CONFERENCE SUMMARY

THE 33RD REAL WORLD EMISSIONS WORKSHOP, MARCH 26 – 29, 2023

Written by Ameya Joshi (see a disclaimer at the very end of this summary) joshia@corning.com

DAY 1 – MONDAY, MARCH 27, 2023

KEYNOTE ADDRESS: JED R. MANDEL

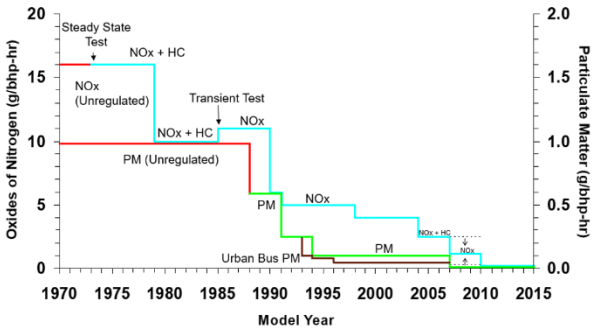
President, Truck & Engine Manufacturers Association

On EMA: Represents US manufacturers of commercial vehicles, engines, and zero-emission powertrains

The Evolution to Clean Diesel

The industry has come a long way in reducing tailpipe pollution from heavy-duty vehicles. The unregulated baseline NOx in 1977 was 16.0 g/bhp-hr. When the first mandate for reducing NOx to 4 g/bhp-hr was approved, it was viewed as the end of diesel engines. Today, the limit is 0.2 g/bhp-hr!

US On-Highway Emission Standards



Low NOx rules (CARB, EPA)

- Nationwide standards are critically important as are lead times and stability. This is the first time that there is non-alignment between CARB and EPA on the HD regulations.
- The Clean Air Act requires 4 years lead time for emission standards
- The waiver process is getting more complicated – CARB is not applying as quickly as they could/should
- Meeting the low NOx regulation in California is difficult and will lead to product "blackouts"

Several challenges with respect to upcoming regulations

- Fleet turnover (only 53% of trucks operating today meet EPA's post-2010 standards)
    - Compared to a 2010 truck, one 2006 truck emits 10X more NOx and one 1990 truck emits 30X more NOX than a 2010 truck
- Impact on transition to ZEVs
- Impact on disadvantaged communities
- Infrastructure and incentives
    - Federal excise tax of 15% on a $300K ZEV truck, takes away the $40K IRA incentive
- Other issues such as battery raw material availability, grid capacity, H2-infrastructure etc.

Tier 5 regulation for non-road equipment (implementation 2029?)

- 75 – 90% reduction in NOx expected along with low load cycle and other provisions from on-highway

- CARB does not have authority to regulate engines < 175 hp used for farm and construction

On HD electrification: Manufacturers are investing billions to develop ZEVs, but -
ZEV mandates fail to address the need for the trucks to be profitable for customers. No assurance on infrastructure development
Adv. Clean Fleets (ACF) purchase mandates are not aligned with ACT

SESSION 1

In-Use Emissions for Light- and Heavy- Duty Vehicles

USE OF REMOTE SENSING DATA TO ASSESS I/M PROGRAM EFFECTIVENESS - Jim Lyons, Trinity Consultants

This study focused on the Colorado AIR Program in the Denver area which is using a combination of testing, OBD and remote sensing to assess emissions compliance of older vehicles.
3-5 million remote sensing based readings of HC, CO and NO have been taken per year at 100 sites in the AIR program for vehicles going back to MY 1982
The data shows that I&M vehicles have lower emissions compared to non-I&M

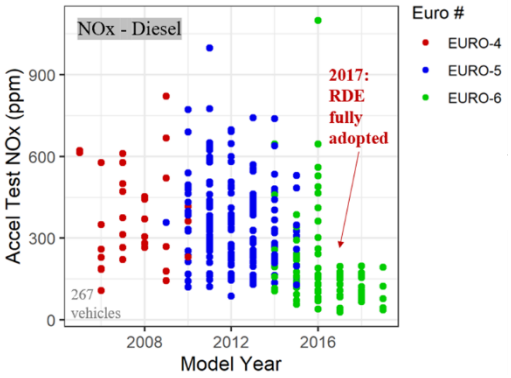
- 2019 calculated benefits, corrected for age of vehicles: HC = 17%, CO = 10%, NO = 17%
- Benefits are mostly from emission reductions from high emitters
- Emissions from vehicles which initially fail and were tested later and passed, were reduced by ~ 30%

Emission reductions for remote sensing agree fairly well with MOVES estimates for NOx (17%), but benefits are lower for HC & CO compared to MOVES

INVESTIGATION OF FLEET EMISSIONS USING ENHANCED INSPECTION AND MAINTENANCE METHODS - Daisy Thomas, 3DATX

This talk discussed the results from a periodic technical inspection PTI Pilot test campaign done in Europe. The enhanced parSYNC FLEX iPEMS was used for this work. Other the high idle test included in the PTI, the protocol included 2 additional 60 sec measurements at low idling, and driving to & from the test shed.
The test fleet included 606 passenger cars (some up to 25 years old), with a wide range of engine sizes. Gasoline/diesel mix was ~ 50/50. ~ 25% were Euro 4 and Euro 6 each, and almost half were Euro 5.

Effect of mileage on emissions control: While SCR equipped Euro 6 diesels have much lower emissions compared to Euro 4 & 5 vehicles, significant deterioration for Euro 6 vehicles was found. For gasoline, modern TWCs were found to have the same deterioration vs. past decades. DPFs greatly reduced PN but also showed deterioration (increased PN)



Model year trends

After 2017 adoption of RDE, step reduction in NOx emissions is seen. The test results were compared with RDE type approval values for 3 gasoline and one diesel vehicle. Acceleration NOx test was found to be most aligned with model type approved RDE emissions

Evolution of fleet emissions relative to Euro 4

PN emissions are high for petrol, highlighting the need for GPFs

INFLUENCE OF SNOWFALL ON CO2 AND NOX EMISSIONS OF WINTER MAINTENANCE VEHICLES - Will Northrup, Univ. of Minnesota

This study addressed the question: How does snow depth affect fuel consumption and emissions from winter maintenance vehicles? Minnesota uses ~ 600 snow maintenance vehicles, which use 0.8M gallons of diesel. They carry 1/3 of their GVW as salt! Idling accounts for 23% of the operating hours and 4.3% of total fuel used. Two Class 8 vehicle types were analyzed from winter of 2019/2020. The road load equation was use to estimate fuel consumption as a function of vehicle mass.

Snowfall and vehicle mass were found to significantly affect fuel consumption: 17 – 23% increase in fuel consumption with 1-2" snow accumulation, with related similar increase in CO2 and NOx emissions.

OVERVIEW OF DIESEL ENGINE MANUFACTURERS' DF VALIDATION RESULTS - Precious Ofoegbu, CARB

Recent test data obtained by CARB has shown that emissions deterioration with vehicle life is higher than what has been estimated through the deterioration factors (DFs).

CARB requested manufacturers to conduct a DF validation program for all pollutants, and the initial results for NOx were presented here. DF validation done using various methods: in-use engines, compliance demonstration on FUL aged engine in lab, or other methods such as procedures in Omnibus regulation.

Field-aged engines with > 35% of FUL mileage were used, and DF validation was considered complete after 85% FUL. Testing was done on HD FTP and HD SET test cycles. 2 on-road and 10 off-road units were found to exceed the FUL NOx and PM emission limits

On-board NOx sensor data from 35 in-use units were collected. Evaluation based on MAW method. Pass recorded for 1.5x certification standard.

Outcome of the DF validation program - Manufacturers have taken necessary measures to comply with CARB emission regulations such as re-evaluation of DF test procedure, re-designing engine systems and performing new durability demonstrations.

IN-USE EMISSIONS TESTING AND FUEL USAGE PROFILE OF ON-ROAD HEAVY-DUTY VEHICLES – THE "200 VEHICLE" STUDY – NOX EMISSIONS - Tom Durbin, UC Riverside

This is one of the most extensive studies of on-road emissions from HD vehicles in the US. The fleet includes diesels, alternative fuels (CNG/LPG) and hybrids, applied to various vocations.

NOx emission results from PEMS

CNG emissions were generally lower than diesels. CNG engines certified to 0.02 g/bhp-hr standard emitted up to 83% lower NOx compared to 0.2 certs. Diesels with SCR showed 27 – 98% reduction compared to no-SCR vehicles. Mostly, SCR temperature < 200 C explains the high NOx data from diesels.

