations with distance from the road across various locations in the U.S. but found that most MSATs showed low correlation with distance or traffic level. Instead, they reflected urban-scale background.

Two talks in this session looked at environmental justice. One presented results from a study that examined the successes, challenges, and improvements needed in implementing AB 617. The talk described the responses to surveys and interviews it received from the various stakeholders ranging from CARB to community representatives, and the resulting recommendations. South Coast AQMD talked about its efforts in providing air quality monitoring support to AB 617 programs. One is the use of mobile monitoring platforms to record emissions from local sources of concern. Another is to work with communities to set up local monitoring networks, which also encourages community engagement.

The last talk in this session was on Covid-19's air quality impacts. This "natural experiment" differed from others, since Covid-19 also affected the health care system. Some effects, such as a temporary drop in traffic related emissions, were expected. Others were less so; for example, BC emissions decreased less than expected because of wood burning, and PM emissions in the Adirondack Mountains increased from more people visiting the region to hike and camp.

Session 4 focused on vehicle MSAT emissions. Two talks in this session discussed non-exhaust emissions. With decreases in tailpipe emissions, non-exhaust emissions are becoming a larger fraction of a vehicle's air quality impact. However, measurements of brake and tire wear debris are difficult, and methods for their measurement are not standardized, as is the case for tailpipe emissions. One talk spoke about progress in designing a brake dynamometer and accompanying brake test cycles. This approach is yielding good results, noting that maintaining real world brake temperature is key, and is under consideration for use in EU regulations. The other talk examined tire wear debris. As with brakes, careful design is needed to collect tire particles. However, laboratory measurements also need to reproduce the correct tire loads and tire-road interface. Results showed that, thus far, laboratory rigs show lower particle emissions than on-road driving.

Two other talks looked at potential emissions impacts from fuel changes. A twenty vehicle study comparing E15 and E10 fuel found an increase in acetaldehyde emissions and a decrease in cold start PM. Overall, the conclusion was that E15 would not lead to air quality degradation. Renewable natural gas from degradation of food, farm, and other waste can benefit greenhouse gas emissions. A vehicle emissions comparison to natural gas revealed near background levels of MSATs. Tests showed emissions toxicity of renewable natural gas to be equal to or less than that from CNG.

Two talks discussed current heavy duty vehicle emissions. One compared emissions from 0.02 and 0.2 g NO_x/hphr CNG engines and post 2010 compliant diesel engines. PM emissions from the 0.02 g engine were sometimes ~100 times lower than the other engines, but in other cases had comparable emissions. This was traced to possible oil leakage that was dependent on engine age, duty cycle, and maintenance practices. The other talk provided an update on in-use performance and measurement capability for 2027+ heavy duty engines. Running real world recorded test drives in the laboratory showed that the 0.02 g NO_x/hphr could meet some 2030 thresholds under real world driving conditions, but more work is needed to ensure such performance more broadly. Comparison to laboratory reference instruments showed very good performance by portable emissions measurement systems. The final talk presented preliminary results of VOC, NO_x, and greenhouse gas surface fluxes measured by airborne eddy covariance. These were compared with CARB's 2020 inventory and were used to examine weekday / weekend and temperature effects.

Session 5 concluded the workshop with three talks looking at accountability in different ways. One examined spatial and temporal trends of on-road pollutants over four decades. A main finding was that traffic related pollutants have flattened out over space and time since 1980. California's rate of traffic pollutant decrease was high, but this was not uniformly the case for states that adopted California emissions standards.

The second talk looked at traffic emissions from the perspective of roadside measurements. These show steady decreases in CO and HC emissions that are now starting to level off. Even though new vehicles are cleaner, the emissions remain skewed to a small fraction of vehicles. The roadside measurements provide a wealth of other results, such as deterioration in early model diesel NOx aftertreatment and real world observations of the VW defeat device. The final talk described work done with EQUATES, EPA's Air Quality Time Series Project. This aims to provide a unified set of emissions, meteorology, and air quality modeling data. It provides improved agreement with observations of seasonal patterns in PM2.5, monthly average maximum daily 8 hour ozone, and other pollutant trends.

The remainder of this report provides summaries of the individual talks. The aim is to highlight each speaker's main points as accurately as possible. These summaries do not represent the opinions of CRC, Workshop organizers or sponsors, and misstatements that may exist are unintentional.

Keynote talks

Introduction to CARB's New Southern California Headquarters, Annette Hebert, CARB

The 10th CRC MSAT Workshop opened with Annette Hebert's introduction to the recently completed Mary D. Nichols Campus in Riverside, CA. The new laboratory and emissions testing facility builds on California's history of air quality research and policy studies, following in the footsteps of the early Los Angeles emissions laboratory and the well known Haagen-Smit Laboratory in El Monte. Work on the Riverside campus broke ground in October 2017, and the newly completed laboratory was dedicated in November 2021.

The laboratory was designed to lead in energy efficiency. It meets California title 24 energy efficiency standards and includes a 10,000 panel photovoltaic system. The design was optimized to make use of natural light and for the efficiency of electrical and plumbing systems. The surrounding landscape was designed to minimize water usage. When certified, it will be the largest zero net energy laboratory in the U.S.

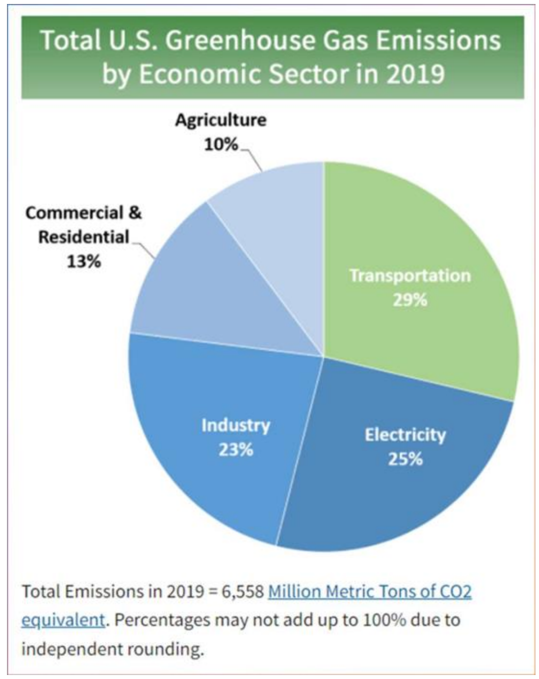
The new emissions laboratory boasts state of the art dynamometer test cells and analytical laboratories. These provide a very wide range of testing capability including engine and chassis dynamometers for motorcycles, cars, light duty, and heavy duty trucks, and the ability adjust test conditions to vary road grade, temperature, altitude, and other factors relevant to real world vehicle operation. This testing is supported by new chemistry laboratories capable of analyzing vehicle exhaust particulate matter (PM) chemical composition, gaseous emissions including MSATs, and fuels. Examples of the capabilities include metal emissions analysis related to catalytic converter deterioration, brake and tire wear, carbon-14 content of fuels, among others. The test cells and laboratories are supported by advanced data acquisition and storage capabilities required to manage the large amount of data that will be generated.

The new emissions testing laboratory will provide the data needed for a scientific basis for future clean air regulations. Asked about the impact of electrification, Annette replied that internal combustion engines will be around for some time and that electrified vehicles will continue to have potential environmental impact, for example through brake and tire wear; thus, the new laboratory is well positioned to address future air quality concerns.

MSATs: Current Status and Future Outlook, Rashid Shaikh, HEI (Retired)

The workshop's second day began with Rashid Shaikh's health perspective overview of MSATs. He began by noting that light and heavy duty vehicle tailpipe emissions have decreased over the past five decades in response to regulations and technology improvements, in many cases by a factor of 10 to 100, and that ambient concentrations have likewise decreased. At the same time numerous problems remain, such as ultrafine particle emissions, cold start, brake and tire wear, high emitting vehicles, and traffic congestion, which impact communities in non-uniform ways and become environmental justice concerns.

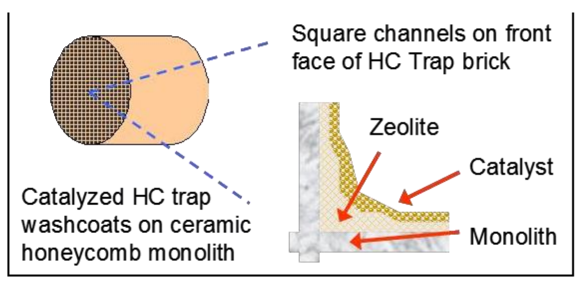
This introduction leads into the theme that tackling climate change may be one of the 21st century's greatest global health opportunities. Long term, zero emissions vehicles (ZEV) represent the best path to a decarbonized transportation sector and improved air quality. However, in the medium term, internal combustion engines will continue to play an important role; thus, greenhouse gas emissions will remain a major focus.



Pathways to reducing climate change impact in the medium term include improving combustion engines and their fuels. Biofuels represent one important option for the latter, but their potential effects on criteria and MSAT pollutants are complex. One example is the impact on acetaldehyde emissions, which are a health concern. Recent trends do not show a decline in its ambient concentrations, as observed for other pollutants. Thus, while biofuels provide an opportunity to reduce greenhouse gas emissions, their MSAT emissions and health risks need to be watched. In questions after the talk, Rashid clarified that biofuels are an interim concern as the motor vehicle fleet shifts to electrification. Battery electric vehicles are too expensive for much of the population, so the question of environmental justice will continue in the medium term.

New Catalyst and Filter Technologies, Christine Lambert, Ford Motor Co.

Whereas the workshop tends to focus on the impacts of MSATs, it is useful to also understand the state of the technology used to control motor vehicle emissions. To address this, Christine Lambert led off the workshop's final day with a presentation on new developments in exhaust aftertreatment. The first part of her talk addressed gasoline vehicle three way catalysts (TWC), which have undergone substantial improvements since their introduction in the 1970's. Their need to simultaneously oxidize CO and hydrocarbons (HC) and reduce nitrogen oxides requires engine operation within a tight window of air / fuel ratio. The TWC relies on platinum group metals (PGM) to catalyze the reactions that convert these compounds into CO_2 and N_2, respectively. Early catalysts relied primarily on Pt for oxidation, but the introduction of unleaded gasoline enabled the use of Pd. Rh is good for NO_x reduction. As PGM costs continue to rise so do research efforts to find substitutes and reduce the amounts needed.



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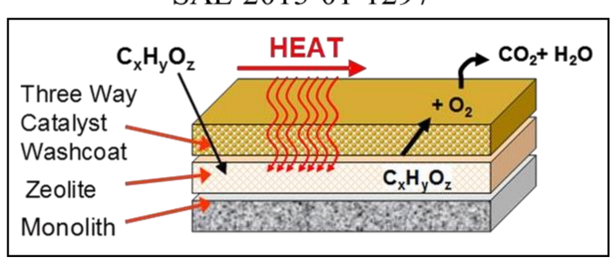


TWCs are very efficient once warmed to operating temperature. Thus, modern gasoline vehicle emissions are dominated by the cold start. Combining a hydrocarbon trap with a TWC may provide a means to control emissions that occur before the TWC is completely functional. A zeolite material that temporarily traps HCs when the exhaust is cold can be incorporated into the TWC washcoat.

As the engine warms the TWC, trapped HCs are released and oxidized by the catalyst. Research is continuing to improve HC trapping and release, and to optimize its location in the aftertreatment system for performance and durability.

The increasing stringency of PM emissions regulations is driving development of gasoline particulate filters (GPF). These are in use in Europe and China to control particle number (PN) emissions and may be required to meet the 2025+ 1 mg/mi LEVIII standard. Advanced filter designs, for example coating wall flow substrates with artificial ash, are needed to fulfill simultaneously the need for high filtration efficiency and low backpressure. Passive selective catalytic reduction (SCR) is being investigated for NO_x reduction. This is needed to enable the benefits of lean gasoline technology, under which the TWC is unable to reduce NO_x.

