Highlights from the Coordinating Research Council 23rd Real-World Emissions Workshop

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For decades, the Coordinating Research Council (CRC) has held an annual vehicle emissions workshop, gathering international practitioners in the field of vehicle/engine emissions to discuss the latest activities in modeling, measurement, and analysis. The most recent, the 23rd Real-World Emissions Workshop, held April 7-10, 2013, in San Diego, CA, covered topics such as trends and modeling, measurements and monitoring, and inspection/maintenance. The workshop consisted of presentations, posters, and demonstrations. Highlights of the 2013 workshop sessions are summarized below.

Emission Rates and Inventory

Emission measurements at the Caldecott tunnel in the San Francisco Bay Area indicate that diesel emission factors are approximately 10 times higher than gasoline, and organic aerosol emissions are mostly due to lubricating oils. Remote-sensing measurements in Southern California indicated that selective catalytic reduction (SCR)-equipped trucks have higher nitrogen oxides (NO_X) emissions at low exhaust temperatures (see Figure 1), and mean NO_X and particulate matter (PM) emissions have remained low since 2010.

Heavy-duty truck field emissions measurements conducted on 938 trucks in Vancouver used the streamlined heavy-duty emissions detector (SHED) to capture moderate-load emissions on each truck (see Figures 2 and 3). Port of Houston entry data from heavy-duty "drayage" trucks show that the fleet wasn't distinguishable from trucks operating in the greater Houston area. Cold temperature emission measurements on nine gasoline Tier 2 vehicles showed that MOVES underestimates cold hydrocarbon (HC) emissions and overestimates cold