Chassis dyno results from UDDS

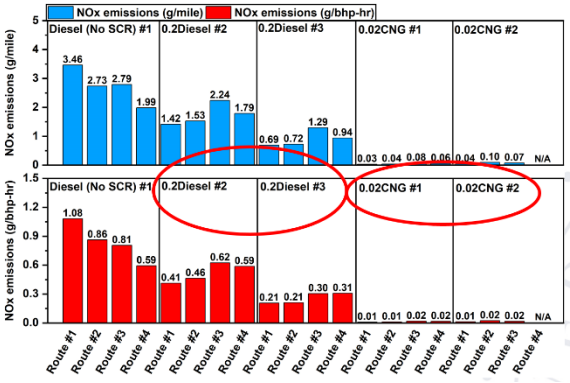
SCR diesels emitted lower NOx vs non-SCR. Most 0.2 diesels higher than cert standards, within 3X of limits

HVO showed reductions for diesel without SCR, but not for SCR-equipped 0.2 certs

Again, the 0.02 CNG vehicles were below the certification limits and were the cleanest.

On-road testing

This was done for highway good movement route with and without elevation change, grocery distribution route and port-drayage route. 0.02 CNG vehicles were considerably lower NOx emitting vs diesels. One of the diesels emitted twice compared to the other, showing that deterioration was different and plays an important role.



ANALYSIS AND EVALUATION OF SENSOR-BASED ONBOARD SENSING, ANALYSIS, AND REPORTING (OSAR) FROM SEVERAL CLASS 8 TRUCKS DURING A LONG TERM MEASUREMENT STUDY - Kent Johnson, UC Riverside

This study showed the use of OSAR - On-board sensing analysis and reporting - developed for continuous monitoring of diesel technologies. This was used to measure real world data on a MY2021 Class 8 truck.

The key point made was that emissions are found to be highly dependent on route, ambient conditions, payload, traffic, etc. and can show significant various over routes For example, in one on-road test, localized emissions were found to range from 1.49 to 0.005 g/bhp-hr.

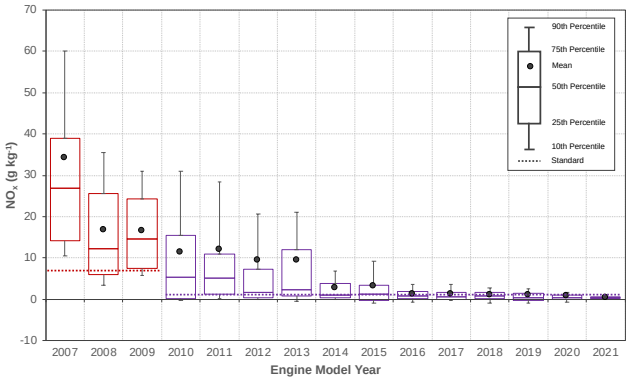
Moreover, emissions can also change from one day to the other due to variability in any of the factors above: Data collected over 2 weeks was 0.2 to 2X that of one PEMS measurement. Two months data changed that range from 0.5 to 2.4X.

All of this points to the deficiency of a single PEMS result and the need for continuous monitoring.

CHARACTERIZATION OF IN-USE HEAVY-DUTY DIESEL TRUCK EMISSION RATES OVER THE PAST DECADE AND EMISSION CONTROL TECHNOLOGY PERFORMANCE - Chelsea Preble, UC Berkeley

Fast responding, high accuracy pollutant analyzers were employed to measure exhaust plumes of trucks entering the Caldecott tunnel. Measurements cover engines back to MY 1985.

Fleet measurements have been done since 2010. In the latest 2021 data, the fleet had 99% vehicles with DPF, 87% with SCR and median MY 2014. Compared to the 2010 fleet, NOx emissions for the 2021 fleet has decreased by 78%.



Majority of pre-2016 engines were found to emit higher NOx than the relevant standards.

The data was also used to assess the deterioration of emissions with time. For example, the MY 2010+ engines with DPF + SCR showed 20% greater NOx emissions in the 2021 fleet compared to 2014-2015.

With the use of DPFs, the fleet-average BC emission factor has decreased by 83% from 2010 to 2021.

With the significant reductions in emissions, the contribution from high emitters is especially highlighted. The highest emitting 10% of the fleet now accounts for 59% of NO_x and 86% of BC emissions.

IMPACT OF LOW AMBIENT TEMPERATURE ON THE TAILPIPE EMISSIONS OF A 2027 HEAVY DUTY LOW NOX ENGINE ON REAL-WORLD DUTY CYCLES - Bryan Zavala, SWRI

NOx emissions were measured under low ambient temperatures between 2 – 10 °C. The SWRI stage 3 low NOx technology was used and testing done on CARB southern NTE and HD-FTP/LLC cycles.

<u>SNTE emission results</u>

3-bin MAW results using 800K aged parts showed increased emissions at low ambient temperature for all bins.

Bin 1 and 2: Low ambient results remained below the 2031 compliance thresholds

Bin 3: exceeded compliance thresholds by 38%

Higher NOx breakthroughs were observed during return-to-service events, high load events and cold starts

SCR temperatures were ~ 30 – 50 C lower compared to the reference.

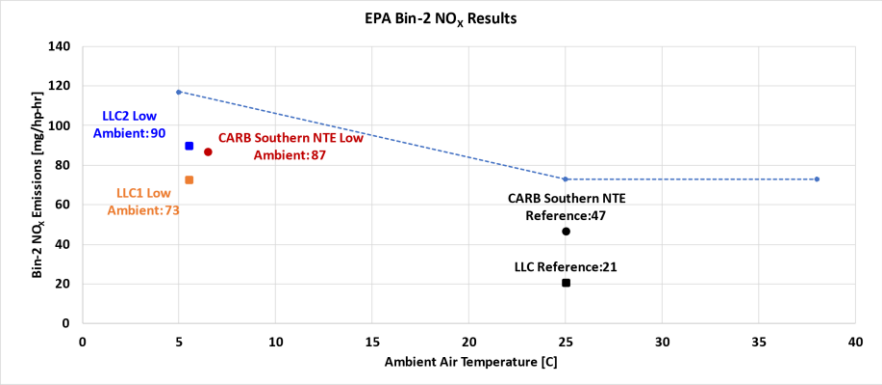
<u>LLC emission results</u>

3-bin MAW: Bin 1 & 2 emissions increased, but remained compliant for bins 1 & 2

The NOx emissions were found to increase from most parts of the test cycle, driven by lower SCR temperatures and extended operation below 200 C

The summary plot here shows the emissions for Bin 2 on the various cycles as a function of ambient temperature. It is seen that the emissions meet the EPA standards but would not the CARB limit which is fixed for all temperatures.

Potential solutions to address the increase in low T NOx include EGR cooler bypass, CDA, e-heater, exotherm across DOC – but all lead to CO2 penalty.



Questions / Comments: Ameya Joshi joshia@corning.com

Note: SCR dosing began at 130 C for upstream SCR (low due to heated dosing) and 180 C for downstream.

EVALUATING THE IMPACT OF CONNECTED VEHICLE TECHNOLOGY ON HEAVY-DUTY VEHICLE EMISSIONS - Stanislav Gankov, Southwest Research Institute

Vehicles with ADAS such as adaptive cruise control could use connected (V2X) data to improve fuel economy.
The focus of this study was to evaluate impact on emissions and after-treatment.
Emissions from class 8 trucks were compare from custom baseline and V2X-powered eco-driving cycles
A production 2017 Cummins X15 platform certified to 0.2 g/bhp-h NOx was used, coupled with the Low NOx after-treatment system.
CO_2 emissions reduced by ~ 8.5% over the eco-routes, however NOx emissions *increased* by 18%

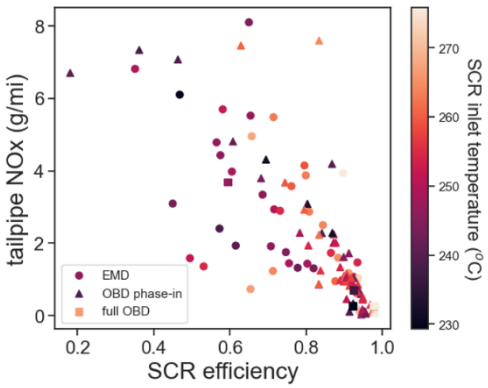
Using the SWRI low NOx system, NOx emissions were found to decrease by 30% in one of the routes by double in another. One of the reasons for the NOx increase is the drop in after-treatment temperature due to eco-driving mode.
After-treatment temperature dropped below 225 C more frequently in the eco driving mode and the reduced performance in regions not previously calibrated.