Modern diesel aftertreatment already is a complex system of oxidation catalyst, SCR, diesel particulate filter (DPF), and sometimes an ammonia slip catalyst (ASC). The ASC exists to remove excess ammonia that may occur in the SCR. An important need is to improve SCR performance aimed at achieving 99% NO_x conversion and a 0.02 g/hphr emissions rate. Current efforts are examining the use of multiple SCRs combined with ASCs to meet the high conversion efficiencies without risking ammonia emissions. A new low load cycle and the new moving average window for in-use testing provide significant challenges.

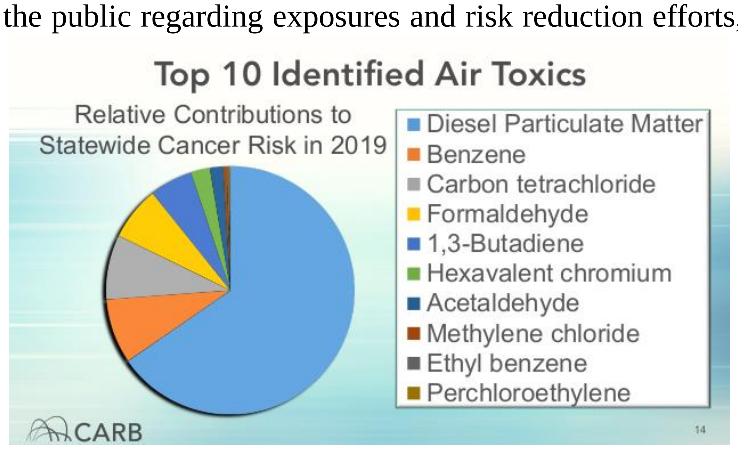
Future aftertreatment technology needs for diesel vehicles include lower PGM use, smaller size, wider temperature window for SCR NO_x conversion, and higher robustness. The needs for TWCs include sulfur and phosphorous poison resistance, faster light-off, higher thermal stability, and lower PGM use. Still, much progress continues to be made, as exemplified by publications discussing technology improvements that may achieve zero impact internal combustion engines (SAE 2019-01-2217). A question was posed regarding hybrid vehicles. The answer is that, since they rely on an internal combustion engine, aftertreatment is needed, but may have to be refined to handle start-stop operation and differences in cold start requirements.

Session 1 - Regulatory needs

Chairpersons: Chandan Misra (CARB) and Seungju Yoon (CARB)

California's Air Toxics Program, Robert Krieger, CARB

Robert Krieger spoke to CARB's work on air toxics. Programs in this area extend from 1983 (AB1807). Since then, other programs have been added: Air Toxics Hot Spots, Risk Reduction Audit and Plan, Children's Environmental Protection Act, and Community Air Protection Program. These aim to identify and control air toxics, inform the public regarding exposures and risk reduction efforts, and address health impacts to communities, children, and sensitive populations.



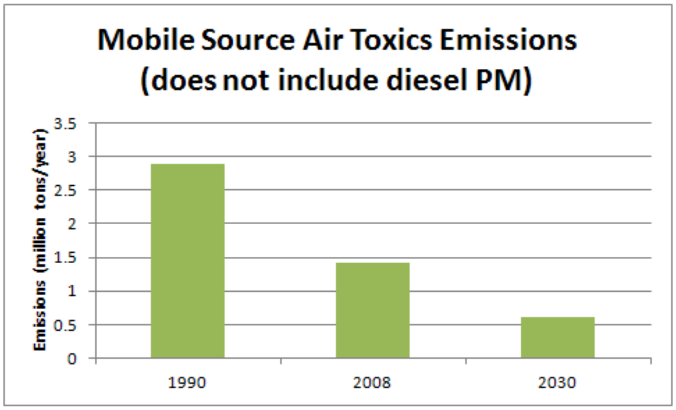
Air toxics are emitted from stationary, mobile, and area sources. Over 200 toxic air contaminants (TAC) have been identified. They include hexavalent chromium from plating operations, diesel particulate matter from stationary, mobile, and portable engines, formaldehyde from wood composites, and nickel, chromium, cadmium, and lead from metal processing, finishing, and welding. The Air Toxics Hot Spots Program collects data for emissions, which are used to prioritize health risks, produce public notifications, and initiate risk reduction actions. The Community Air Protection Program enhances public outreach and aims to reduce harmful air exposures in disadvantaged communities.

Over 30,000 sources have been identified statewide and led to 95-99% emissions reductions through facility based control technologies. Examples of successful reductions in air toxic emissions include a 100% reduction in perchloroethylene from dry cleaning operations, a 95% reduction in benzene from gas stations, and a 100% reduction in hexavalent chromium and cadmium from automotive coatings.

Current efforts of the Air Toxics Program are focused on identifying sources of community exposure, improving decision making tools, and reducing emissions of greatest concern. These include a strong component of community engagement. This helps promote community based monitoring and develop neighborhood scale inventories to help address localized issues and improve community education. Future scheduled actions include: gas station industry wide technical and supplemental policy guidance, identification of the next risk management strategy, chrome plating air toxic control measure amendments, composite wood products air toxic control measure amendments, and cumulative impacts methodology.

Mobile Source Air Toxics (MSATs): Regulators' Perspective, Molly Zawacki, US EPA

Molly Zawacki talked about air toxics work at the national level. Past regulatory actions have had a successful impact on nationwide MSAT reductions. Mobile source hazardous air pollutants were reduced by nearly 2 million tons between 1990 and 2014, with estimates of an 80% reduction by 2030. Mobile source diesel PM reductions have a similar estimate of 90% from 2005 to 2030. Specific toxics, such as benzene, have seen declines at most monitoring sites across the U.S.



The U.S. EPA performs air toxics screening assessments. These utilize data from the National Emissions Inventory (NEI) and air quality modeling, which combines photochemical and dispersion models to predict concentrations. The assessment estimates census tract level risks assuming a 70 year exposure. All of the information that goes into the assessment will be posted on the EPA air toxics website (https://www.epa.gov/haps). The next assessment is planned for release in spring 2022.

Upcoming Office of Transportation and Air Quality regulatory work includes a goal set by executive order 14307 for 50% of new car and light duty truck sales to be zero emissions vehicles by 2030. EPA is also working on new multi pollutant and greenhouse gas (GHG) emissions standards for light and medium duty vehicles for model year 2027+ and on 2030 GHG standards for heavy duty engines and trucks. Beyond this, efforts are underway to examine best practices to reduce exposure for near-road populations, for example via a truck route demographic analysis.

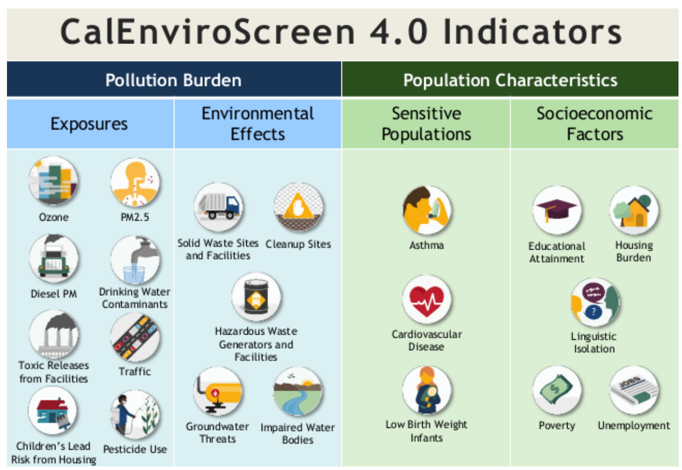
A systemic literature review is being conducted into the air quality impacts of airports and into lead emissions from piston engine aircraft that still operate with leaded fuel. The EPA ports initiative is working with port stakeholders to help accelerate adoption of cleaner technologies, emissions inventory development, and community engagement. The Diesel Emissions Reduction Act provides funding that has helped retrofit more than 67,300 engines since 2008. Following executive order 14008, a demographic analysis of people living in close proximity to transportation related emissions is underway to address environmental justice concerns.

Brake and tire wear represent a new research need. A better understanding of the health impacts from compounds specific to brake and tire emissions is necessary. Consistent methods to sample, collect, and analyze these emissions and determine emissions rates are required. Methods to capture real world activity related to these emissions are also needed. One question after the talk asked if brake and tire wear include MSATs. They do. Another question asked if particle number counting used for aircraft emissions would be extended to other areas. There are currently no plans to do so.

Mobile Source Contributions to California's Cumulative Impacts Screening Tool, CalEnviroScreen: Recent Updates and Future Directions, Laura August, OEHHA

Laura August provided an overview of the latest version of CalEnviroScreen 4.0, which was finalized in October 2021. This tool performs a geographic analysis of the relative burdens in California communities that arise from pollution and population vulnerability. It evaluates 21 indicators to provide a census tract scale score, which identifies communities most affected by and vulnerable to pollution sources. This work arose in connection with California environmental justice statutes at the turn of the century. Advisory committee recommendations in 2004 led to a cumulative impacts work group, workshops, and consultation processes from 2008 to 2018. Public versions of CalEnviroScreen 1.0 - 4.0 were developed between 2013 and 2021.

The components of CalEnviroScreen are: Exposure, Environmental effects, Sensitive populations, and Socioeconomic factors. Indicators are selected based on the following criteria: they contribute understanding of the component, the information is publicly available, it is location based and detailed, and the information is of good scientific quality. Data sources include California EPA's boards and departments, the U.S. EPA, California Department of Health Care Access and Information, California Department of Public Health, U.S. Census Bureau, and the University of California.



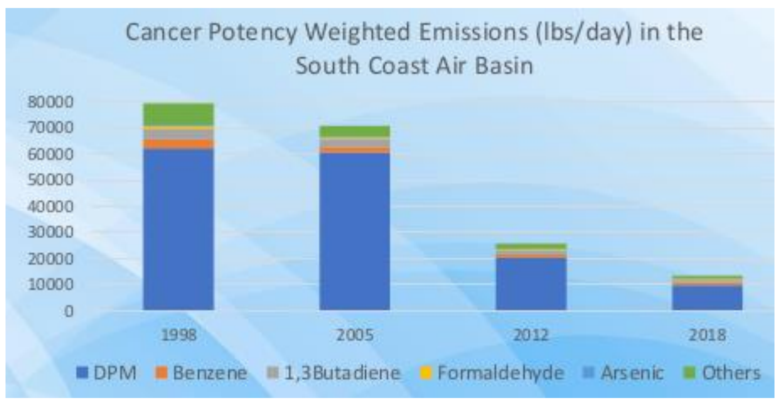
Version 4 includes major indicator updates and a new one for children's lead risk in housing. The PM2.5 indicator represents census tract mean PM2.5 concentration for 2015-2017, which is determined from satellite data in combination with land use, meteorology, and ground level monitor data. Future efforts will investigate how to incorporate low-cost sensor monitoring data. The diesel PM indicator represents census tract level diesel PM emissions from on-road sources, non-road, and stationary sources. The traffic impacts indicator represents the number of vehicles per hour within 150 m of the census tract, adjusted by the total length of these roads. The score represents the composite of the pollution burden and population characteristics. It is converted to a percentile of the roughly 8000 census tracts in California. The results show disproportionately high scores for greater Los Angeles and the San Joaquin Valley. CalEnviroScreen is used by California EPA, in city and county considerations of environmental justice, as a model for other states and as a teaching tool. A question was asked if use of local and regional data might lead to double counting diesel PM emissions. Laura responded that efforts were taken to avoid this possibility.