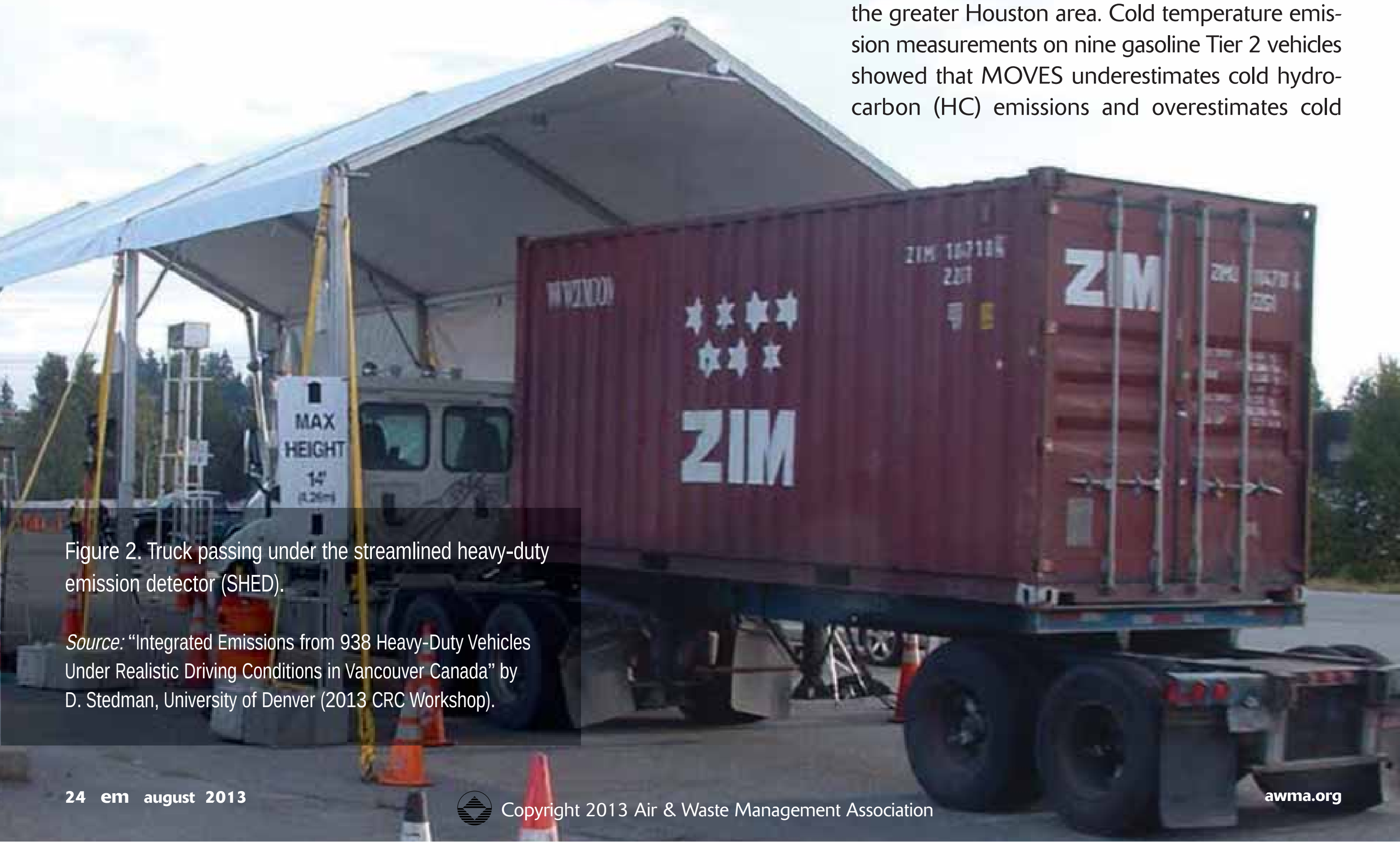

Figure 2. Truck passing under the streamlined heavy-duty emission detector (SHED).

Source: "Integrated Emissions from 938 Heavy-Duty Vehicles Under Realistic Driving Conditions in Vancouver Canada" by D. Stedman, University of Denver (2013 CRC Workshop).

carbon monoxide (CO) emissions, while predicting cold PM emissions well.

Emission Control Measures and Emerging Technologies

In the Advanced Collaborative Emissions Study (ACES) project, three 2010-compliant engines demonstrated emissions substantially below the 2010 standards for NO_x (60% below), CO (97%), nonmethane hydrocarbons (NMHC;100%), and PM (92%), and were also significantly reduced compared to ACES results on 2007-compliant engines (see Figure 4).

Infrastructure and in-vehicle inducements are working in California to ensure SCR in diesel trucks is effectively reducing NO_x. Different strategies to keep SCRs operational during low-load operations can lead to large differences in NO_x emissions from low-load operations in 2010-compliant engines. Novel in-cylinder strategies, such as alternative ignition systems (laser spark plugs) and multiple injection sequences during low-temperature combustion, were reviewed, showing potential to lower PM and NO_x, and greenhouse gas (GHG) emissions.

Results from train stations with diesel-powered locomotives show increased levels of PM, sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) at the platforms, the latter beyond local limits. The use of cloud computing technology in conjunction with remote-sensing devices can provide real-time information on pollutant levels and vehicle emission distributions.

I/M and In-Field Measurement Methods

In-use data indicate there are few high-emitting vehicles in the fleet equipped with on-board diagnostic system information (OBDII), especially for MY2000+. Analysis of inspection and maintenance (I/M) program records found that evaporative emissions OBDII monitors were "not ready" (i.e., the full diagnostic check was incomplete) on 3%-16% of the vehicles arriving for inspection. Evaporative control system trouble codes were set on 0.3% to 2.5% of the "ready" vehicles, depending on age.

In-use diesel emissions retrofit technologies equipped on school buses indicated very good in-use durability and performance, showing PM reductions over 90%. Time-aligning, second-by-second data from portable emissions measurement systems (PEMS) is a challenge, as synchronization errors can lead to substantial underestimation of emissions differences across operating modes (see Figure 5). Prolonged sampling times improved accuracy for heavy-duty engine PM conformity testing in Europe using PEMS-PM devices. Two systems to measure in-use fuel economy were evaluated for assessment of "hyper-miling." Both systems were repeatable, and distinguished a 2% difference in fuel economy.