SESSION 2

Emissions Control Measures

LONG-TERM TRENDS OF IN-USE NOX AND CO2 EMISSIONS FROM HEAVY-DUTY ON-ROAD VEHICLES IN CALIFORNIA - Georges Saliba, CARB

HD vehicles contribute ~ 31% of NOx and ~ 9% of GHG emissions in California.
OBD data is being used to assess real-world emissions and will be used in the HD I/M program. Objective was to understand performance of current OBD NOx sensors and their potential to flag high emitting HD vehicles
Data was analyzed for 227 MY 2010 – 18 HD diesels covering 1M + VMT in a wide range of end applications
Good agreement between on-board sensor and PEMS NOx during hot operation but no OBD data for low temperatures – missing >20% of high emission NOx data when exhaust temp < 150 °C.
Vehicle-average tailpipe NOx emission factors calculated from OBD data.
In-use hot NOx emissions have reduced following HD OBD
SCR efficiency has improved from on average 70% to over 90% after full OBD phase-in
No statistically significant differences in CO_2 emissions found, but distribution is narrowing to lower values. CO_2 emissions found to decrease with higher average vehicle speeds measured up to 40 mph.



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COMPREHENSIVE INTEGRATED SIMULATION FOR ENABLING NEAR ZERO EMISSION VEHICLES - Andrea Strzelec, U. Wisconsin-Madison

Simulation tools will play an important rule to predict NOx emissions over vehicle useful life and to examine the role of new / renewable fuels. This project aims to develop and validate an integrated model of engine combustion, and after-treatment system to enable near zero emissions.

A multi-cylinder stochastic reactor model was developed and calibrated for combustion. Engine out NOx and soot emissions are predicted well for a 4-cylinder engine.

Engine out and tailpipe THC, CO and NOx emissions were measured and used for calibration of after-treatment model. The model captures NOx, CO, and THC conversion data very well.

EVALUATION OF EMISSION WARRANTY COST ESTIMATION METHODS FOR THE CALIFORNIA AIR RESOURCES BOARD'S HEAVY-DUTY ENGINE AND VEHICLE OMNIBUS REGULATION - Shunsuke Nakao, CARB

Background – there was an order of magnitude difference between estimates of warranty cost by CARB staff ($1,104) and by industry stakeholders (e.g. $13K by EMA). CARB requested staff to explore the reason for this difference.

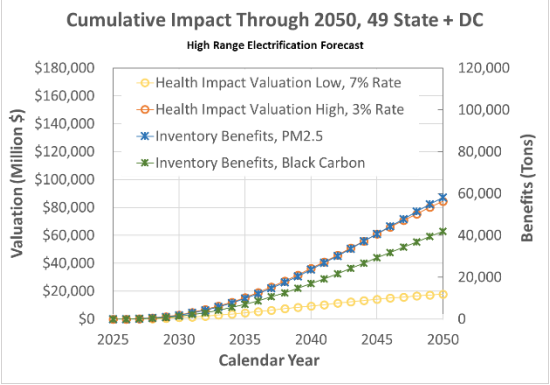
CARB study shows that most owners choose to purchase significantly longer emission warranties than required. A survey showed that pre-2022, 40% of population had a 500,000-mile warranty. Such a voluntary warranty was included in their analysis. Another point noted was that the industry has ignored the hour limits, which was also used in CARB estimates. CARB also used repair costs today and extrapolated into future since most future components are expected to be similar to existing technology.

PM EMISSION BENEFITS FROM A NEW U.S. LIGHT-DUTY VEHICLE STANDARD - Michael Geller, MECA Clean Mobility

The US currently trails the other major automotive markets in the world on particulate emission standards. PN standard of $6x10^{11}$ #/km in Europe, China and India approximately translates to a 0.5 mg/mi limit, half of the standard in California and 6 times lower than the EPA nationwide limit of 3 mg/mi today.

Modeling was done assuming nationwide standard of 0.3 – 0.6 mg/mi on the FTP cycle starting MY 2027. Three ranges of electrification were considered. The highest considers 50% by 2030 and then linearly increasing to 100% by 2050.

Based on these various scenarios, 60,000 to 115,000 of PM emissions are avoided. These result in ~ 5,000 to 22,000 fewer premature mortalities and significantly reduced asthma attacks and lost workdays.



Questions / Comments: Ameya Joshi joshia@corning.com

Fuels impact was not considered. PM effects of tires and brakes from electrification was not included – moving to electrification makes that problem worse.

SESSION 3

Off-Road / Non-Road

CARB'S OFF-ROAD IN-USE COMPLIANCE PROGRAM OVERVIEW - Hyun Ji (Julie) Lee, CARB

Off-road is the highest (35%) contributor to transport NOx in California. Objective was to gain experience and validate test methods for off-road in-use compliance. The pilot program contains two phases -
Phase 1: Data logging of parameters from ECU | Phase 2: Field testing – PEMS measurement and SCR induced verification, AECD testing
Various kinds of equipment are being tested, covering several manufacturers and power ratings
Engine speed was found to be the only parameter consistently broadcast by all equipment
% of time at % torque was measured
For PEMS, 7 out of 8 pieces of equipment experienced multiple NTE events, but were compliant. Only 2 out of 4 engine families passed the SCR inducement tests, probably due to DEF quality sensor issues.
Under normal operation, in-use compliance can be done using NTE on most off-road equipment such as excavators and dozers.
HD Off-Road IUC Program Development was discussed: Testing will be done using PEMS to assess compliance with NTE. In-field testing will be done using NTE protocol for compliance evaluation, while operating the equipment at normal site and intended application. If 3 or more engines fail, then it will be considered a fail
From Q&A - No equipment tested > 560 kW

MODELING SPATIAL VARIABILITY IN LOCOMOTIVE FUEL USE AND EMISSION RATES BASED ON REAL-WORLD MEASUREMENTS - Tongchuan Wei, N. Carolina State Univ.

This project aimed to develop a model to predict real-world passenger locomotive fuel use and emissions. A 173-mile rail track was used as the test case.
Over-the-rail emissions were measured using PEMS, along with other supporting information such as train speed, engine data, pollutant concentrations, intake air pressure, etc. The experimental matrix included 4 different consist types of locomotives and consist types, and ULSD and B20 fuels.
Locomotive power demand (LPD), the tractive power to overcome resistive forced opposing train motion, was estimated using a multi-variate model dependent on speed, acceleration, grade, etc. The model was then used to identify emission hotspots along the route.

DEVELOPMENT OF AN OFF-ROAD EMISSIONS SCREENING PROCEDURE FOR ANALYZING IN-USE EMISSIONS USING A THREE-BIN MOVING AVERAGE WINDOW (3B-MAW) METHOD - Christian Bartolome, CARB

For the first time, CARB is considering an off-road in-use testing (ORIUT) program, to supplement the Tier 5 low NOx rule. Use of PEMS testing could be costly, so NOx sensor data would be leveraged.

Manufacturers would have to annually submit NOx sensor data for 75% engines per engine family. Emissions would be binned into 3 bins (idle, low load and high load) and CARB would flag emissions factors with emissions twice the standard. Manufacturers would have to take corrective steps for non-compliance.

The methodology would follow the 3-bin moving average window method from on-highway. A study was done for 4 pieces of Tier 4f equipment, using 300-second windows. Sum-over-sum NOx emissions were calculated for each bin.

Compared to PEMS, the sensor-based NOx measurements deviated by ~ 6% - 18% for all data collected. Sensors were inactive during cold operation, and further development of sensors was found to be required. Further analysis with a 2-bin MAW is also being investigated.

KEYNOTE ADDRESS: CHRIS TENNANT

Executive Director, Coordinating Research Council

Through this informative and entertaining talk, Chris walked us through the history and ongoing work at CRC.

Progress through collaboration seems common sense today, but it was a pioneering thought at one point. Here are some words from T. A. O'Donnell in 1919, President of the American Petroleum Institute (API), on the need for cooperative work:
"We have arrived at the era of community effort. The individual efforts of a century ago served fairly well in meeting the demands of the times. We are rapidly approaching, if we have not already reached, a point where the individual effort in the oil industry will find its best exemplifications in cooperative action."

CRC traces its origins to the Cooperative Fuels Research committee of the SAE and was incorporated in 1942 to support the military's efforts in WW II. Today it continues to advance various topics through collaborative research. The research done at CRC is balanced and objective, the reports go through multiple rounds of peer review, and are published and made available for free for all on the website.

Picture of early PEMS measurement – 1955 Los Angeles Riverbed study
Emission rates were given in "lbs/hour" – we have come a long way.

What type of research does CRC do?