Session 2 - Air quality and exposure modeling of MSATs

Chairpersons: Sang-Mi Lee (AQMD) and Toshihiro Kuwayama (CARB)

Air Toxics Modeling and Cancer Risk Estimation for the South Coast Air Basin and Coachella Valley, Xinqiu Zhang, SCAQMD

Xinqui Zhang gave a talk on MATES V (multiple air toxics exposure study). This was the fifth in a series of year long measurements, inventory development, modeling and risk assessment of air toxics and criteria pollutants. The modeling employs CAMx RTRAC v6.50, covers the South Coast Air Basin and Coachella Valley with 2 km resolution, and the period from May 1, 2018 to April 30, 2019. The emissions inventory for MATES V includes point sources from the 2018 Annual Emissions Reporting program, on-road mobile sources, with emission rate data based on EMFAC 2017, ocean going vessels, off-road mobile sources, and speciated gaseous and particulate air toxics. Emissions from motor vehicles and ships were allocated based on their spatial and temporal traffic patterns. Modeled and observed annual average concentrations of EC2.5 generally agreed within about 20% over a broad selection of communities in the modeling domain. Differences in daily concentrations were larger, but the model tracked with periods of high concentrations.

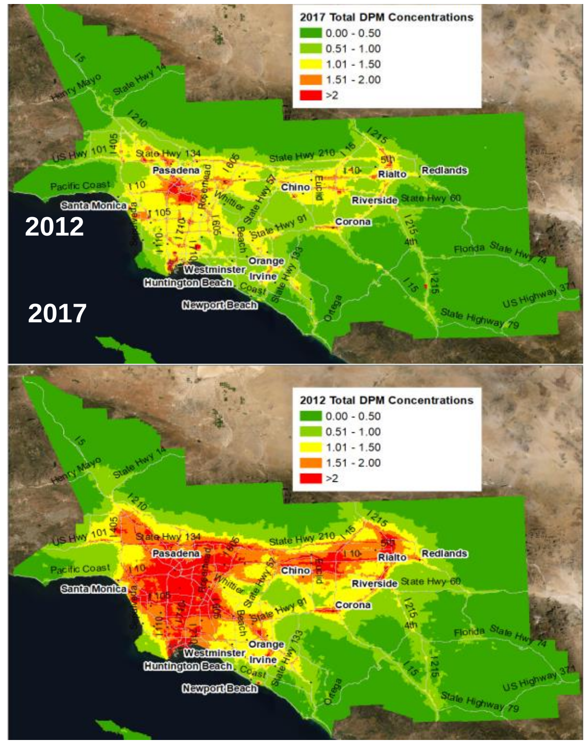


The risk assessment was based on the Multiple Pathway Cancer Risk, which includes additional risks from arsenic, hexavalent chromium, and lead. MATES modeled and measured risk agreed reasonably, with differences mostly below about 30%. When compared to 1998, MATES V indicated an 83% reduction in cancer potency weighted toxics emissions, and an 84% reduction in diesel PM emissions. The simulated cancer risk fell by 82% and the diesel PM cancer risk decreased by 83%. However, more than 80% of the simulated air toxics cancer risk in 2018 is from on and off-road mobile sources, and 67% is from diesel PM. Responding to a question after the talk, Xinqiu clarified that non-road point source diesel emissions include construction sites, rail yards, and ocean vessels.

Reduction of Diesel Particulate Matter from Mobile Source Emissions in California, Shuming Du, CARB

Shuming Du presented modeling work carried out to characterize mobile source diesel PM emissions in California. This work supports California's Air Toxics Programs, the Board's Diesel Risk Reduction Plan, and the Community Air Protection Program (AB 617). The air quality model CALPUFF was selected for this study because of its accurate characterization of emissions sources, accurate source-receptor relationships, and ability to calculate local concentrations without grid cell averaging. The emissions categories included off-road mobile and stationary point sources, on and off-road line sources, and off-road mobile and other area sources (agriculture, construction, etc.).

The main topics in the MSAT workshop presentation were diesel PM in the South Coast Air Basin in 2012 and 2017, model evaluation, and assessment of CARB's diesel reduction rules. The on-road traffic link day of week and hourly temporal variations from CALVAD were last updated in 2012 and, thus, were used for both years. Model predictions of total and fossil EC2.5 data followed the observational data trends across 11 sites, but generally under predicted them by roughly 10 - 50%. However, they showed a consistent decline of on-road, off-road & area, and total annual diesel PM concentrations from 2012 to 2017.



The principal conclusions from the study are: CALPUFF was able to characterize transportation corridor concentration gradients from micro to regional scale, it provided reasonable modeling performance based on comparison to observed total and fossil EC2.5, it showed that the decline of diesel PM from 2012 to 2017 represents a success of CARB's Diesel Risk Reduction Plan, and that diesel PM remains a major California health risk.

Air Quality and Public Health Benefits of On-road Vehicles in support of Carbon Neutrality, Michael MacKinnon, UC Irvine

Michael MacKinnon presented modeling work, which looks at how initiatives towards a carbon neutral transportation system by 2045 can benefit air quality and public health. The work compares model simulations of emissions for vehicle scenarios under Executive order N-79-20 and the Advanced Clean Trucks regulation, which require all light duty vehicle and medium heavy duty truck sales to be zero emission by 2035, to simulations of business as usual.

The model includes exhaust, evaporative, and brake & tire emissions. The latter were assumed to be equivalent for conventional and zero emissions vehicles (ZEV). All other emissions sources were held constant between the carbon neutral and reference scenarios. A caveat is that the simulation does not account for changes in fuel production and distribution that may also occur. The modeling approach uses SMOKE to determine spatially and temporally resolved on-road vehicle emissions and CMAQ to translate these into air pollutant concentrations, such as summertime ozone and annual PM2.5.

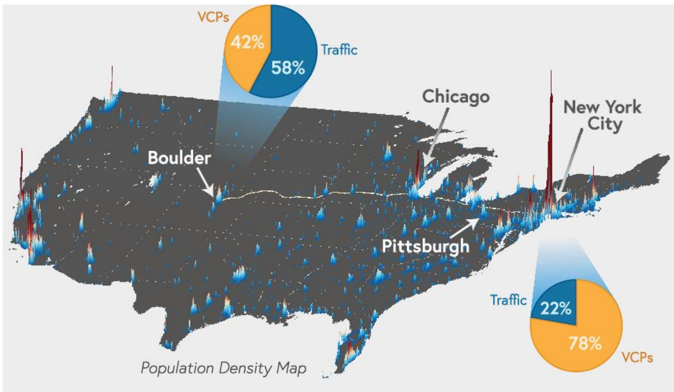
The simulations show a ~2 ppb ozone reduction during ozone season, with the largest improvements occurring in the eastern part of the South Coast Air Basin. They also show reductions in annual PM2.5 by more than 0.8 mg/m^3, with peak impacts in the South Coast Air Basin and Central Valley. Health benefits were estimated from the Environmental Benefits Mapping and Analysis Program (BenMAP). These showed a $28B benefit from the carbon neutral scenario for all cause mortality. Based on CalEnviroScreen, the public health benefits occur with higher frequency in disadvantaged

	$PM_{2.5}$ Health Reduction	$PM_{2.5}$ Health Benefits (million 2015$)	Ozone Health Reduction	Ozone Health Benefits (million 2015$)
Mortality, All Causes	3,123	$ 27,233.76	111	$970.82
Hospital Admissions, Cardiovascular	377	$17.47	--------	--------
Hospital Admissions, All Respiratory	335	$11.21	80	$1.80
Emergency Room Visits, Asthma	221	$0.12	1,860	$ 0.98
School Loss Days, All Cause	--------	--------	110,535	$24.24
Minor Restricted Activity Days	--------	--------	310,773	$ 5.55

communities, especially those near areas with high heavy duty truck volumes, such as the Ports of LA and Long Beach.

Evaluating Contributions of Volatile Chemical Products to Ozone and Urban Atmospheric Chemistry, Carsten Warneke, NOAA

Carsten Warneke spoke about the growing importance of volatile chemical products (VCP) emissions. These chemicals are found in personal care products, adhesives, solvent based coatings, fragrances, insecticides, water based coatings, and cleaning products. Since these are largely associated with consumer products and services, their emissions are strongly correlated with population density. Given the mobile source emissions reductions over the past few decades, volatile organic compounds (VOC) from VCPs are becoming comparable to, or exceeding, those from traffic sources in many urban centers across the U.S. VCPs are not air toxics, and they do not derive from mobile sources, but they have a major impact on air quality across U.S. cities and are, therefore, important for air quality.



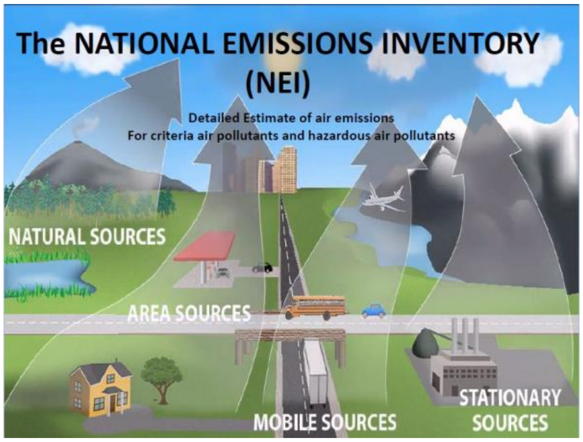
Recent research at NOAA has made comprehensive VOC measurements across the country, including mobile laboratory measurements, canister sampling, and mass spectrometric analysis. These measurements have identified specific VCP tracers to help constrain emissions inventories and show that VCPs are needed to explain the observed VOC ratios of alkanes, oxygenates, and higher aromatics.

A modeling study was undertaken to evaluate ozone formation in New York City. The model was able to successfully reproduce the daily ozone levels during July 2018, thus, the study focused on the highest ozone exceedance during a heatwave event on July 2. WRF-Chem simulations were conducted to examine ozone production under various scenarios: biogenics + NO_x, biogenics + NO_x and fossil fuels, biogenics + NO_x, and fossil fuels + VCPs. The results show that the base case underestimates the maximum 8 hour ozone by about 30%. When fossil fuels are added, the underestimation reduces to ~15 %, but when VCP emissions are also included, the predicted ozone level is only a few percent below the observed value of about 115 ppb.

Additional VCP field work is continuing. The Southwest Urban NOx and VOC experiment was conducted in 2021, and the Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) is gearing up for 2023. The key takeaways from the talk were that VCPs account for ~50% of the ozone produced from anthropogenic VOCs and that improved model constraints on VCP emissions should remain a near term priority in ozone modeling. A question was asked if past regulatory actions have led to lower VCP emissions. The reply gave the example of VOC reductions that followed as a result of the shift from solvent to water based coatings.

Overview of Mobile Source Air Toxics EPA's National Emissions Inventory (NEI), Janice Godfrey, U.S. EPA

Janice Godfrey presented an update on EPA's National Emissions Inventory, including results on air toxics. This inventory is one of the key inputs for regulatory air quality modeling. It is also used for the Annual Air Toxics Data Update, NAAQS implementation, international reporting, research, and education. The NEI includes point sources (electric generating units, airports, and rail yards), non-point sources (commercial cooking, locomotives, marine vessels, and biogenics), on-road vehicles, non-road mobile equipment, and events (e.g., prescribed burns).



NEI mobile sources include aircraft, commercial marine vessels, locomotives, gasoline, diesel, and other non-road equipment, and on-road light and heavy duty, diesel and non-diesel, vehicles. On-road emissions factors come from MOVES3, which incorporates miles traveled, fleet characteristics, and speed and temporal profiles. The non-road portion of MOVES3 and SMOKE provide non-road emissions factors.