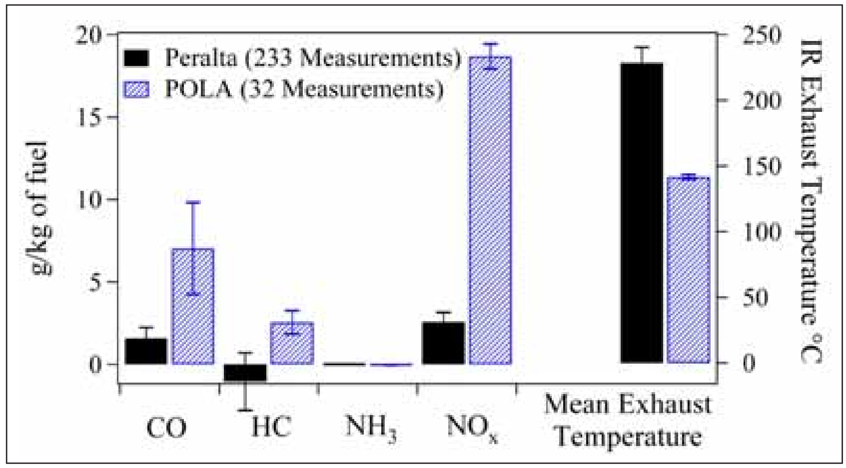

Figure 1. Emissions and exhaust temperature of SCR-equipped trucks at two locations.

Source: "Emission Trends in Heavy-Duty Trucks in the South Coast Air Basin" by G. Bishop, University of Denver (2013 CRC Workshop).

Modeling

Emissions data for compressed natural gas (CNG)-fueled transit buses were compiled from literature and compared to the MOVES2010 model. Proposed MOVES emission rates for total HC,

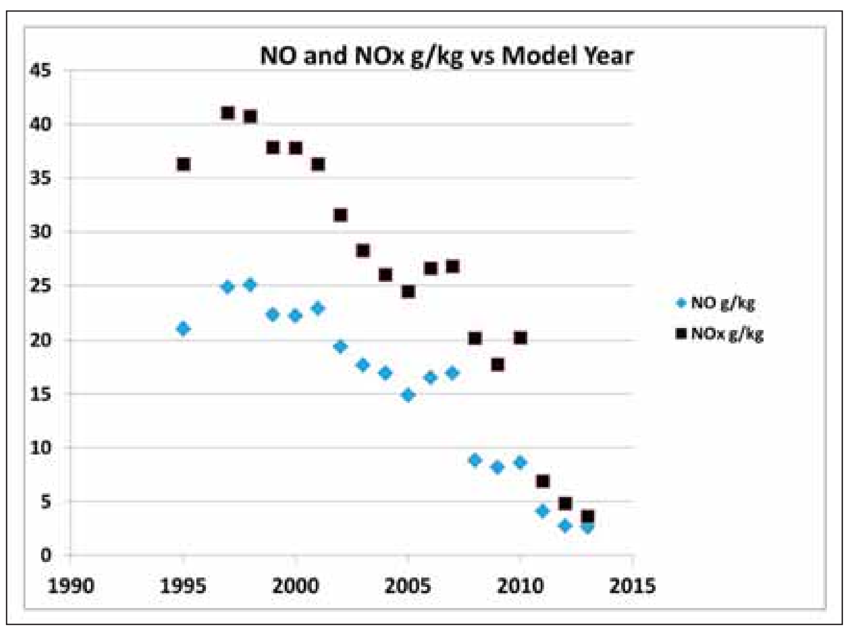

Figure 3. NO and NO_x g/kg rates by model year measured in emissions SHED.