Experiments | Analysis | Events | Reference

Read the annual report and other information at www.crcao.org

CRC member groups
Auto/Oil program committees
➔ Performance, Atmospheric Impacts, Emissions and Advanced Vehicle / Fuel / Lubricants

Sustainable Mobility Committee
Electrification, Fuels, Novel carbon reduction strategies, Life Cycle Analysis

Aviation Committee
Example –Aviation fuel issues such as safety, operability

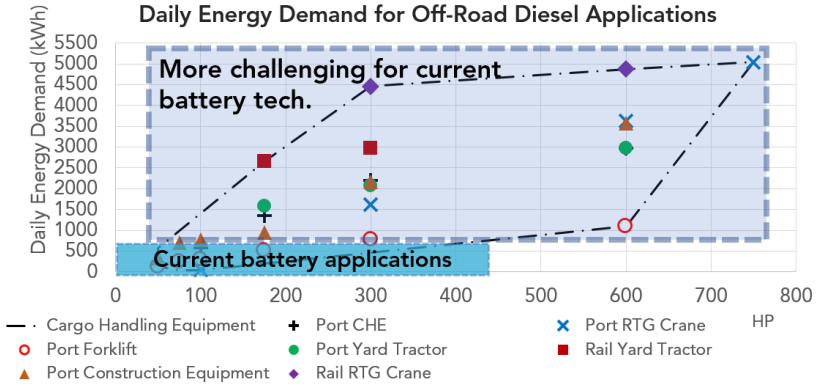
CRC conferences coming up
Sustainable Mobility:
November 7-9 – SAE Energy & Propulsion Conference & Exhibition
Life Cycle Analysis of Transportation Fuels:
October 3-5, 2023 @ Argonne National Lab
Aviation Committee: May 1st week (annual) @ Lake Washington, WA

SESSION 4

Electric and Hybrid Vehicles

POTENTIAL EMISSION BENEFITS OF ZERO EMISSION TECHNOLOGY ADOPTION SCENARIOS IN OFF-ROAD EQUIPMENT SECTORS - Junhyeong Park, CARB

There are > 500 ZE off-road equipment models. Majority of the equipment is under 200 kW power and 400 kWh capacity. But off-road applications could require up to 300 kW and 5000 kWh to get the job done.



Alternative charging solutions are a critical need for electrifying this segment. These include - Plug-in battery electric, Grid-electric, Mobile power station, Battery swapping, Catenary systems, and H_2 fuel cell powered

Currently battery equipment can cover 71% of electrification needs and reduce NOx by 30%. Alternative charging can increase this to 96% market share and reduce NOx further by 76%.

CHALLENGES FOR REAL GHG REDUCTION UNDER CURRENT TAILPIPE REGULATIONS - Graham T Conway, SWRI

OEMs who exceed CO_2 standards can purchase credits from OEMs with a high shared of BEVs

This study evaluated the use of a lifecycle analysis approach. Five vehicle segments, five powertrains (with varying levels of electrification) and 12 different fuels / electricity were analyzed.

For electric vehicles, the lifecycle approach requires counting GHG emissions from:

(1) Upstream electricity generation. Carbon intensity of the US grid varies according to location : ~ 139 lb-CO2/MWh for Washington but 871 b-CO2/MWh for Wyoming.

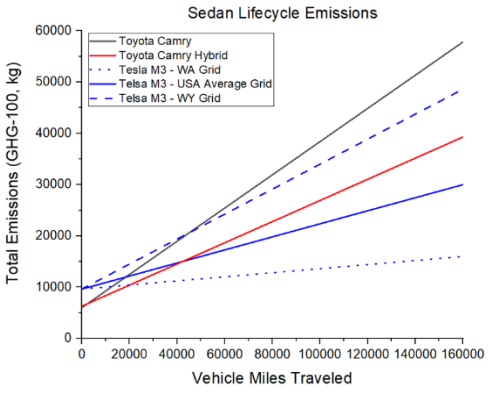
(2) Battery manufacturing – Tesla Model 3 30 kWh pack has 4 tons of embedded CO2 emissions

Lifecycle (160K mi) emissions reduction vs a Toyota Camry:

Toyota Camry Hybrid ~ 33%

Tesla ~ 50% for average US grid (break-even point at 40,000 miles)

However, when considering the Wyoming, grid, the Tesla emits more than the hybrid throughout the lifetime.



It was shown that when using a lifecycle approach and converting the fleet to hybrid, a high tailpipe emitting OEM could have met the requirements without the need to purchase credits. Moreover, 37 hybrid battery packs are equivalent to 1 battery pack for a Tesla, so more GHG reductions could have been achieved for the same amount of batteries if used on a hybrid.

ACTIVITY AND PERFORMANCE FOR HEAVY-DUTY DIESEL AND BATTERY ELECTRIC VEHICLES IN REAL-WORLD OPERATIONS

Tianyi (Jerry) Ma, UC Riverside, CE-CERT

Questions / Comments: Ameya Joshi joshia@corning.com

Performance and energy data was collected for 15 diesel Class8 trucks, 6 Class 7 electric box trucks and 11 Class 8 electric tractors.
For diesels, higher NOx emissions were found to be associated with idling time and the associated lower SCR temperature. Yard tractors emit higher NOx, and spent ~ 50% of time idling & 40% under low load conditions
BEV daily mileage was between 20 – 80 mi, and on average ~ 2.6 hrs of operation – this falls into short-haul / local distribution usage.
The energy consumption rate was measured at ~ 1.2 – 3 kWh/mi for box trucks, 1.7 – 3.4 kWh/mi for Class 8 trucks, variation probably related to routes and loads.
Mostly, charging was done during 5 – 10 p.m. when the renewable energy was at a low fraction.

SESSION 5

Improving the Emissions Inventory

A TALE OF TWO FLEETS: RSD MEASUREMENTS IN NORTHERN BAJA, MEXICO AND IMPLICATIONS FOR THE BORDER EMISSIONS INVENTORY

John Koupal, Eastern Research Group

Objective was to improve characterization of vehicles in Baja California (Mexico) and assess the prevalence of illegal “Chocolate” vehicles
Remote sensing data was collected to characterize the fleet, assign emissions to various vehicle segments and identify contributions from the chocolate vehicles.
Compared to a 2010 campaign, there is a >50% reduction in HC emissions. One of the main drivers is the reduction of sulfur levels from 500 to 35 ppm and also the phase in of tighter emission regulations
Chocolate vehicles account for ~ 1/3rd of annual on-road emissions in Baja California.

NEXT STEP OF EMFAC DEVELOPMENT: HIGHER SPATIAL RESOLUTION EMISSION INVENTORY

Jiachen Zhang, CARB

EMFAC (https://arb.ca.gov/emfac/) is getting new data sources: Road side monitors and automated VMT and other activity data through “big data” transportation resources such as StreetLight Data
High-res emissions inventory is being developed to increase resolution to census tract level. This will also help to inform the benefits of electrification by vehicle vocation and census tract.

APPLICATION OF AUTOMATED LICENSE PLATE READERS (ALPR) FOR FLEET CHARACTERIZATION AND EMISSIONS INVENTORY

Sara Forestieri, CARB

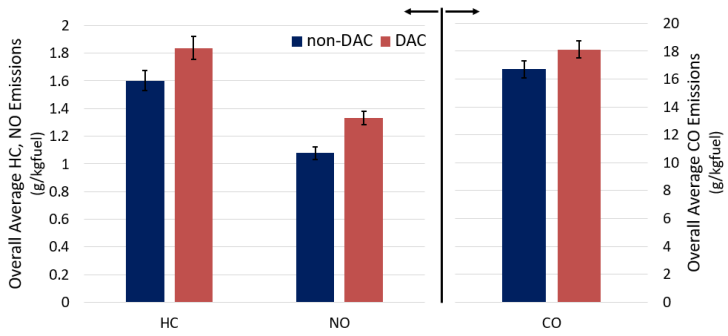
ALPR digitizes the license plate number and state / country, and that is linked to registration data to get vehicle characteristics such as GVWR, model year, fuel type.
Potential applications include improving characterization, compliance rates, new technology penetration, etc.
As example, data was collected in Environmental Justice neighborhoods in San Diego to corroborate emissions inventory assumptions. The fleet was characterized and compared to the assumptions made in EMFAC
94% - light-duty, 1% in medium-duty and 5% heavy-duty – similar to EMFAC
51% were heavy-HD (Class 8) trucks, much higher than assumed in EMFAC
Further, the fraction of vehicles operating in the EJ communities was then calculated.