Toxic compound emissions are estimated as fractions of total VOCs and total organic carbon PM2.5, except for metals, dioxins, and furans. These latter species are estimated directly from emission rates that are assumed independent of operating mode. Construction of this data set undergoes intensive evaluation and quality assurance. Brake and tire wear require post processing outside of MOVES. Additional considerations for brake wear include liner composition, front versus rear braking, and deceleration levels. For tire wear these include driving style, seasonal influence, heavy braking and acceleration, and highway geometry. Determination of aircraft emissions use the FAA Aviation Environmental Design Tool and landing and takeoff data. Separate calculations are done for rail yards, class I and class II/III fleets. Hazardous and criteria pollutants are estimated from ratios applied to PM10 and VOC emissions. Commercial marine vessel emissions are estimated separately for category 1-3 vessels from similar ratios and Automatic Identification System activity data,

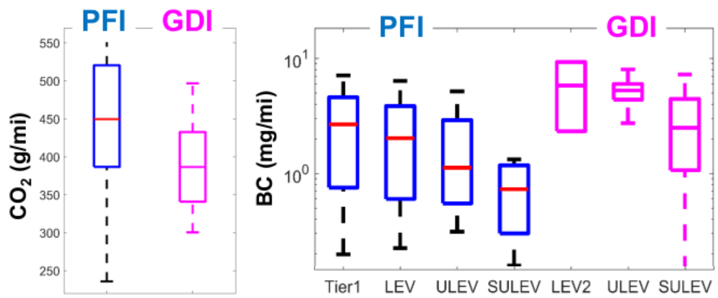
2017 NEI MSAT emissions range from over 400,000 tons of toluene to about 60,000 tons of ethyl benzene. On-road is the main source for toluene, whereas events dominate acrolein emissions. Benzene and ethylbenzene emissions originate primarily from gasoline engines, whereas black carbon comes mostly from diesel powered sources. Non-road equipment and on-road heavy duty vehicles remain the primary source of diesel PM, but there is a strong contribution from commercial marine vessels.

The 2020 NEI benefits from a number of improvements in MOVES3, but there remain further research needs. These include complete speciation of commercial marine vessel PM and VOCs, complete speciation of brake and tire wear, locomotive emission rates, gasoline direct injection vehicle toxics emissions, and biodiesel exhaust speciation.

Public Health and Climate Implications of Shifting the U.S. Light-Duty Gasoline Fleet to GDI Technologies, Rawad Saleh, U. Georgia

Rawad Saleh addressed the costs and benefits of the ongoing shift in the U. S. light duty vehicle fleet to gasoline direct injection (GDI) technology. The higher efficiency of GDI engines compared to port fuel injection (PFI) provides improved fuel economy, but at the cost of higher PM emissions. The increase in PM exposure from a shift to GDI vehicles introduces a public health cost. At the same time the black carbon component in PM offsets the greenhouse gas (GHG) reductions from the fuel economy benefit.

A modeling study was undertaken to address this question, using WRF-Chem with coupled chemical transport and radiative transfer calculations. It compared simulations using 2011 NEI emissions representing the PFI fleet to simulations with NEI emissions modified by increasing black carbon (BC) emissions by a factor of 4.2 to represent GDI emissions. There are some limitations in modeling climate versus public health. Climate change is global and involves time horizons of decades. In contrast health exposures are regional and occur on short time scales.

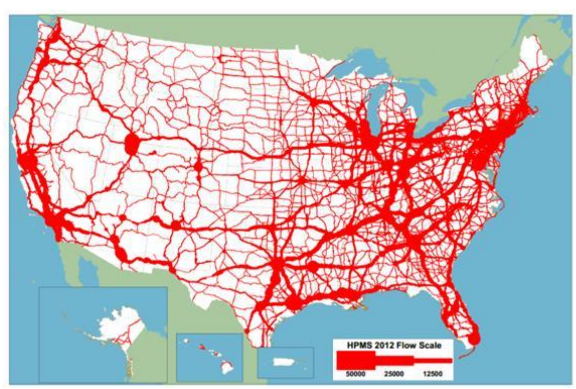


Model simulations of BC surface level concentrations showed a significant increase with a shift from PFI to GDI vehicles, particularly in the urban regions of the northeast U. S. and upper Midwest. The direct radiative effect from BC increased by 0.05 W/m^2 in July and 0.1 W/m^2 in January. The winter increase coincided geographically with BC, but the summer radiative increase shifted to the southeast. In contrast, the estimated radiative decrease from lower CO_2 emissions ranged from -0.005 to -0.017, based on the assumptions that: the GDI fuel economy benefit is 5 - 15%, PFIs are globally replaced by GDIs, and gasoline vehicles contribute 7% of global CO_2.

The conclusions from this study are that the climate change impact is hard to quantify; there is a benefit to global climate, but costs to regional climates. The public health impact is more tangible; while there is a benefit to fuel economy, there is a cost to public health, particularly for near roadway communities.

Estimation of Population Size and Demographic Characteristics among People Living Near Truck Routes in the Conterminous United States, Chad Bailey, U.S. EPA

Chad Bailey presented a demographic study of populations near U.S. truck routes. These routes were mapped using Freight Analysis Framework v4 (FAF4), which includes 446,000 miles of roads in the continental U.S. The study used dasymetric allocation of population from the EPA EnviroAtlas to the truck routes at distances of 100, 200, 500, and 1000 m. Demographic data was from the 2010 decennial census. Race and socioeconomic data were taken from the American Community Survey. Spatial variation was specified by region and Rural-Urban Classification Code (RUCC). The statistical modeling was based on a logistic regression using R's generalized linear model. It was applied to census tracts. Model performance was evaluated using 20% of the data sampled evenly about the median p value for the U.S.



The overall 48 state population did not vary much with race between 100 and 500 m of a FAF4 route, but there was a significant increase in non-Hispanic white, and decreases in Hispanic and Black, populations beyond 1000 m. This pattern was roughly similar across U.S. regions. Large racial gradients with distance were found in the large metro counties of all regions but were not apparent in most non-metro counties.

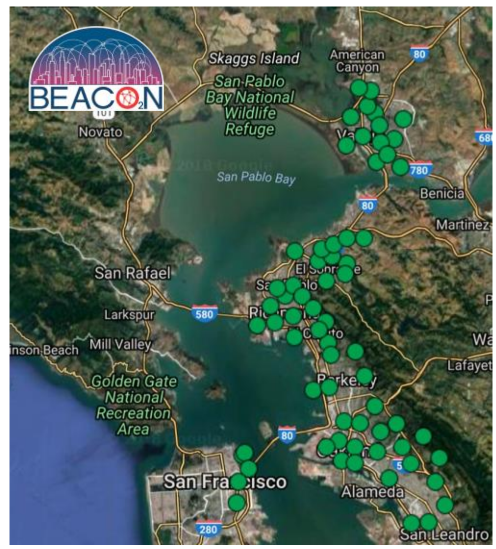
The study revealed that 39 million people in the lower 48 states live within 100 m, 30 million between 100 - 200 m, and 73 million from 200-500 m of a truck route. Multivariate model estimates found that Hispanic, non-Hispanic Black, and non-Hispanic Asian populations were consistently more likely to live within 200 m of a truck route. They also showed that higher household income was associated with a lower likelihood of living withing 200 m. These disparities are significantly greater in metro, as opposed to non-metro areas.

Session 3 - Air quality and exposure measurements of MSATs

Chairpersons: Jason Low (AQMD) and Abhilash Vijayan (Sonoma Technology)

Insights Into Urban Vehicle Emissions from BEACO$_2$N, Ron Cohen, UC Berkeley

Ron Cohen described the use of BEACO$_2$N to simultaneously address CO_2 and air quality issues. The motivation for this work comes from questions such as: "What observations would support cities' evaluation of successes reducing emissions?" and "How can observations point to win-win-wins for climate, air quality, and equity of exposure?"



BEACO$_2$N represents a dense observing systems approach to measuring emissions in an urban environment. The idea is to have a network of hundreds of monitors instead of the tens of standard monitoring sites that are typically deployed in urban areas, often in a non-representative manner. Each monitor measures NO_2, NO, O_3, CO, CO_2, and particles. The cost is about $8500 per unit, plus about 10% per year for maintenance. The cost for data analysis and interpretation is higher; thus, 1 person year for analysis is about equivalent to 20 monitors.

The advantages of the dense network are that they can provide high spatial resolution, with their small footprint they can be strategically located, and the large number of monitors help overcome biases from any individual instrument or site, which reduces uncertainty. Data from the network are posted as they come in and are open for the public to use.

When combined with other data, for example vehicles per time or vehicle speed, the dense network data can quickly provide comparisons such as CO_2 emissions versus number of vehicles and fuel economy as a function of vehicle speed, both by location and averaged over a region. Further analysis of the speed data suggest that the vehicle fleet is slightly more fuel efficient than models predict. BEACO$_2$N supplied data to examine the impact of COVID shelter in place actions. These show a 25% overall and 45% vehicle related decrease in CO_2 flux from before mid-March, 2020 to after. The network data show a decrease in CO flux as well.

Interest in BEACO$_2$N is increasing. New networks are being set up in Glasgow, Los Angeles, Leicester, and Providence, RI, where they can support local air quality improvement and greenhouse gas reduction efforts.

Mobile and Sensor Measurements to Assess Local-Scale Impacts and Mitigation Strategies for Transportation Facilities, Rich Baldauf, U.S. EPA

Rich Baldauf talked about air quality impacts from transportation and the methods used to address them. Estimates suggest that over 50 million people live within 100 m of a major highway or other transportation facility and that 17,000 schools are within 250 m of heavily trafficked roads. Traffic generated pollutants typically take a few hundred meters to decay to regional levels; thus, these people are subject to elevated exposures.

Several methods have been used to access this impact, including field measurements, wind tunnel studies, and modeling simulations. Field studies employ both Federal Reference Methods and mobile measurements of PM10, PM2.5, ultrafine particles, NO_x, CO, and CO_2, as well as wind speed and direction, temperature, humidity, and pressure.

These methods have been applied to investigate possible mitigation strategies. One study examined roadside vegetation and found that thick, full coverage, plants were more effective at reducing pollution levels than those with gaps or a more porous structure. Noise barriers also help reduce pollutants, but when combined with vegetation the benefits may be greater than from either method alone.

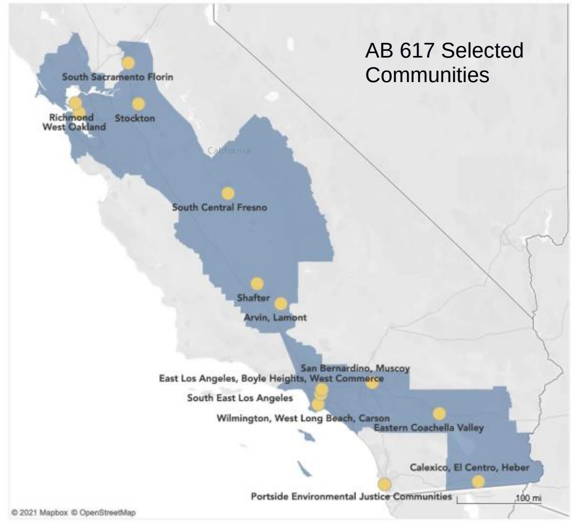
A number of resources have arisen from research into near-road exposures. The EPA Office of Transportation and Air Quality maintains a web page on issues related to emissions, air quality, exposure, and health effects, as well as links to additional resources. EPA has released recommendations for roadside vegetation design, which have been used for projects in Oakland and Detroit. And EPA has prepared a Best Practices for Reducing Near-Road Pollution Exposures at Schools to help provide schools and parents practical solutions to mitigate traffic related pollution. Asked about the effects of elevation and grade, Rich replied that these have been looked at.