Source: "Integrated Emissions from 938 Heavy-Duty Vehicles Under Realistic Driving Conditions in Vancouver Canada" by D. Stedman, University of Denver (2013 CRC Workshop).

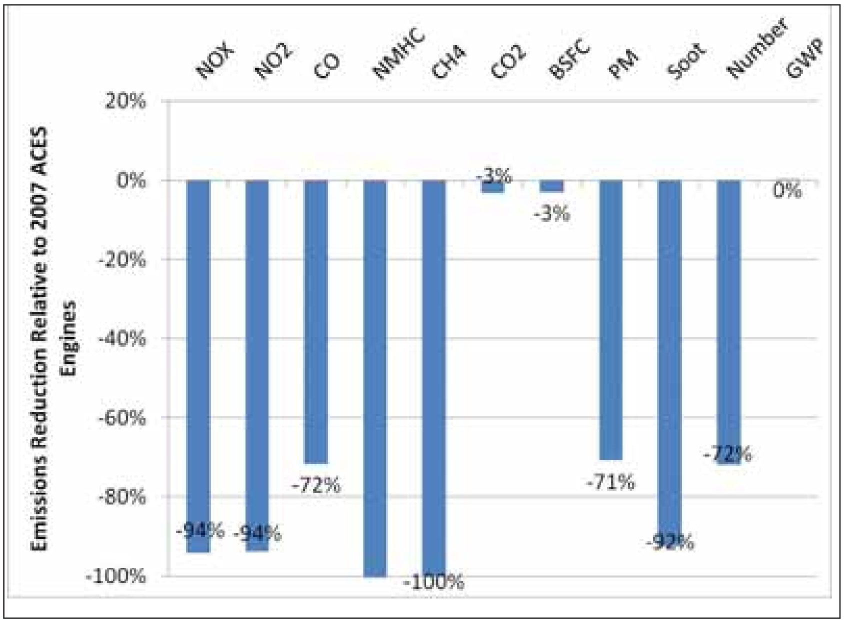

Figure 4. Emission reductions of tested 2010-compliant engines relative to tested 2007-compliant engines.

Source: "Phase 2 of the Advanced Collaborative Emissions Study (ACES): Highlights of Project Findings" by I. Khalek of Southwest Research Institute (2013 CRC Workshop).

methane (CH_4), and PM result in significant changes, including a nearly 400-fold increase in CH_4 emissions from CNG transit buses in 2012.

MOVES2010, EMFAC2007, and EMFAC2011 vehicle emissions inventory models were compared for light-duty vehicles in 2025. MOVES2010 predicts more vehicle miles traveled (VMT), carbon dioxide (CO_2), HC, NO_x, and CO than EMFAC2011 (see Table 1). Models agree that the majority of emissions are from older vehicles.

Planned updates to EMFAC2013 include the integration of advanced clean cars, updated diesel truck emission rates, and updated forecasts of VMT/vehicle sales/attrition. Forecasting updates are based on historical fuels sales, changes in population/demographics, and economic factors (i.e., fuel prices, employment).

Table 1. Predicted emissions from California LDV fleet in 2025 (without new CAFE impact).

		EMFAC 2007	EMFAC 2011	MOVES 2010
HC	T/day	127	83	123
CO	T/day	1030	758	2968
NO_x	T/day	82	70	247
CO_2	10^3 T/day	437	361	384
VMT	10^6 km/day	1470	1310	1590

Source: "Projecting 2025 California light-duty vehicle fleet emissions—MOVES, EMFAC, and suggested updates" by R. Sawyer and K. Lo, University of California at Berkeley (2013 CRC Workshop).

The California Air Resources Board plans to update emissions modeling for off-highway recreational vehicles to account for the recession's effect on sales, increased vehicle lifetimes, more four-valve engines, and reduced activity based on owner surveys, resulting in lower emissions.

MOVES2010 was coupled with a traffic simulation model to estimate emissions for drive cycles. The "simplified model" generated results similar to those from MOVES for a variety of emissions and vehicle types with much faster model run time.