APPLYING REAL-WORLD HEAVY-DUTY EMISSIONS DATA TO INFORMING INVENTORY DEVELOPMENT – DATA ANALYSIS ON PEMS - Mo Chen, CARB

The goal of this work was to use PEMS to better inform EMFAC HD emission rates.
566 vehicles were analyzed, covering MY 2003 – 2017.
Instantaneous NOx emissions were correlated with engine power, exhaust temp., vehicle speed and acceleration. Multivariable regression model using these variables could explain ~ 50% of NOx emissions for pre-2010 vehicles without SCR, but only ~ 20% of SCR equipped vehicles.
PEMS data on "Micro-trips" – smaller subsections of the overall trip – was next analyzed. This provides larger sample size and higher vocation resolution

REMOTE SENSING MEASUREMENTS OF LIGHT-DUTY VEHICLE EMISSIONS AT MULTIPLE CALIFORNIA LOCATIONS - Alan Standard, Eastern Research Group

The goal of this study was to investigate disparities between disadvantaged and non-disadvantaged communities due to emissions from light-duty vehicles. Remote sensing data was collected at 9 locations across California.
8 – 23% higher gas emissions were found for disadvantages communities. This was mostly attributed to average age of vehicles in DAC. No plans to measure PM in this project



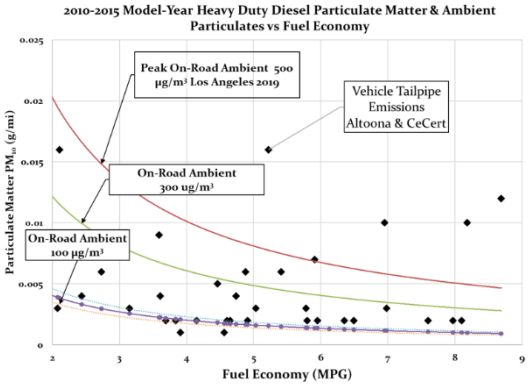
Light duty vehicles, all scans from multiple sites
Error bars indicate 95% CI

EVs had a 4X lower share in disadvantaged communities (0.4% vs 1.6%). Hybrid share was also lagging.

WHEN AND WHERE SUPER-CLEAN GASOLINE- AND DIESEL-POWERED VEHICLES OUTPERFORM ZEVS ON CRITERIA POLLUTANT EMISSION REDUCTIONS - Gary Yowell, Stillwater Associates

Questions / Comments: Ameya Joshi joshia@corning.com

A key idea expressed was the need to deduct ambient air pollution from tailpipe emissions to accurately evaluate the impact of vehicular pollution on the environment. Field data collected on 76 trucks with 7 – 15L engines was used to show that the air consumption is primarily a function of fuel economy, not engine size. Tailpipe PM emissions were then shown to be comparable to on-road ambient pollution levels, leading to cleanest diesels being net-zero PM emitting. Moreover, on-road ambient air pollution is 2 – 10 X higher than official remote monitoring stations. The study calls for CARB's EMFAC emissions to be adjusted to better account for ambient pollution.



Another view expressed in this talk was that NOx reductions in the past two decades has been much greater than VOC reductions, leading to a stalling of ozone attainment. After the recession in 2007, fuel consumption dropped by ~ 10%, but ozone violations increased by ~ 10%, which also suggests that NOx reductions have been counterproductive to ozone reduction.

SESSION 6

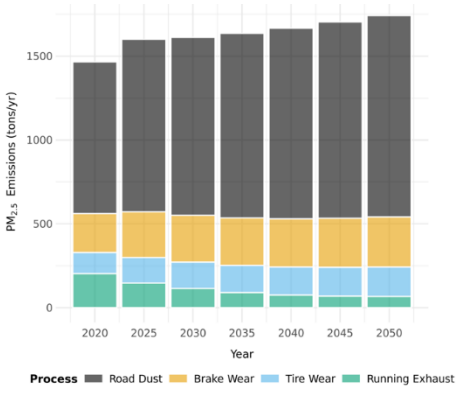
Emissions Modeling

FINE-SCALE ROADWAY EMISSIONS INVENTORY FOR SAN FRANCISCO BAY AREA USING TELEMATICS-BASED DATA AND EMFAC2021

Yuan Du, Bay Area Air Quality Management District

A fine-scale roadway emissions model is being developed to assess the contributions of vehicular pollution to PM2.5 and its health impact on near-road communities in the San Francisco area.

Vehicular activity was estimated using telematics data, and EMFAC2021 used to assess the emissions. Ambient concentrations were calculated using dispersion modeling and finally linked with assessment of exposure at census block levels (concentration times population).



PM sources considered include tailpipe, running losses, brakes and tires and resuspended road dust. The overall PM increases with time due to increase in VMT. Road dust is the major source at 60 – 70%. Exhaust PM decreases with time while brake and tire particles gain in share. High cancer burden was found in blocks adjacent to freeways.

EVALUATION OF MODEL PREDICTIONS OF REAL-WORLD EMISSION HOTSPOTS BASED ON MEASURED VEHICLE ACTIVITY AND EMISSIONS

Christina Quaassdorff, Technical University of Madrid / NC State University

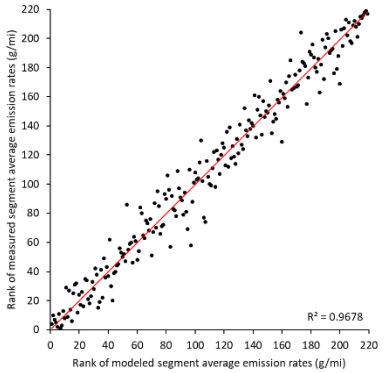
This study aims to predict emission hotspots for a given route based on known vehicle fleet and driving characteristics.

The study included 232 light-duty vehicles covering model years 1997 to 2019 consisting of 39% cars, remaining light trucks.

A pre-defined route was selected and broken into segments. Based on vehicle type and activity, emissions for individual segments were calculated using the EPA MOVES 3 model.

Emission hotspots were identified, defined segments within top 10% for emissions for each pollutant.

The model was successful in predicting the emission hotspots for CO2, NOx and HC emission, with accuracies > 93%.



SWITCHING FROM MOVES2014B TO MOVES3: CHANGES IN EMISSION RATES AND IMPLICATIONS ON AIR QUALITY PLANNING

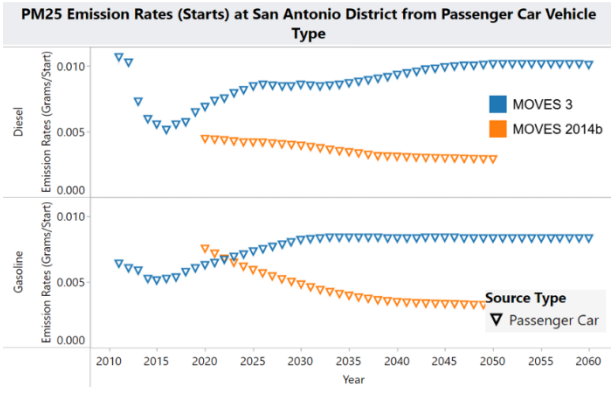
Chaoyi Gu, Texas A&M transportation Institute

The MOVES model is used widely in state implementation plans, predicting emission hotspots (see study above as example), congestion mitigation, etc. The US EPA recently released MOVES3, which includes several updates to the emission rates and activity data.

The output of the previous and new model was compared for emission rate look up tables and county level activity and emissions for the state of Texas.

While both models predict a decrease in NOx emission rates with time (the analysis was done to 2060), MOVES 3 predicts higher emissions in urban areas. Same for CO2, due to lower fuel efficiency standards in MOVES 3 following the “SAFE” standards by the previous administration.

The PM2.5 emission rates diverge significantly, with the previous version predicting a decrease and MOVES3 predicting an increase. This is possibly due to the increase in GDI engine percentage with time (without GPFs).



EPA PLANS FOR ELECTRIC VEHICLES MODELING DEVELOPMENT IN MOVES

Tiffany Mo, U.S. EPA Office of Transportation and Air Quality (OTAQ)

While the previous talk quantified changes in MOVES3, the next version - MOVES4 - is planned to be released this summer. It will include improved capability of modeling both light and heavy-duty electric vehicles, and fuel cell vehicles. The model will include temperature effects to account for energy consumption for cabin heating and cooling. Also included is the impact of aging on battery. The efficiency drops from 95% for new vehicles to 83% for 10 years or older vehicles. Charger efficiency is fixed at 94%. No change will be made for

plug-in hybrids. The EV penetration rates are still under development and will be based on GHG standards for MY 2023 and beyond, IRA incentives, etc.

PREDICTING HEAVY-DUTY VEHICLE EMISSIONS USING ADVANCED MACHINE LEARNING ALGORITHMS - Abdul Motin Howlader, CARB

Machine learning and deep neural network algorithms are being explored to predict emissions from the transport sector. The use of two predictive algorithms was reviewed –
Feed-forward neural network (FNN) and Long short-term memory (LSTM). The mathematical framework and flow chart was described. Input data included speed profile, engine family, model year, vehicle model, ambient conditions, etc.
Predicted emissions from both models were within 10% for CO_2 and NOx and 1.5% for PM.

SESSION 7

Air Quality / Effects of COVID-19 on Air Quality

NEW EUROPEAN STANDARDISED METHOD FOR MEASURING PARTICLE AND CARBON DIOXIDE POLLUTION IN THE VEHICLE CABIN - Nick Molden, Emissions Analytics Ltd

Particles can enter a vehicle through HVAC systems via cabin filter. There is very limited regulation on in-cabin air quality today. Recirculation can help but leads to CO_2 build-up and drowsiness, so should be used sparingly. There is no standard method today for real-world particle ingress testing. A new concept has been proposed in 2019 and has been adopted in a publication in Sept. 2022

- Key concept: Ratio of average inside to average outside particle concentration converges to repeatable value for given vehicle set up, with wide boundary conditions.
- Test procedure for getting to the converged value includes 30 - 120 mins of driving, under urban driving conditions of 30 – 50 km/h.
- A “Clean Air Quality Index (CAQI)” is calculated as ratio of particles inside to outside and is independent of outside concentrations and ambient temperature. Good repeatability of this procedure was shown on various vehicles and tested at various locations.