The Murky Politics of Clean Air: AB 617 and Environmental Justice, Jonathan London, UC Davis

Jonathan London provided perspectives on the challenges of dealing with air quality issues in disadvantaged and over burdened communities. AB 617 requires CARB each year to consider selecting communities for participation in the Community Air Protection Program. A number of community focused actions fall under this, including the Community Emission Reduction Program (CERP) and the Community-level Air Quality Monitoring Program (CAMP). Other elements include accelerated retrofit of pollution controls, enhanced emissions reporting, increase penalty provisions and grant opportunities.

A CARB sponsored study was undertaken in 2019 - 2021 with the goals to analyze the perceptions of successes, challenges, and improvements needed for implementation of AB 617, to provide information for community and agency leaders and the legislature to make improvements, and to highlight issues needing additional dialogue between all stakeholders. This study was conducted using surveys and interviews. The surveys, both baseline and follow-up, included all stakeholders: community steering committees, air districts, CARB, and consultation group. Interviews were held with 66 individuals in person and by phone.

One observation resulting from this was the existence of tensions in the allocation of authority. Some AB 617 selected communities had steering committees led by the district, whereas others were led by the community. These raised questions of who set the agendas, budgets, CERP strategies, CAMP activities, etc. Residents generally wanted more empowerment, expressing that even if they get some things wrong, the result will still be better than the status quo. The survey showed general dissatisfaction with CARB's role; many called for a more pro-active role. The air districts faced challenges of time and funding. There were concerns about the alignment of CAMPs and CERPs with community priorities. Underlying these was the need for better inter-agency collaboration. Other issues observed from this study were: the role of industry, problems of time and resources, and the diverse perspectives on environmental justice including the extent to which it is socioeconomic versus race based.

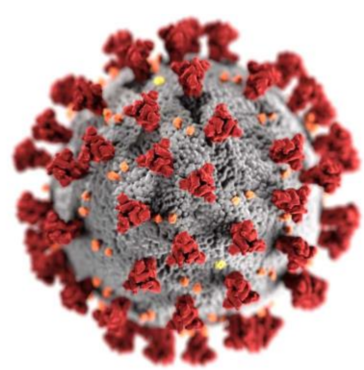


A number of recommendations arose from the study. The main ones include: advocate the legislature for increased resources, adopt CARB's statewide practices to serve other disadvantaged communities, have air districts expand benefits, develop industry wide air quality standards, improve stakeholder collaboration, and better integrate environmental justice principles.

The COVID-19 Natural Experiment - Expected and Unexpected Impacts on Ambient Air Quality in New York, Dirk Felton, New York State Department of Environmental Conservation

Dirk Felton presented observations on the air quality impacts of Covid-19 in New York. The sudden changes in people's activity brought by the pandemic have been likened to a natural experiment. Previous examples include a year long strike at a Utah steel mill in 1987, a ban on coal use for home heating in Dublin in 1990, and a reduction in vehicle traffic during the Atlanta Olympic Games. Each had associated outcomes: 2/3 fewer children hospitalized near the steel mill, a 17% decline in respiratory disease mortality in Dublin, and a 42% reduction in asthma related hospitalizations in Atlanta.

The Covid-19 natural experiment was different. Some outcomes were expected; severe heart attacks decreased during the shutdown. Others were unexpected; delays in treatment lead to worse in-hospital outcomes. A reduction in haze was expected from lower traffic and industrial emissions. But unexpectedly, global lightning activity also fell by 8% during the lockdown in 2020.



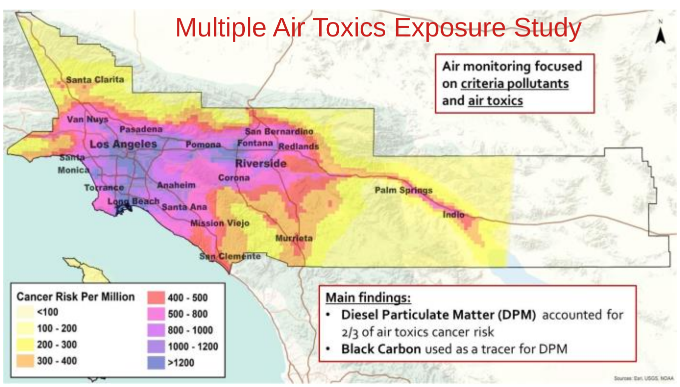
The New York governor issued a state of emergency on March 7, 2020, and a state wide stay at home order began on March 20. Phase 1 reopening began May 15 for counties meeting qualifications. New York City met qualifications for phase 2 on June 22, and schools were allowed to reopen August 7. During the interim, traffic on I-90 in Buffalo decreased by 54% in April and 27% in June relative to 2018 and 2019 levels for short vehicles, but only by 14% in April and 2% in June for long vehicles. On I-87, short vehicle traffic fell by similar amounts, but the number of long vehicles also decreased. I-87 is a toll road, whereas I-90 is not. The shutdown curtailed individual traffic, as observed on both roads. The amount of truck traffic was less affected, since they still needed to deliver goods, but it was able to shift away from toll roads.

Examinations of New York City traffic showed a 3-4 month decrease in bridge and tunnel crossings, after which car traffic returned to normal, but bus traffic only partly did. Although traffic fell during the shutdown, the average number of speeding citations in NYC went from 10,800 in early February to 24,800 in April. In other cities, traffic fatalities dropped by 1/2. NYC subway ridership fell to a low of 8% but has only recovered to 50%.

Mobile source pollutants showed some expected behavior. NO, NO_2, CO, BC, PM2.5, and ultrafine particle concentrations decreased, and the decreases were larger at near-road sites as compared to neighborhood sites. It was noted that other changes in people's behavior than driving also had impacts. For example, increased time at home led to increases in recreational wood burning, which limited the decline in BC relative to other pollutants. Another unexpected impact was on ozone. It increased in NO_x source regions but decreased in NO_x limited regions. Air toxics generally decreased, but the largest decrease was associated with dry cleaning. PM2.5 largely decreased, but increases were noted in the Adirondacks due to a surge in camping and hiking.

In conclusion, correlations between changes in air quality and health outcomes are complicated by the impact of Covid-19 on the health care system and by pollutant levels prior to the shutdown. Near-road pollutant reductions were the largest. Car traffic was impacted more than trucks, but the impact was temporary. And new emissions sources arose from people’s activities while staying at home.

Advanced Air Toxics Monitoring in Environmental Justice Communities of the South Coast Air Basin, Payam Pakbin, South Coast AQMD



Payam Pakbin spoke on South Coast AQMD's air quality monitoring efforts contributions to environmental justice initiatives. Over the past 30 years, the region has seen significant air quality improvements even as population and vehicular traffic have grown. At the same time, studies such as the Multiple Air Toxics Exposure Study find that diesel PM accounts for 2/3 of air toxics cancer risk.

The Community Air Protection Program (AB 617) aims are for a community driven process to improve local air quality. Accomplishing this requires better understanding of local air quality and emissions sources, with data to inform emissions reductions strategies. In turn, this requires a shift in air monitoring focus from regional to community level. South Coast AQMD's approach combines three sets of tools. Mobile monitoring is used survey large areas to identify emissions hot spots and perform inspections. Fixed monitoring can assess emissions levels in the community, support Community Emission Reduction Programs, and track progress. Sensor networks provide a fine grid within the community and help engage community participation.

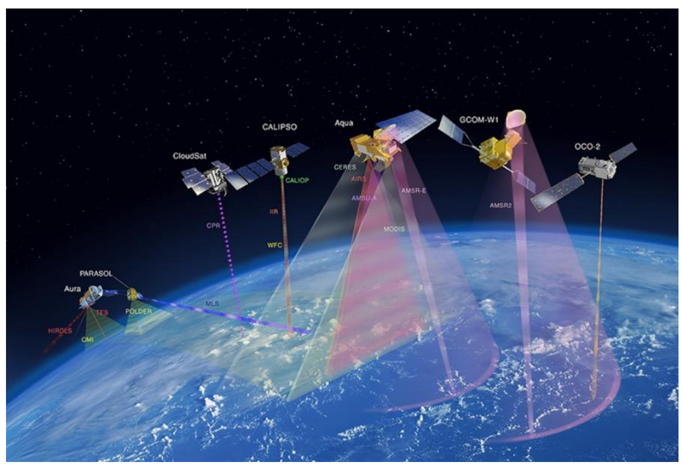
South Coast AQMD has a variety of mobile platforms for: diesel PM, metals, VOCs, and optical remote sensing. These have sophisticated capabilities; for example, the VOC mobile platform includes a proton transfer mass spectrometer. They can be deployed for measurements in rail yards, metal processing facilities, refineries, waste facilities, etc., to help monitor priority areas identified by the community and to assess community impact. Data, such as elevated NO_2 and black carbon levels near freeways and major roadways, and downwind of rail yards, are disseminated via South Coast AQMD's website to inform community members and allow them to explore the data.

A community sensor network has been established in San Bernadino to measure PM2.5, PM10, O_3, NO_2, temperature and humidity. The sites were selected and most of the sensors installed by the community. They can access the data via a dashboard. These, and the other monitoring data, can be used by the community to prioritize actions, such as installing air filtration in schools, pursuing enforcement of idling truck regulations, assess relative impacts of different emissions sources, and identify opportunities for their reduction. The question of using satellite data was asked. However, these data are generally of insufficient spatial resolution. Another question asked about high emitter vehicles. The answer was that two communities have incorporated license plate readers, but their use for enforcement is complicated.

Satellite Data to Support Health and Air Quality, Tracey Holloway, U. Wisconsin

Tracey Holloway gave an overview of the Health and Air Quality Applied Sciences Team (HAQAST). This is a NASA funded applied sciences team consisting of 14 members and 70+ co-investigators with a mission to connect NASA science with air quality and health applications. It is in its 3rd generation, which extends from 2021-2025. The $15 M project includes three types of work: member projects, collaborative projects, and outreach, engagement, & rapid response.

The team has multiple satellite tools related to air quality. One is the ability to measure tropospheric column densities of pollutants. For example, measurements by the Tropospheric Monitoring Instrument aboard the European Space Agency's Sentinel-5 satellite show geographically resolved reductions in NO_2 during the COVID-19 lockdown. Another ability is to measure aerosol optical depth. For example, the Moderate Resolution Imaging Spectroradiometer on NASA's Terra satellite shows aerosol plumes across the Atlantic Ocean.



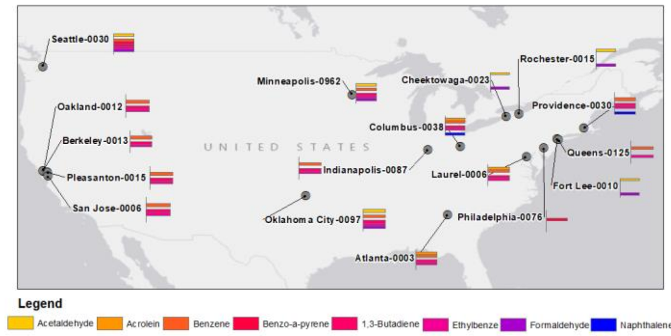
There are various applications where HAQAST can help, including: Develop regional pollution trends for urban and rural areas; evaluate population, land use, and transportation impacts on air quality; evaluate air dispersion models; and provide air quality information to the public. An example is the recent use of satellite formaldehyde data for model evaluation, which highlights the potential for satellite data to support near surface concentration estimates for EPA's National Air Toxics Assessment,

Satellite data have some limitations. In most cases, these data provide daily snapshots as a function of location on Earth, whereas many air quality questions need hourly or higher time resolution. This limitation can be alleviated with the advent of geostationary satellites. Health and exposure studies require ground level data as opposed to column densities, and methods are being developed for these applications.