Laboratory Measurement Methods

Instrument presentations included particle generators for studying aerosol formation and measurement, photo-acoustic soot sensors (PAS) for detecting low concentrations of PM in real time, and particle sensors and Fourier transform infrared spectroscopy (FTIR) analyzers used in measuring particle number and mass. Test approaches described included examination of their limitations of current practices for gravimetric PM measurement, mass quantification using limit of detection (LOD) and limit of quantification (LOQ) statistics, and the high temperature oxidation method (HTOM) for measuring engine ash emissions.

Modern diesel engines and after-treatment technologies and their impact on test repeatability and emission predictions were assessed for the contributions to emissions variability from specific technologies (i.e., mechanically injected and early-generation electronically injected diesel engines, electronically controlled cooled exhaust gas recirculation and complex injection strategies, active exhaust particulate filtration, and urea SCR).

Instrument presentations focused on their acceptance for certification and research. Certification testing and pending SAE Standard Operating Procedures for FTIRs were discussed, as were the limitations of gravimetric analysis for standards of 1 mg/mi for PM. Testing showed some test methods were valid for certifying low emission rates. Difficulties were noted for the various engine technologies as related to measurement procedures to highlight the continuing need for research and development of new instruments and methods.

Particulate Matter Characterization

Diesel and dual-fuel engines equipped with diesel particle filters (DPF) yielded total particle number (PN) over a urban dynamometer driving schedule cycle between 10^{12} to 10^{13} (particle #/km). Non-regeneration DPF efficiency averaged over 99%. High nuclei-mode PN concurrent with DPF regeneration was observed at elevated temperatures by multiple researchers. Size-segregated diesel PM results showed aftertreatment-based effects on mass and number. Elevated regeneration sulfate levels are largely responsible for the enhanced nucleation mode and were generally contraindicative of a solid particle accumulation mode. Simulation of engine combustion using a soot generator revealed that particulate morphology can be comparable to diesel engines. A novel wind tunnel design proved to be a valuable tool for PM aging research. Primary organic aerosol (POA) compounds were classified as semi-volatile from in-use fleet measurements on gasoline and diesel vehicles, representing contradiction of initial assumptions indicating non-volatile POA.

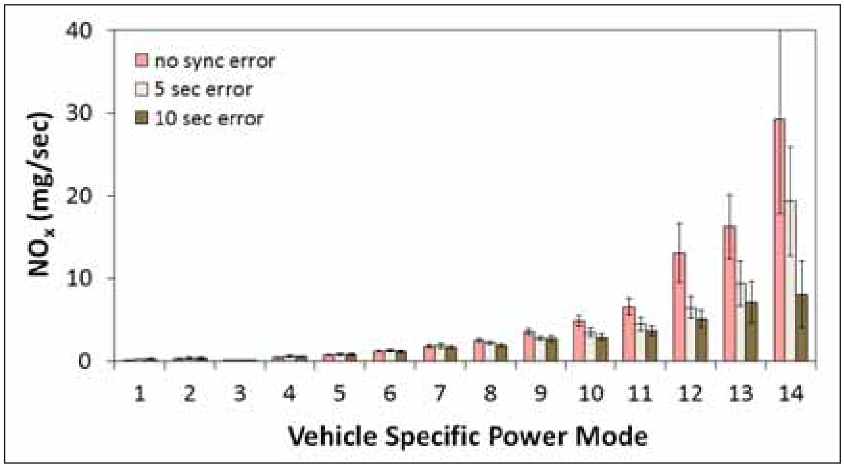

Figure 5. Impact of synchronization error on NO_X emission rates by vehicle specific power mode.

Source: "Effects of Errors on Vehicle Emission Rates from Portable Emissions Measurement Systems" by G. Sandhu and H.C. Frey, North Carolina State University (CRC Workshop, 2013).