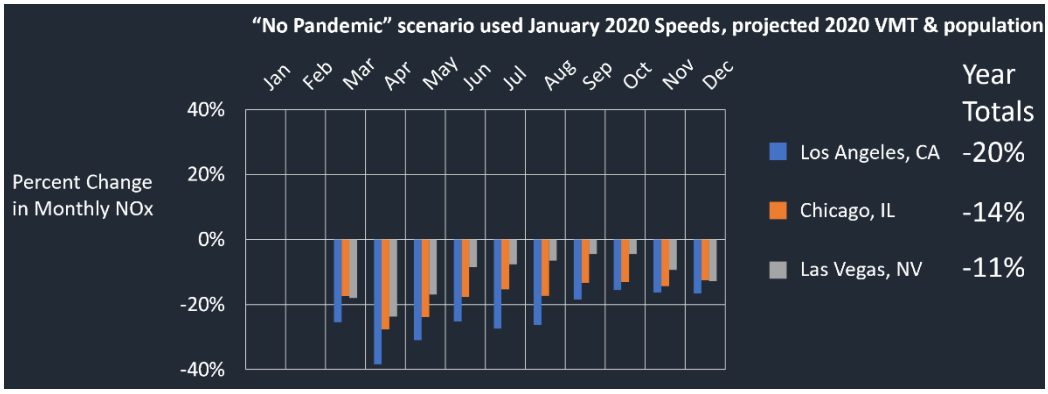
This was then applied to the Nissan Qashqai Euro 6 diesel. It was tested with OEM existing and new filters. Just by changing the filter, a factor of 3 difference was found in the air filtration between the various filters. Price range for changing the filters was $30 - $50.
A HEPA filter (like on Tesla) can provide even better performance but is expensive.

COVID-19 PANDEMIC EFFECTS ON VEHICLE ACTIVITY AND EMISSIONS - Allison DenBleyker, Eastern Research Group

This study explored the use of smartphone location data as a new source for vehicle activity, informing the changes in vehicular activity during the pandemic. StreetLight data was used to retrieve and summarize vehicular activity according to vehicle type, speeds, distance, time, etc.

The average speeds are typically lower during peak-hour congestion. Due to reduced driving activity during the pandemic and corresponding decreased traffic congestion, average vehicle speeds were much higher over the course of the day across several major cities. Such data could be correlated with vehicle accidents to understand, for example, the impact of driving speeds on safety.

Interestingly, data from some of the major cities studied suggests that while the vehicular miles traveled decreased significantly during the pandemic (by as much as 75%), NOx levels only decreased by 11 – 20%.



USE OF LINEAR REGRESSION TECHNIQUES FOR DEMONSTRATING THE EXCEPTIONAL IMPACT OF THE COVID-19 HEALTH EMERGENCY ON OZONE AIR QUALITY IN THE DISTRICT OF COLUMBIA - Joseph Jakuta, District of Columbia Department of Energy and the Environment

In 2020, DC saw a 77% decrease in traffic congestion, accompanied with a 21% decrease in NO_2 and 7% decrease in ozone. The decrease in ozone for a few months was seen as an exceptional event. It would have led the 3-year average of the region being well below the NAAQS based on this abnormal reduction. To ascertain if 2020 was exceptional, a counter factual model was developed using two regression tools – ordinary least squares and quantile regression. These tools were reasonable for predicting differing percentiles of ozone and the counter factual pointed towards ozone being exceptionally low in 2020. These tools are increasingly being used in forecasting applications.

COVID-19 AND VEHICLE EMISSIONS INSPECTION FRAUD IMPACT - Chris Klaus, North Central Texas Council of Governments

This talk gave an overview of vehicle emissions inspection fraud during COVID-19 in the Dallas-Fort Worth area. The number of vehicles registered without passing inspections increased starting 2019 and reached a factor of 4 increase by 2021. Some of this registration fraud is being done using temporary and fake tags. Other methods include hooking up another cleaner vehicle which is capable of passing the test, or even using an OBD simulator which can be bought online(!)

Various solutions to this problem were proposed including an emissions task force and legislation which would require metal license plates, increasing penalties, etc.

Questions / Comments: Ameya Joshi joshia@corning.com

DAY 3 – WEDNESDAY, MARCH 29, 2023

SESSION 8

Fuel Effects on Emissions

EFFECT OF FUEL PROPERTIES ON PM EMISSIONS FROM 4-CYCLE GASOLINE NONROAD ENGINES - Aron Butler, EPA's Office of Transportation and Air Quality

Heavy aromatics have been known to lead to high PM emissions and SOAs in light-duty vehicles. This study extends to non-road.

A 726 cc / 24 hp 4-stroke engine was studied, as used in lawnmower and portable generator applications.

4 different fuels studied, covering PMI ranging from 1.4 – 2.7, aromatics content from 23.2% to 27.3%, and C10+ aromatics content from 4.2 – 7.2% by volume. 3 of the fuels were E10, the remaining was E15. Sulfur levels were similar at ~ 7 ppm across fuels.

Testing was done on the RMC cycle.

- The fuels had an impact on performance, with the lowest aromatics found to provide highest power.
- PM emissions were found to be highly sensitive to PMI. The E15 fuel had lowest PM, CO and NOx but also notably higher NOx.

Particle size distribution showed a single nucleation mode peak at ~ 10 nm for all fuels.

RESULTS FROM AN ULTRA LOW-EMISSIONS VEHICLE: FUEL PROPERTY EFFECTS FOR CONVENTIONAL AND SYNTHETIC FUELS - Alexander Voice, Aramco Americas

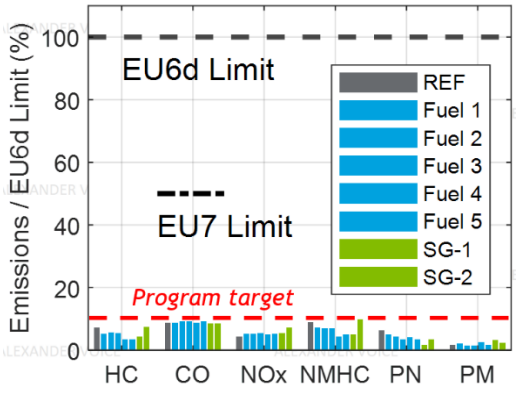
The combination of advanced engine and after-treatment technologies, and fuels was studied for meeting upcoming ultra-low emission requirements. Some of the advanced technologies included TWC with high PGM loading, heater and next generation GPFs.

Seven fuels were tested, covering 64 fuel properties such as C9+ aromatics, C11+ aromatics, E150 (amount of fuel distilled at 150 °C). The matrix included two synthetic fuels - gasoline E10 and gasoline M30 (30% methanol). The PMI ranged from 0.7 to 2.2.

The combination of advanced technologies with any of the fuels was shown to comfortably meet the Euro 7 limits even at -7 °C.

PN did not correlated well with PMI. Physical properties were better correlated with emissions. The final boiling point gave a slightly better correlation with PN (although still not good enough to be predictive).

Engine out hydrocarbons were well predicted with middle distillation (T50), but the correlation was lost at the tailpipe following the use of advanced technologies.



While there were no categorical differences were observed between conventional and synthetic fuels, the latter provided 80% reduction in lifecycle CO_2.

Alex provided a summary of his talk in verse – using ChatGPT.

Fuel alone cannot define,
The emissions of a car's design
Consider also the technology
And routes with different topology

Sulfur, octane, density and more
Fuel properties we can explore
But combustion is complex and diverse
And the process can be hard to reverse

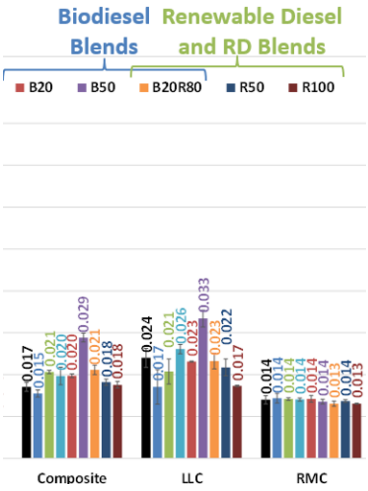
Variables such as temperature and air
Catalysts and filters, all play a fair share
And so predicting emissions is a game
With many factors and many aims

We strive to create fuels cleaner,
To reduce emissions and be greener
But the difficulty of prediction remains

SHORT-TERM FUEL IMPACTS ON TAILPIPE EMISSIONS FROM A 2027 HEAVY-DUTY LOW NOX ENGINE - Chris Sharp, Southwest Research Institute

Objective was to quantify short-term impact of fuels on low NOx HD engines representative of MY 2027+ EPA certification, CARB reference diesel, and 6 other diesel fuels were tested on FTP, LLC and RMC cycles. CARB stage 3 Low NOx engine (Cummins X15 with cylinder deactivation and other technologies) was used along with parts hydrothermally aged to 435,000 miles.