HAQAST's mission is to help support health and air quality initiatives. The team has learned that two way dialogue with stakeholders is important, not just communicating science, and that it needs to be sensitive to the priorities and norms of its partner organizations. It sees new opportunities to grow relationship within the virtual world and is looking to grow the user community.

Recent Trends in Near-Road Mobile Source Air Toxics Concentrations in the United States, Olivia Ryder, Sonoma Tech

Olivia Ryder presented an air toxics versus distance to road trends analysis across the U.S. The motivating questions were: "What is the relationship between MSATs, traffic, and distance to roadway?", "How do these compare with urban concentrations?", and "What are the health implications?" The analysis used 2016-2018 MSAT data from EPA's Air Quality System combined with nearby wind data to allocate the fraction of time up versus down wind.



The results showed the lowest acetaldehyde concentrations in Cheektowaga (1.1 mg/m^3) and highest in Oklahoma City (2.07 mg/m^3), with no trend with distance to road or average annual daily traffic (AADT). Benzene ranged from 0.58 mg/m^3 in Pleasanton to 1.1 mg/m^3 in San Jose, Columbus, and Providence, with no distance or AADT trends. Ethylbenzene was lowest in Atlanta (0.12 mg/m^3) and highest in San Jose (0.74 mg/m^3), again with no discernible trends. 1,3-butadiene ranged from 0.016 mg/m^3 in Pleasanton to 0.25 mg/m^3 in Columbus, which unexpectedly decreased with AADT. Formaldehyde, typically 2.5 mg/m^3, showed a positive trend with distance to road. These results suggest that near-road MSATs were driven primarily by urban scale background.

A deeper look into the incremental increase in near roadway concentrations was carried out by subtracting daily roadway values from those at nearby ambient sites. These were then average over three years and aggregated by chemical species across the study sites. Three MSATs were found to be significantly higher at near road sites: benzene (17%), formaldehyde (14%) and acetaldehyde (12%). These showed little correlation with distance to road or AADT.

The concentrations of gaseous MSATs were compared for chronic non-cancer and cancer outcomes against various EPA and state agency benchmarks. The near road concentrations were consistently below 100 per million cancer and non-cancer health benchmarks. An audience comment was that warmed up vehicles on the roadway have very low emissions. Olivia responded that airports, ports, and industry may be larger sources.

Session 4 - Measurement and modeling of vehicle emission MSATs

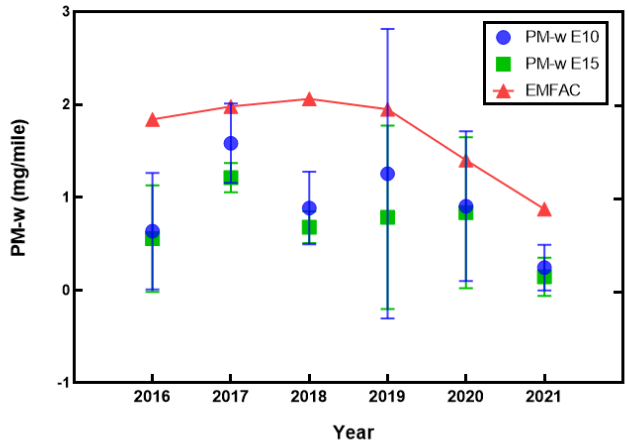
Chairpersons: Jenny Sigelko (VW) and Seungju Yoon (CARB)

Mobile Source Air Toxic Emissions from a Fleet of GDI and PFI Vehicles Operated on California Reformulated Gasoline Blends of E10 and E15, Georgios Karavalakis, CE-CERT

Georgios Karavalakis compared air toxics emissions from port fuel injection (PFI) and gasoline direct injection (GDI) vehicles run on California reformulated E10 and E15 fuels. CARB is considering increasing the blend limit to E15, but there exist limited data on the emissions impacts of E15.

The study compares the two fuels across twenty light duty vehicles representative of the current fleet. It used triplicate testing on the Federal Test Procedure (FTP) drive cycle. A large number of regulated, particulate, and MSAT species were measured. A 14 vehicle subset was tested for secondary aerosol formation using 30 m^3 mobile chamber. The test vehicles ranged from model year 2016 to 2021. The fuel testing sequence was randomized by vehicle. Fuel changes included a preconditioning procedure to avoid any influence from the previous fuel.

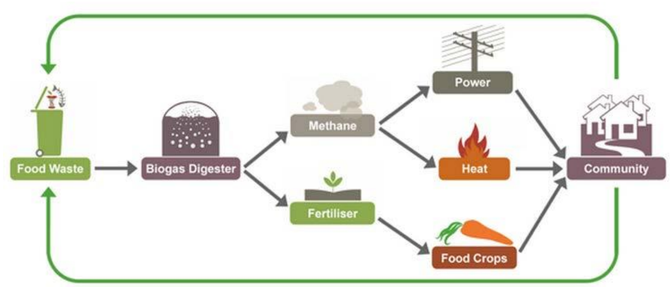
Looking at MSATs, acetaldehyde showed a statistically significant 32% increase across all vehicles, due primarily to the increase in ethanol content. In contrast, formaldehyde did not show a statistically significant dependence between E10 and E15. Benzene emissions also did not change between the two fuels. Ethylbenzene, however, decreased by 11%, likely due to the higher oxygen content in E15. The xylenes showed a marginally significant decrease of ~10%, due to the lower aromatic content. 1,3-butadiene emissions showed no difference between fuels.



The ozone forming potential was lower for E15 for both PFI and GDI vehicles. The weighted and cold start PM mass emissions declined by 18% and 17%, respectively, for E15 across the 20 vehicles. The trend with model year followed EMFAC. Black carbon likewise decreased for E15. Solid particle number emissions declined by 12%, with high concentrations observed for particles below 23 nm. The main conclusions are that the introduction of E15 will likely reduce MSAT and other emissions and not lead to air quality degradation in California.

Chemical and Toxicological Properties of Emissions from a Light-Duty CNG Vehicle Fueled with Renewable Natural Gas, Michael Kleeman, UC Davis

Michael Kleeman presented an investigation into the emissions and toxicological impacts from renewable natural gas (biogas) fuel use in a light duty vehicle. Biogas is produced by anaerobic bacterial degradation of organic matter, such as food, animal, & farm waste, and the organic part of municipal waste. This yields a twofold greenhouse gas benefit by converting possibly fugitive CH_4 emissions into a renewable fuel that displaces fossil carbon CO_2 emissions. However, it is important to investigate potential air quality and public health impacts before widespread biogas use.



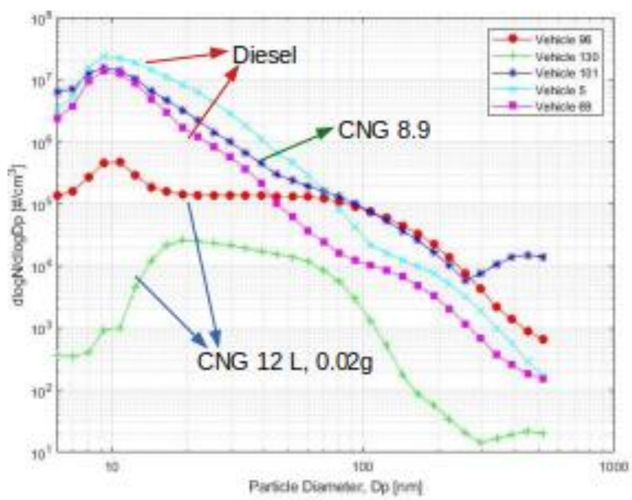
The study includes a biogas composition analysis, as well as emissions testing. The major biogas components include methane, carbon dioxide, nitrogen, and oxygen, the concentrations of which vary with feedstock origin. Small quantities of trace metals, halogenated hydrocarbons, BTEX, siloxanes, and silicon containing nanoparticles were found, generally associated with landfill derived feedstocks. The concentrations mostly fell well below Cal/OSHA and OEHHA risk levels, but some halogenated hydrocarbons and silicon nanoparticles may need monitoring. The levels of sulfur containing compounds appeared comparable to natural gas. Various bacteria were found in 17 - 30% of the samples tested.

Emissions testing was done on a chassis dynamometer with a natural gas vehicle run over the California Unified Cycle, comparing compressed natural gas (CNG) with two biogas fuels. The biogas fuel economy is slightly lower, by about 2 - 5%. CNG emits more HCs during phase 1 than biogas, but there are no consistent trends for NO_x, N_2O, or NH_3. The emissions of alcohols, aldehydes, organic acids, and other unregulated compounds were mostly comparable to background signals. Photochemical aging of exhaust revealed no significant differences between CNG and biogas. CNG fuel led to higher PM mass than biogas, but lower particle number. The size distributions were unimodal with a nucleation mode at 10 nm or lower. CNG fueled emissions showed a significantly higher oxidative stress than from biogas, with a consistent trend of elevated pro-inflammatory marker expression.

The conclusions from this work were: Fuel economy decreased with biogas due to a lower heating value. Test variability and backgrounds over-rid emissions differences between CNG and biogas. Emissions toxicity of biogas powered vehicles is less than or equal to that of CNG fueled vehicles. Photochemical aging does not differ between CNG and biogas engine exhaust.

Overview of Particulate Matter Emissons from Current Technology Natural Gas Engines, Arvind Thiruvengadam, WVU

Arvind Thiruvengadam provided an update on PM emissions from current model heavy duty CNG vehicles. These vehicles employ stoichiometric combustion, a three way catalyst, cooled EGR, and closed crankcase ventilation. Compared to legacy vehicles, they have an order of magnitude lower PM mass emissions. Some studies have shown higher particle number emissions, but these may be linked to lube oil consumption.



Data from two different CNG engines were presented that have rather different particle number (PN) emissions. The particle size distribution for an 8.9 L CNG engine was very similar to that from a DPF and SCR equipped diesel engine. In contrast a 12 L ultra low NO_x CNG engine had two orders of magnitude lower PN emissions than either the 8.9 L CNG or aftertreatment equipped diesel engine. Part of the reason may be that the 12 L engine was newer and had less mileage than the 8.9 L engine. Engine temperature impacts PM emissions, but the trends can vary. One CNG test vehicle showed a large nucleation and accumulation mode during cold start. The first hot start repeat had a smaller accumulation mode, but still large nucleation mode. The second and third repeats had much smaller nucleation modes.

Vehicle mileage has an impact. A comparison of two 0.02 g NO_x engines used for goods movement, one with 39 k miles and the other with 145 k miles, exhibited more than an order of magnitude difference in accumulation mode PN emissions that correlated with mileage. Vocation also makes a difference, but not a consistent one. For 0.2 g NO_x engines, emissions from a refuse truck with 80 k miles and school bus peaked at 10 nm and were two orders of magnitude higher than PN from a transit bus with 400 k miles. Vehicles with 0.02 g NO_x engines showed a different trend; this time a transit bus with 37 k miles had two orders of magnitude higher PN than a 26 k mile refuse truck.

An elemental carbon versus organic carbon (EC/OC) comparison of emissions under different duty cycles reveals that duty cycles with more idle show higher EC fractions, while duty cycles with higher freeway type operation show higher OC fractions. Oil consumption is expected to be higher at idle and low load conditions, which can lead to soot formation.

These results are consistent with PN emissions deteriorating with vehicle age and mileage. However, the impacts depend on vocation based aging and the engine duty cycle. These affect engine component deterioration, such as piston ring sealing, cylinder surface wear, spark plug seals, and closed crankcase filtration system failure. Another factor is the diligence of maintenance procedures, for example ensuring the use of manufacturer recommended lube oil.