Off-Road Emissions

Emissions inventories and measurements were presented from a diverse collection of off-road sources, including construction and mining equipment, locomotives, ocean-going vessels (OGV), tugboats, and snow vehicles. Benefits of biofuels, hybridization, and use of PEMS were discussed. Inventory

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developments from the U.S. Environmental Protection Agency's 33-vehicle 2007-2008 Midwest NonRoad Pilot Study were described. PEMS testing on 27 Tier 4i-certified pieces of equipment showed a downward trend in emissions. NO_x benefits of Tier 2 relative to Tier 1 locomotive engines were determined during a remote-sensing campaign; however emissions were higher than reports in the literature.

Important differences were found for projected growth for OGVs (e.g., for passenger ships, growth has leveled off). Benefits of hybridization for a tugboat included emission reductions on the order of 30% for PM, NO_x, and CO_2; however, the reason for the reductions was the diesel-electric drivetrain used for auxiliary power, rather than energy storage function.

Biodiesel up to B20 used in a locomotive was beneficial for NO_x reductions, but PM was found to increase for any level of biodiesel. A 50% algae-biofuel blend used in a 48L D398 engine powering an ocean surveillance ship led to 25%, 18%, 10%, and 5% reductions in PM, CO, NO_x, and CO_2, respectively. Important advances in the understanding of off-road emissions and, most importantly, potential options for reductions of various air and climate pollutants were presented.

Fuel Effects: Spark Ignition

A study compared PM mass and number between various light-duty gasoline and diesel engine technologies fueled by conventional fuels, biofuels, and CNG; preliminary results show differences in the size and quantity of PM and also some indication of varying toxicity. Results of a study of 27 test fuels, varying ethanol, distillation, aromatics, and vapor pressure on 15 2008 high-sales vehicles were used to develop models for predicting the effects of fuel parameters on light-duty Tier 2 Vehicles.

Effects of gasoline fuel sulfur level on emissions from 81 Tier 2 in-use vehicles were used to fit a model for predicting the impact of lowering fuel sulfur from current levels on the fleet emissions. Five vehicles were tested on gasoline blended with ethanol or iso-butanol to explore the effects on emissions of criteria pollutants, toxics, and PM number distribution. Ammonia emissions were shown to be significantly lower in newer CNG heavy-duty vehicles. The ability of higher ethanol-content blends to cause a malfunction indicator lamp (MIL) illumination were demonstrated. The impact of natural gas fuel composition on criteria and toxic emissions from transit buses was tested, finding some effect of the methane content of the fuel, that varied according to the vehicle type.

Fuel Effects: Compression Ignition

Tests of the effects of biodiesel on emissions of modern light-duty vehicles were initiated, with both DPF+SCR and SCR+LNT technologies represented. Experiments will be performed on an heavy-duty diesel engine following a robust certification procedure, requiring at least 20 replicate tests on B5 blends.

Another study focused on test plans and in-use data collection techniques for medium and heavy-duty commercial fleet vehicles that are good candidates for deployment of low-emission and fuel-efficient advanced technologies (hybrids). An extensive testing program in South America involving hybrids, electrics, and diesel buses will help in policy-making. Research conclusions validate emissions reduction for parallel hybrids, but series hybrids show less reduction than expected. Fuel consumption is improved by parallel hybrids compared to standard diesel buses.

Impacts of biodiesel blends of different origin on exhaust emissions of two heavy-duty trucks equipped with different aftertreatment configurations was described. Impacts of aftertreatment technology on the regulated and gaseous toxic pollutants were analyzed.

Next Workshop

The extensive global effort to reduce emissions and assess the effects of new technologies and fuels is ongoing. There is a continued need for more complete data, better measurements, more accurate models, and information exchange amongst researchers and practitioners to support the development of policy for the goal of improved air quality worldwide.

The 24th Real-World Emissions Workshop is tentatively scheduled for March 30-April 2, 2014. **em**

Full proceedings of the 2013 workshop are available from CRC online at www.crcao.org.