<u>NOx</u>



- Tailpipe NOx emissions were similar on the RMC, regardless of fuels
- Emissions for most fuels were within 3 mg/hp-hr, which is within the variability
- B20 had no impact on emissions
- B50 increased tailpipe NOx as much as 10 mg/hp-hr, ~ 17% of in-use standard
  - Attributed to reduced SCR temperature in critical low temperature regions by 10 – 15 °C, leading to transient NOx breakthroughs
  - B50 also reduced power, consistent with 5.5% oxygen content
- Renewable diesel (R50 and R100) showed similar emissions and performance as base diesel. Engine out NOx was lowest for R100. It also had 4% lower CO_2 emissions at tailpipe (in addition to the upstream CO_2 reduction)

<u>Soot</u>

B20 and R100 significantly reduced engine out soot and resulted in lower rate of soot accumulation and ~ 50% reduction in pressure drop

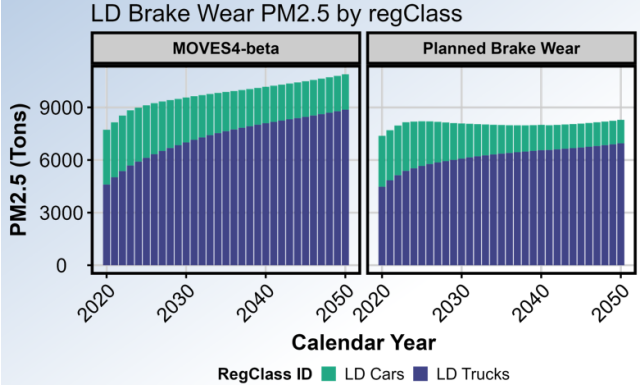
Questions / Comments: Ameya Joshi joshia@corning.com

SESSION 9

Brake and Tire Wear

DEVELOPMENT OF NEW BRAKE WEAR EMISSION RATES FOR EPA'S MOVES MODEL - Michael Aldridge, U.S. EPA Office of Transportation and Air Quality

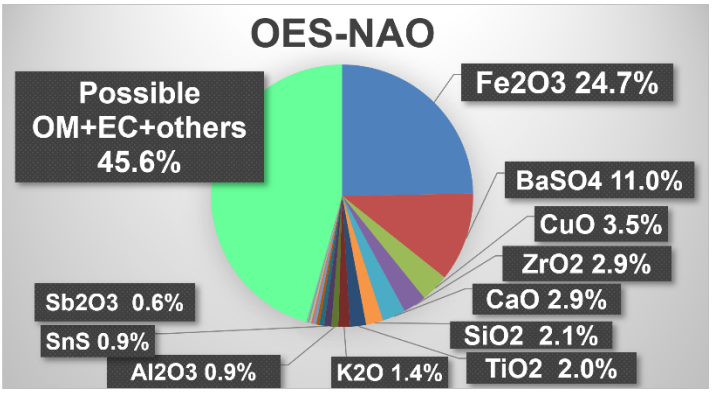
MOVES4-beta modeling shows that brake wear will be the highest contributor to PM2.5 emissions in the coming years. The braking fractions across the vehicle operation modes are being updated in MOVES. Brake wear rates were measured using 7 vehicles including one EV and one hybrid. The wear mass rates were differentiated according to material (non-asbestos organic and low-metallic) and combined for front and rear brakes. Wear rates were plotted as a function of vehicle mass. The wear rate on the Tesla were very low, due to regenerative braking. This is leading to a significantly reduced inventory of brake wear PM. Or light-duty, future emissions are dominated by light trucks.



TRACE METALS AND CHEMICAL COMPOSITION ANALYSIS FROM BRAKE WEAR PARTICULATE MATTER (BWPM) EMISSION AMONG DIFFERENT BRAKING PAD MATERIAL TYPES ON LIGHT-DUTY VEHICLE BRAKING SYSTEMS

Chia-Li Chen, CARB

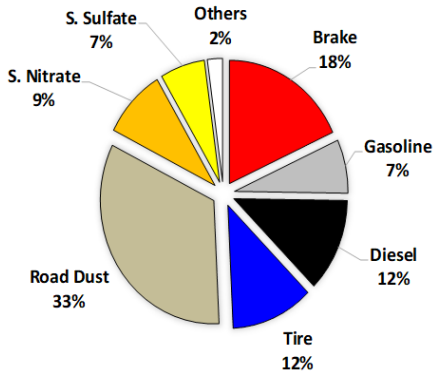
This study by CARB preformed a chemical analysis of the PM emissions from brakes. A brake dyno and CVS setup was used to measure wear from 6 test vehicles. Fe and Ba were two major trace metals found, accounting for ~ a quarter of the NAO PM and half of the low metallic PM. Oxides of Cu, Zr, Ca, Si, etc. were also found and help to close the mass balance. Emission rates depend on the vehicle mass. PM10 emissions were as high as 30 mg/mi on light-trucks.



ELEMENTAL CONTENT OF BRAKE AND TIRE WEAR PM2.5 AND PM10 AT NEAR-ROAD ENVIRONMENTS - Brenda Lopez, University of California Riverside

Measurements of brake and tire PM2.5 and PM10 were done at two locations in California. Brake and tire wear accounted for 30% of the near-road PM2.5 in one location and 15% in another. In both cases, the contributions were higher than from the tailpipe.

The elemental analysis shows that Fe, Cu, Zr, Ti, Ba and Zn are some of the elements which can be correlated with non-tailpipe emissions. Size analysis was also done, showing that brake particles are 1 – 10 μm while tires at 10 – 18 μm.



CHARACTERIZING PARTICLE SIZE DISTRIBUTION AND TOXICITY OF TIRE WEAR EMISSIONS - Molly Haugen, University of Cambridge

Elemental analysis was done on newly manufactured tires from 60 light-duty vehicles and 17 heavy goods vehicles. 25 elements were quantified. Zn, Al, Fe and Mg were found in abundant quantities while several other elements such as Ti, Cu, Ba etc. were found in lower concentrations.

The tire composition was further analyzed and compared for

- Tread vs sidewall (sidewalls could be scrubbed on roundabouts, as an example)
- Various manufacturers - significant differences were found
- Light vs. heavy-duty vehicles

An interesting remark made during Q&A was that the tire manufacturing location and destination also matters (expect differences between tires made for local vs international markets). A participant also noted that Europe is working towards a PM/weight of tire metric as part of Euro 7 discussions.

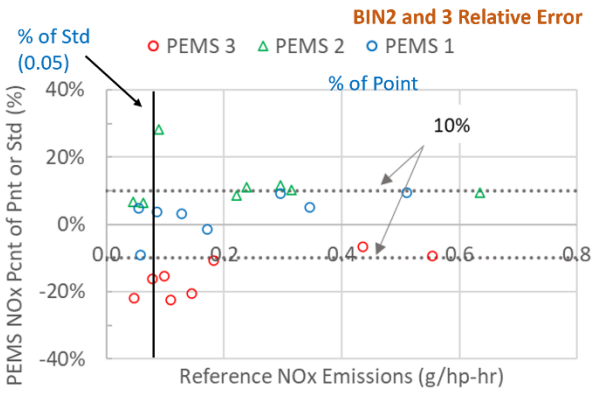
SESSION 10

Emissions Measurements Methods

A COMPREHESIVE EVALUATION OF ALL THE NEW STATE OF THE ART 1065 COMPLIENT PEMS DESIGNED FOR EMISISONS AT AND BELOW 0.05 G/HP-HR NOX. - Kent Johnson, University of California, Riverside

New NOx PEMS seems to be ready for quantifying emissions for future low NOx HD standards set by CARB/EPA. 1065 approved gas PEMS equipment from Horiba, AVL and Sensors, was used for this study. These were upgraded for low NOx measurements with improved thermal management for lower zero drift and better signal processing. One uses chemiluminescence and other two are UV-based.

Measurements were done on Class 8 truck with a 15L engine. Emissions were compared with those from a mobile reference laboratory over varying routes: Highway goods movement at varying elevations, Grocery Distribution, and Port Drayage
Bin 1 NOx emissions were an order of magnitude below the idle limit of 7.5 g/hr, and relative errors were mostly within 10%
Bins 2 and 3 emissions below the 0.05 g/bhp-hr reference were < 10% for two of the PEMS devices.