Surface Fluxes of VOCs, NOx, and Greenhouse Gases in the Los Angeles Basin Derived by Airborne Eddy Covariance, Allen Goldstein, UC Berkeley

Allen Goldstein presented preliminary results from a study of VOCs, NO_x, and greenhouse gases in the Los Angeles basin. The objectives of the study were to use airborne eddy covariance (AEC) for direct measurements of emissions across spatial scales relevant to model development and to use these measurements to help improve emissions inventories.

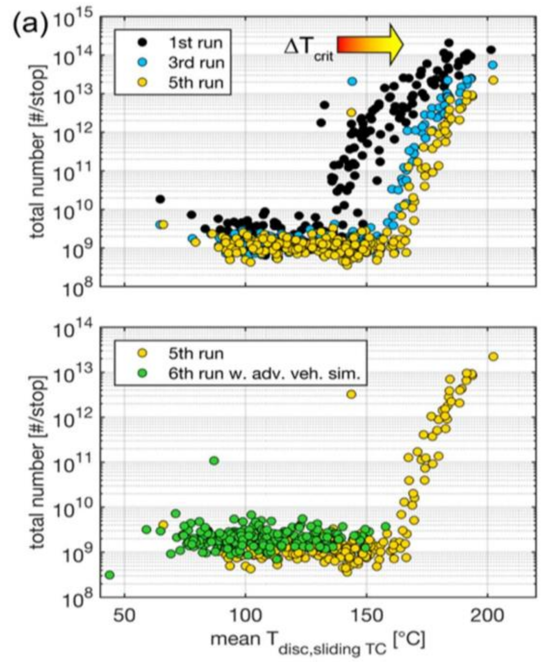
The measurement campaign took place in June 2021. The NPS Twin Otter airborne instrumentation included LIF for NOx, a VOCUS-PTR-TOF mass spectrometer to record ~600 VOCs, and Picarro for CO_2, CO, CH_4, and H_2O. The campaign included 7 flights of ~6000 km over the San Joaquin Valley and 9 flights of ~9000 km over LA. Fluxes are derived from the covariance of species concentrations and vertical wind profiles using wavelet transformation and applying the vertical flux divergence.

Los Angeles VOC fluxes are dominated by oxygenated VOCs. Aromatic species exhibit a weekend effect that is temperature and location dependent. Weekend trimethylbenzene fluxes have little temperature dependence between 15 - 40 ^{o}C and are similar across locations. Weekday fluxes are elevated and increase with temperature in LA, more so downtown as compared to the coast, whereas those in San Bernadino and Santa Ana Valleys show less temperature dependence and remain closer to weekend levels.

A preliminary comparison of the flux data was made with CARB's 2020 inventory, with a one day shift to match weekdays and weekends. A comparison will be made to the 2021 inventory when available. For trimethylbenzene, the 2020 inventory generally matches measurements, but is lower in the San Bernadino Valley. Toluene and xylene are higher in the inventory than from the flux measurements. Biogenics exhibit a strong temperature dependence. A weekend effect is found for monoterpenes, but not isoprene. The 2020 inventory is higher for isoprene and lower for monoterpenes as compared to measured data. Inventory values are also lower for ethanol and acetaldehyde. NO_x fluxes do not show a weekday/weekend effect or temperature dependence. CO_2 and CO fluxes are generally highest in the northern basin near highways and the downtown area. Estimated CO2 emissions are lower than recent literature and inventory values. A more comprehensive analysis and interpretation are underway.

Brake Wear Particle Emissions – Measurement and Impact, Rainer Vogt, Ford Motor Co.

Rainer Vogt talked on recent developments in understanding the contribution of brake wear particles to motor vehicle PM emissions. Given the strong decrease in tailpipe PM emissions in the past two decades (~45%), attention is turning to non-exhaust sources. This includes brake, tire, & road wear, and resuspended road dust. Roadway brake PM contributes a few mg/m^3, typically less than 5% PM10.



Brake particle measurement is difficult owing to their loss in sampling systems from impaction and gravitational settling. Vehicle based measurements, on the road and with a chassis dynamometer, have employed open and enclosed sampling approaches. The currently preferred method, and proposed for regulatory measurements, is an enclosed brake dynamometer. This approach employs an air supply and dilution system designed to capture and transport brake wear particles from a brake rotor and caliper to the sample inlet with low losses. The brake dynamometer is run over a "drive cycle" designed to represent on-road driving. This system provides real-time measurements of brake wear size distributions and particle number emissions. Filter collection provides gravimetric PM2.5 and PM10 mass.

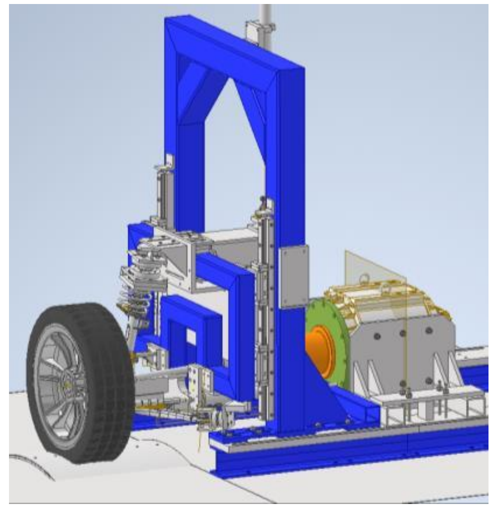
Brake wear is primarily a function of initial rotor speed, brake pad pressure, and initial brake temperature. The latter is very important for PN formation. Brake emissions are relatively insensitive to temperature below about 160 °C, but increase very rapidly above this temperature from sub-micron particles produced by the pyrolysis of organic material in the pads. Measurements show that on-road brake temperatures are mostly well below 150 °C, so it is important that this is accurately reflected in dynamometer testing, such as in the WLTP brake test cycle.

The UN-ECE Particle Measurement Program (PMP) has a group currently working non-exhaust vehicle emissions. This includes stakeholders from OEMs, instrument and brake dynamometer suppliers, brake industry, and research laboratories. The work is divided into four task forces: brake test cycle, sampling and measurement, inter laboratory comparison, and regenerative braking. The aim is to submit a technical report and technical rationale & justification by January 2023. Key to this is understanding the sources of measurement variability and establishing a repeatable procedure robust across a wide range of existing and new brake technologies. One question asked after the talk was how representative is the dynamometer approach. The answer was that it generally compares well with on-road data if the brake temperature is controlled well, but that better understanding of brake particle capture by the wheel is needed. The answer to a question on mitigation approaches was that emissions could be reduced by regenerative braking, application of coatings to the disc, and potentially with a capture device.

Methods for the Determination of Brake and Tire Wear Particle Emissions Under Varying Test Environments, Toni Feißel, Technische Universitat Ilmenau

Toni Feißel described the development of stationary and mobile measurement methods for non-exhaust vehicle particle emissions, particularly for tire wear. This work combined modeling of particle trajectories from a tire, test bench measurements of tire wear particle formation in laboratory conditions, and vehicle measurements under real driving conditions.

The modeling work examined particle dispersion from the tire, the effects of turbulence, and the influence of the boundary layer. The objective was to understand particle transport and deposition, whether onto the vehicle or in the environment. For example, simulations of particle flow in the wheel housing were compared to particle image velocimetry measurements of injected test dust. Modeling was also used to design a constant volume sampling system which could efficiently collect and dilute tire wear particles.

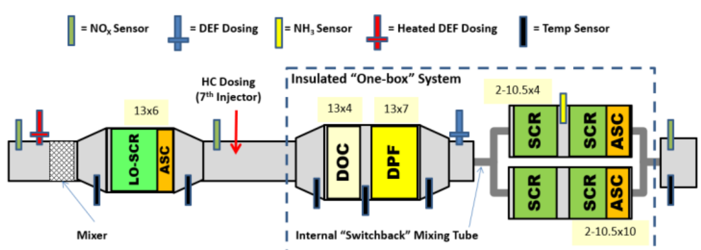


A tire dynamometer was designed capable of producing lateral and longitudinal stresses on the tire that mimic real world driving. This included dynamic changes to tire load, slip, and slip angle. Collection and sampling wear particles adopted a dual dilution system for low background and to decouple cooling and sampling air flows. Measurement capability includes real-time particle size determination and particle collection for gravimetric mass and off-line microscopy. Tire wear particles were measured for summer tires. The number emissions correlate with changes in speed and acceleration, but the concentrations were low, ~25 cm^{-3}.

Tire particles were also measured on-line and collected during on-road RDE compliant driving. Position, speed, lateral and longitudinal accelerations, tire temperature, tire rpm, and tire load were also recorded. These tests revealed much higher particle concentrations than seen with dynamometer testing. They showed strong correlations with acceleration and slip velocity. The size distribution had a number weighted maximum < 2 mm and a mass weighted peak > 5 mm. More work is continuing to identify all of the factors that influence tire wear particle formation and to understand the impact on the environment.

Characterization of In-Use Performance and Measurement Instrumentation Capability at Low NO_X Levels for 2027 and Beyond, Chris Sharp, SwRI

Chris Sharp gave an update on 2027+ low NO_x engine performance and measurement capability. The main objectives of this work were to see if regulatory cycle performance is indicative of on-road emissions, to see if any incremental variability allowance is required for portable emissions measurement systems (PEMS) relative to laboratory measurements, and to examine the status of sensor based NO_x measurement. These questions were addressed by replaying field recorded engine duty cycles on a laboratory Stage 3RW low NO_x engine and comparing simultaneous PEMS, sensors, and reference measurements.



The EPA stage 3RW low NO_x demonstration uses a 2017 Cummins X15 engine equipped with an advanced dual SCR - dual dosing aftertreatment system. This system employs a light-off selective catalytic reduction (LO-SCR) catalyst in addition to a downstream SCR. NO_x is primarily controlled with the LO-SCR at cold start and under low load but shifts to the downstream SCR at high load. The demonstration target is 0.02 g/hphr NO_x emissions at 435k miles, with no adverse GHG impact. The FTP emissions at 435k miles are at the standard, but with no margin.

Real world emissions are analyzed using a 300 s moving average window. The NO_x data are binned into three bins (idle, low, and med/high) according to the window normalized average CO_2 rate, which is a surrogate for load. The ratio of summed NO_x to summed CO_2 is then scaled by the brake specific CO_2 emissions over the FTP cycle to provide the brake specific NO_x emissions in g/hphr. Test results showed that bin 1 and 2 emissions were below the 2030 threshold with margin for a variety of real world routes, such as CARB's southern not-to-exceed route, a grocery delivery route, a drayage route, etc. Bin 3 emissions were below 2030 threshold for some cycles, but above or close for others. Other insights from the test results indicate that the "traditional" issue of high NO_x emissions at low load does not apply to the stage 3 engine, the LO-SCR reacts quickly to low temperature accelerations, and that under normal operating temperature, the aftertreatment can handle low load and low space velocity.

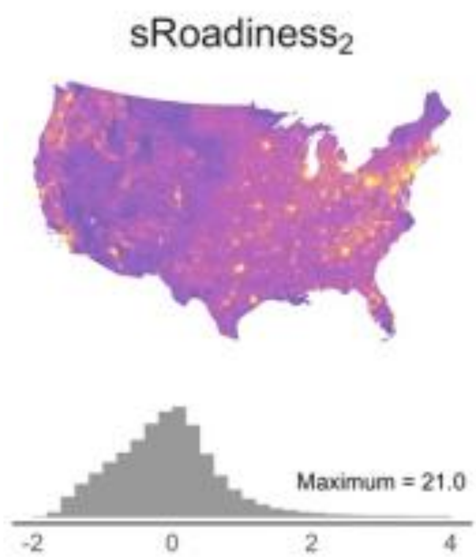
Comparison to laboratory reference measurements showed very good PEMS performance over a 6.5 hour test. An important aspect of this is the ability of the PEMS to perform periodic zero and drift corrections. The PEMS must also measure exhaust flow. The PEMS flow measurements reproduce the laboratory measurements well but exhibited up to 5% span errors and had intermittent issues measuring flows near idle. Overall, PEMS differences were larger than those between lab instruments. However, there was no evidence of bias or offset.

The NOx sensors tested are the same type as used by OEMs for on-board diagnostics (OBD). Sensors from various suppliers were tested, but not aged prior to testing. The sensor based NO_x measurements follow the laboratory instrument data but are considerably noisier. Filtering the noise with a 10 s moving average reveals offsets from the reference measurement, which do not exhibit a pattern. A closer look reveals that rapid changes in speed or torque increase noise. Large swings in O_2 or H_2O levels in the exhaust also appear to affect sensor readings. Improvements are needed if sensors are to be capable of compliance level measurements. A question at the end of the talk asked about sensor advancements. Chris replied that the OBD type sensor are undergoing somewhat slow incremental improvements, but that new sensor approaches are being developed which may have better capabilities.

Session 5 - Accountability

Chairpersons: Chris Rabideau (Chevron) and Sandy Winkler (Ford)

Spatial-temporal trends in four decades of United States on-road air pollution, Lucas Henneman, George Mason



Lucas Henneman examined the important changes in U.S. traffic related air pollution (TRAP). The questions he addressed include: "How much information about time and space gradients exist at road locations?", "How do chemical transport models and satellites capture changes over time and space?", and "Do TRAP gradients differ in states that did and did not adopt California's emissions standards?"

Central to these questions is proximity to roads. One way to define this is via USGS's road link network and the concept of "sRoadiness". A 4 km grid is overlaid on the road network and "sRoadiness" is defined as the sum over all roads in each cell of road length normalized by the D^{th} power of distance to that road from any point i. The present work set D = 2. The data sets for NO_x, NO_2, CO and EC include observations from

EPA Air Quality System monitors from 1980 - 2019, CMAQ models, and satellite measurements.

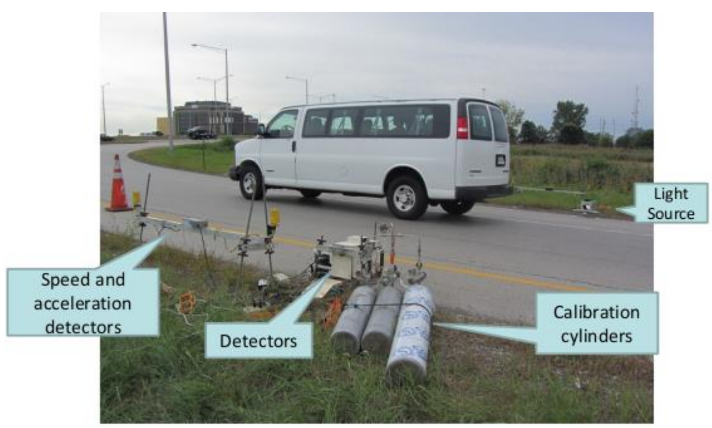
NO_2 depends strongly on road proximity, but its levels have seen large decreases over the past 20 years according to observations and models. CO has a weaker relationship with road proximity, but its concentrations have also decreased steeply in this time frame. When the observations are fit to a hierarchical model, the results show that besides the decrease in NO_2 concentration over time, the average rate of decrease per year has remained mostly flat and the relationship between concentration and sRoadiness has weakened. For CO, the rate of decrease per year has declined, and the relationship with sRoadiness has also weakened. CMAQ models estimate NO_x temporal trends well and capture the relationship with sRoadiness.

A comparison of NO_2 trends in California, states that adopted California emissions standards, and those that did not reveals that 2010 average NO_2 was highest in California and the Yes states. The rate of decline per year was also highest in California and Yes states. The relationship with sRoadiness was mixed; it was highest in California, but lowest in the Yes states.

The main conclusions from these comparisons are that TRAP pollutants have flattened in space and time since 1980. CMAQ (12 and 36 km) captures NO_2 trends between 2002 and 2010. Satellite data is overly sensitive to NO_2 decreases near roads. And all states saw NO_2 reductions from 2010-2019, but these were not faster in Yes states.

On-Road Vehicle Emission Measurements and Their Use in Evaluating Emission Control Effectiveness, Gary Bishop, U. Denver

Gary Bishop described vehicle emissions trends over time as recorded by roadside measurements. These were made using the Fuel Efficiency Automobile Test (FEAT) system, which records fuel specific emissions of CO, HCs, NO, NH_3, SO_2, and NO_2. The measurements are made optically across a roadway at near tailpipe height. Typically, a site such as a highway on ramp, is chosen that has a gradual incline requiring modest vehicle acceleration. A number of these measurement campaigns were CRC projects, such as E-23, E-106, E-123, and E-124.



Roadside measurements in Southern California show that light duty CO and HC emissions have decreased steadily from 100 - 200 gCO/kgfuel and 25-50 gHC/kgfuel in 1989 to about 10 gCO/kgfuel and 2 gHC/kgfuel in 2019. The decreases were steep during 1995 - 2008 but have begun to level off. The distributions remain skewed, but the 99th percentile emissions fell by a factor of ~5 for CO and ~10 for HCs.

NO emissions have similarly fallen from ~10 gNO/kgfuel in 1999 to ~3 gNO/kgfuel in 2018. The dependence on vehicle age also differs. In 1999, emissions increased nearly linearly with vehicle age up to about 18 years. In 2018, NO emissions remain flat with vehicle age up to about 11 years and then increase roughly linearly.

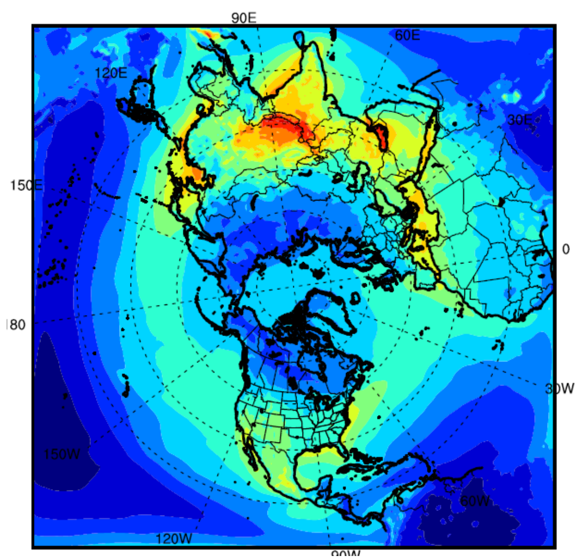
Diesel vehicle NO_x emissions decreased from nearly 40 gNO_x/kgfuel in 2002 to ~20 gNO_x/kgfuel in 2010, and then abruptly fell to < 5 gNO_x/kg fuel after 2010, reflecting the advent of diesel NO_x aftertreatment. However, the subset of VW diesel vehicles did not show this decrease, consistent with the existence of a defeat device. While NO_x emissions have fallen, the NO_2 fraction has increased from about 0.3 to 0.6.

A comparison of 2020 heavy duty vehicle measurements in Utah at -7 to 10 ^{o}C to 2017 measurements in California at 15.5 - 20 ^{o}C show similar low NO_x emissions for chassis model years 2017 and newer. However, for chassis model years between 2008 and 2016, the NOx emissions measured in Utah are substantially larger than those in California. Then for model years between 1998 and 2007, the NO_x emissions are again comparable in the two locations, but much higher than for the 2017 and newer models. This suggests that after about 5 years, the SCR catalyst is losing its effectiveness at the colder ambient temperature. A comparison of the Utah heavy duty measurements to MOVES3 corroborates this picture. The measured values agree with the MOVES model for model years 2017 - 2021 and for 2003 and earlier, but not for the model years in between.

Ammonia emissions are mostly from natural gas heavy duty vehicles and the light duty fleet. Measurements in 2005 and 2009 show similar increases in ammonia emissions with vehicle age, which plateau for vehicles more than 10 years old. Measurements in Denver in 2020 show that 1995 model year vehicle nitrogen compound emissions were about 90% NO_x and 10% NH_3. In contrast, model year 2012-2016 vehicle emissions were about 50% NO_x and 50% NH_3. After that, the trend reverses, so 2020 model year vehicles had roughly 70% NO_x and 30% NH_3 emissions. This variation is likely a result of catalyst formulation changes and aging.

Overall conclusions affirmed the significant declines in light and heavy duty emissions over the past three decades mentioned by earlier speakers. They also show that a small fraction of vehicles remains responsible for a majority of emissions. The roadside data indicate that early generation SCR systems have on average reduced capabilities and that vehicle fleets are a significant ammonia source in urban areas.

Evaluation of Modeled Trends from the EPA's Air Quality Time Series (EQUATES) Project, Kristen Foley and Heather Simon, U.S. EPA



Kristen Foley and Heather Simon described their team's work with EQUATES. One of the uses of models, such as the Community Multiscale Air Quality (CMAQ) model is to help evaluate the impact of emissions control policies. Models themselves are evaluated via multi-year simulations as to their ability to quantify the impact of changes in emissions and meteorology on air quality. Past evaluations have used various approaches for this. EQUATES's goals are to provide a unified set of emissions, meteorology, and air quality modeling data to characterize trends, provide dynamic model evaluation, and serve as a consistent base for accountability modeling.

The EQUATES modeling effort covers 2002-2017; 2018 and 2019 will be added later. The spatial domain includes the Northern Hemisphere and contiguous U.S. (CONUS). Meteorological and emissions inputs are from WRFv4.1.1 and EPA's 2017 NEI, respectively. It uses CMAQ version 5.3.2. The methods used to develop 2002-2017 CONUS emissions varied with source. Mobile on-road emissions, for example were based on MOVES3 and CARB inventories from EMFAC2017. As a result, the NO_X

and VOC emissions from highway vehicles exhibited smoother trends over the 2002-2017 time frame than platform inventories based on a mix of NEIs and emissions modeling platforms. Off-road NO_x and VOC emissions are similarly smoother. They fall somewhat below the platform values due to lower emissions from railways, commercial marine vessels, and airports.

EQUATES anthropogenic NO_x emissions decrease from 25M tons in 2002 to about 10M tons in 2017. On-road vehicles are the main contributor, but the fraction falls from 50% to 33% over this time. Anthropogenic VOC emissions decrease less, from about 13M tons to 10M tons. The on-road contribution decreases from 29% to 10%, and non-road falls from 16% to 8%. Oil & gas and fires' contributions increase to 21% and 28%, respectively.

The seasonal patterns in monthly average PM2.5 from EQUATES CMAQv5.3.2 show much improved agreement with Air Quality System (AQS) observations as compared to ECODEP CMAQv5.0.2 simulations. Monthly average maximum daily 8-hour (MDA8) ozone level simulations from EQUATES and ECODEP both agree well with observations. EQUATES somewhat under predicts spring and over predicts late summer levels but captures the decrease in monthly average. It captures most of the trends in 95th percentile MDA8 O3 across the U.S. but misses some of the leveling off in the East between 2015-2017, and shows a low bias in the West. Previous ECODEP simulations followed the observed decrease in NOx emissions from 2002 - 2017, but showed a high summertime bias. This is greatly reduced in EQUATES, but winter emissions are underestimated, primarily in California and the Northeast coast.

The initial operational evaluation of EQUATES shows how it has improved over previous simulations and that it captures the large emissions reductions that have come from regulatory controls. Future work will seek a deeper understanding of the contributions from specific sources and sectors using source apportionment modeling. Following the talk, a couple of questions were asked about improvements in PM as well as the impact of grid size. The replies were that the group is actively looking into CMAQ SOA mechanisms and that spatial distributions usually occur across sufficiently large scales that 12 km provides an adequate grid size.