PEAQS EMISSION CLUSTERING FOR CLASSIFYING HIGH-EMITTING HD TRUCKS - Daniel Phillips, CARB

This study discussed the use of Portable Emissions Acquisition System for quantifying in-use emissions from HD trucks using plume measurements. Data collected at three locations was analyzed for NOx, HC and black carbon emissions. Correlating emissions of multiple species is being used to identify types of emission failures. For example, high emitters of NO correlated with high emissions of N2O point to newer model year trucks with SCR technology, while high NO emissions were also associated with high BC emissions. Very high statistics will be required to characterize the modes of emission control failures.

HORIBA TORQUE MATCHING – ELIMINATING THE NEED FOR ON-ROAD EMISSIONS MEASUREMENT - Alex Mason, HORIBA MIRA

This work introduced Horiba's "Torque Matching" technique to replicate road tests in the lab, to reduce variability. The idea is to measure emissions on the road under worst case conditions, emulate the test in the lab using measured road load, then create an empirical digital twin to predict emissions across a wide range of operating conditions.
An example was shown for a full hybrid, in which the difference between lab and road measurements was 0.5% for CO2, 1.7% for NOx and 2.7% for PN. Energy use was predicted to within 1.5%. Only CO was measured on the lower side in lab by about 30%.
Based on the lab emulation, a high-fidelity model is developed using neural networks. The digital twin so generated was shown to reduce physical testing time for RDE tests significantly, leading to up to 70% reduced time in validation of vehicle calibration.

UNLOCKING THE BENEFIT OF ON-BOARD MEASUREMENTS, CLEANER COMBUSTION, AND OPERATIONAL IMPROVEMENTS FOR MOBILE SOURCE GREENHOUSE GAS REDUCTIONS - Kent Johnson, University of California, Riverside

This talk discussed preliminary thinking done on the potential use of on-board emission measurement systems for quantifying GHG reductions and helping ensure transparency of the emission reduction credits and other tools being used for carbon offsets. The idea is to use on-board measurements to demonstrate and certify GHG reductions, which could lead to a tradeable commodity. The on-board devices will measure both the baseline and improved emissions and track the GHG reductions over the life of the project. Carbon credits

generated and could be traded on the market. A key feature of such a technology could be its ability to monitor such emissions real-time and include the use of telematics to ensure that the reductions occur under real-world conditions.

SESSION 11

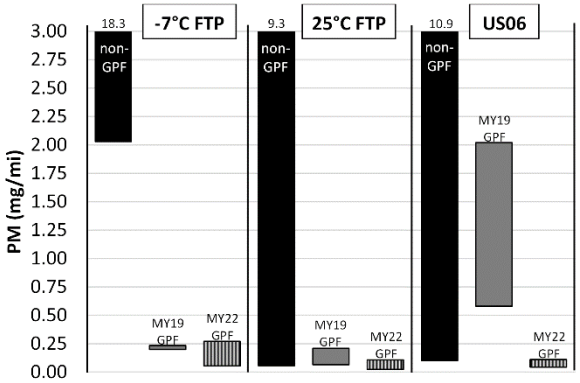
Particulate Emissions and Measurement

DRIVE CYCLE PM MASS MEASUREMENTS CAPABLE OF RESOLVING GPF-LEVEL EMISSIONS FROM LIGHT-DUTY VEHICLES - Stanislav Bohac, U.S. EPA Office of Transportation and Air Quality

This study compared the tailpipe particle emissions from 5 light-duty and medium-duty vehicles with and without the use of gasoline particulate filters.

Measurements were done on the FTP cycle at 25 °C and -7 °C and on the US06 cycle using existing test procedures. These conditions cover the broad range of real world ambient and on-road driving conditions.

Testing was done at 3 different labs – EPA, Environment Canada and FEV – to account for measurement variability.



Results show that in all cases, the vehicles with model year 2022 GPFs emitted PM well below 0.5 mg/mi PM, filtering the engine-out PM with efficiencies > 95% in most cases. Engine out emissions increased significantly at low temperatures (as much as 18 mg/mi) but tailpipe emissions were low even in those conditions.

LUBE OIL EFFECTS ON PARTICLE EMISSIONS FROM A GDI ENGINE OPERATING ON HIGH AND ULTRA-LOW PMI GASOLINE FUEL - Imad Khalek, Southwest Research Institute

This study evaluated the impact of different lube oil formulations on the particulate emissions from a GDI engine under cold-start WLTC testing, done on a 2.3L 2018 Ford Ecoboost engine. Data collected included PM, PN (down to 10 nm) and also real-time ash.

The matrix included 3 different fuels – EPA Tier 3, CARB LEV III, and a very low PMI fuel representative of an e-fuel – and 7 different oil formulations.

The low PMI CARB fuel reduced PM but showed an increase in the PN in the 10 – 23nm range, suggesting a shift of the particle distribution to a smaller range. This is a new and unexpected finding.

The very low PMI (0.27) fuel showed up to a 91% reduction in PM along with a significant reduction in PN. The particle size distribution shows a ~ 25% contribution of sub-23 nm particles during the cold start likely derived from lube oil, but these dropped substantially when a TWC was used.

APPARENT TEMPERATURE DEPENDENT REMOVAL EFFICIENCY OF CRANKCASE CONTROL DEVICES - David Kittelson, University of Minnesota (presented by Imad Khalek)

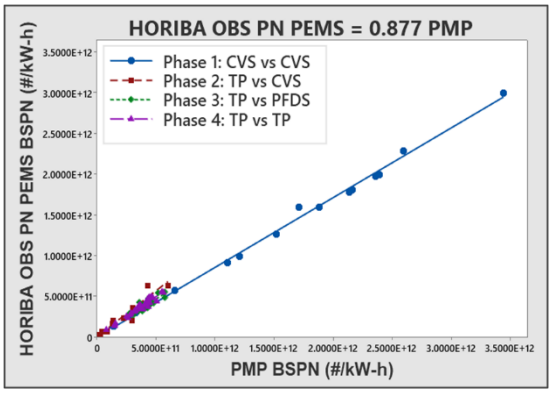
About 1% of combustion products leak past the piston rings and are either recycled to the engine or vented out. These crankcase emissions are getting increased attention. Currently, most engines do not have crankcase controls.

This work explored the issues associated with measurement of volatile particles coming from the crankcase, as measured by two devices: coalescing filter and rotating inertial separator. An unusual temperature dependence of the particle filtration efficiency was observed, attributed to particle shrinkage and growth along the sampling and measurement stages. This was used to make recommendations on best practices. Caution should be used when taking such measurements.

ASSESSMENT OF CPC-BASED PN-PEMS FOR HEAVY-DUTY CNG ENGINES - Thinnesh Ragupathy, Western Michigan University

This study compared the performance of the CPC-based Horiba OBS PN-PEMS device with lab grade PMP systems as applied to HD CNG engines. The system utilized two diluters separated by a catalytic stripper, and a CPC. Measurements were done on several engines, test cycles and using a matrix targeting various locations – CVS, partial flow dilution system or tailpipe locations for the PEMS and PMP systems.

Overall, good correlation was observed in all cases, with PEMS on the lower side. Specifically for the tailpipe location, the error was 2.9 ± 6.5%.



EVALUATION OF PM AND SUB-23 NM PARTICLE NUMBER EMISSIONS FROM A HEAVY-DUTY DIESEL VEHICLE DURING ON-ROAD OPERATION - Tianyi (Jerry) Ma, UC Riverside, CE-CERT

Particulate emissions were measured from a Class 8 MY 2019 truck with a 15L engine and emissions control using EGR, DOC, DPF, SCR. Testing was done on various real-world routes representative of goods movement, highway driving, port-drayage and grocery distribution.

For normal operation, solid PN emissions were on the order of ~ 10^{10} #/bhp-hr, but these increased by 1 – 2 orders of magnitude during regenerations. The PN count increased by a factor of as much as 365 when including particles below 23 nm for one of the routes. Some of these elevated emission during regeneration were found to occur in highly populated, environmental justice areas.

NOTE FROM THE AUTHOR

Questions / Comments: Ameya Joshi joshia@corning.com

No good deed goes unpunished. I wrote some meeting notes on the CRC conference last year and the organizers asked me to do so again. I happily agreed since this is one of the best conferences of the year. Still, typing away 25 pages describing other people's talks can be daunting. Hope you find this useful. If you have positive feedback, let me know (if you have negative feedback, hold on to it and write this yourself next year).

Please note that the intent here is to capture some of the highlights and not to give a detailed description of each talk. Look up the presentations and contact the authors if you have detailed questions. Any errors and omissions here are mine, please do not attribute to the excellent speakers.

Finally, I maintain a website to keep track of developments in the field of transport emissions, do sign up for a monthly newsletter if such summaries are of interest:
www.mobilitynotes.com

Ameya Joshi