THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

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November 13, 2018

RE: Proposed revisions to on-board diagnostic system requirements for heavy-duty engines, passenger cars, light-duty trucks, and medium-duty vehicles and engines

The International Council on Clean Transportation (ICCT) would like to take the opportunity to provide comments on the California Air Resources Board's *proposed amendments to California's Heavy Duty Engine On-Board Diagnostic System Requirements (HD OBD) and On-Board Diagnostic System Requirements for Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines (OBD II).* The ICCT is an independent nonprofit organization founded to provide unbiased research and technical analysis to governments in major vehicle markets around the world. Our mission is to improve the environmental performance and energy efficiency of road, marine, and air transportation, as well as their fuels, in order to benefit public health and mitigate climate change.

The ICCT strongly supports the CARB proposal. The proposal would significantly enhance the utility of existing OBD systems by leveraging the technological advances that have been made over the past decade. The introduction of the REAL concept would allow for collection of data that can be used for improving the effectiveness of existing and future regulations that will ultimately lead to a decrease in real-world emissions and an increase in the associated health and climate benefits. In addition, the novel concept being proposed would secure CARB's position as a global leader in transportation policy and promoting advanced technology adoption.

We would be glad to clarify or elaborate on any points made in the attached comments. If there are any questions, CARB staff can feel free to contact our Heavy-Duty Vehicle Program Director, Dr. Rachel Muncrief (*rachel@theicct.org*).

Best regards,

Drew Kodjak
Executive Director
International Council on Clean Transportation

Comments on the proposed revisions to on-board diagnostic system requirements, including the introduction of real emissions assessment logging, for heavy-duty engines, passenger cars, light-duty trucks, and medium-duty vehicles and engines

Public submission of the International Council on Clean Transportation to the

California Environmental Protection Agency and the California Air Resources Board

Submitted: November 13, 2018

Hearing Date: November 15, 2018
Agenda Item: (18-9-4)

California Air Resources Board staff is presenting a proposal to the Board on November 15, 2018, to update the heavy-duty vehicle on-board diagnostics requirements. The proposal, the first major revision since 2012, covers a series of modifications to some OBD technical requirements, including OBD testing and deficiencies enforcement, and is adding key requirements on storing and streaming of parameters that track real-world emissions performance and assist with CARB's emission compliance programs.

These comments focus on that last HDV OBD proposed item: implementing tracking of key OBD parameters on heavy duty vehicles related to real-world emissions and fuel consumption. The concept, *Real Emissions Assessment Logging* (REAL), is to use existing onboard sensors to calculate, track, bin and store NOx emissions and fuel consumption against vehicle speed and engine power. The proposal is similar to the OBD II updates for LDVs on broadcasting of OBD fuel consumption and activity parameters that were adopted in July 2016.[1] HD OBD systems would be required to track and report data that characterize in-use NOx emissions and fuel consumption starting with MY2022.

ARB staff envisions that REAL data could be used "to identify populations of vehicles for additional testing, identify the conditions in-use where vehicles are not performing as expected with regard to emissions control, and generally better inform CARB's inventory, regulatory, certification, and enforcement programs."

Table 1 presents the list of parameters that ARB staff is proposing to add to the OBD data stream for MY2022 and newer engines:

Table 1 ARB Staff proposal for HDV OBD parameter broadcasting additions for MY2022 and newer engines. Source: ARB ISOR

No	Parameter	System monitoring target	Rationale
1	Commanded DEF dosing	SCR	Commanded DEF dosing quantity (mass based).
2	DEF dosing mode	SCR	The specific mode of DEF dosing operation (e.g., fill mode, sustain mode, etc.)
3	DEF dosing rate	SCR	Actual quantity of DEF dosed into the aftertreatment system.
4	DEF usage for current driving cycle	SCR	The accumulated amount of DEF introduced into the aftertreatment system for the current driving cycle.
5	Target ammonia storage level on SCR	SCR	The target storage level of ammonia on the SCR catalyst that the DEF dosing system seeks to achieve.

[1] California Code of Regulations Title 13, Sections 1968.2 and 1968.5

6	Modeled actual ammonia storage level on SCR	SCR	The modeled actual storage level of ammonia on the SCR catalyst.
7	SCR intake temperature	SCR	Temperature of exhaust entering the SCR catalyst.
8	SCR outlet temperature	SCR	Temperature of exhaust exiting the SCR catalyst.
9	NOx mass emission rate - engine out	Overall emissions control	The rate of NOx emitted by the engine (grams per second) based on NOx concentration measurements made upstream of the NOx aftertreatment system.
10	NOx mass emission rate - tailpipe	Overall emissions control	The rate of NOx emitted by the engine (grams per second) based on NOx concentration measurements made downstream of the NOx aftertreatment system.
11	Stability of NOx sensor reading	SCR/Overall emissions control	An indicator as to whether the NOx reading of a NOx sensor is stable as determined by the manufacturer's control software.
12	EGR mass flow rate	EGR	The flow rate (mass basis) of the exhaust gas that is recirculated into the combustion air.
13	Vehicle fuel rate	Fuel consumption and Aftertreatment fuel injectors	The amount of fuel consumed by the engine summed with the amount of fuel injected directly into the aftertreatment system per unit of time.
14	Hydrocarbon doser flow rate	Aftertreatment fuel injectors	Mass flow rate of external hydrocarbon dosing into the aftertreatment system.
15	Hydrocarbon doser injector duty cycle	Aftertreatment fuel injectors	Percentage of the maximum hydrocarbon dosing of an external dosing system.
16	Aftertreatment fuel pressure	Aftertreatment fuel injectors	The measured pressure of the fuel supplied to the external hydrocarbon doser in the aftertreatment system.
17	Engine operating state	Engine	An indicator as to whether the engine is in warm-up mode.
18	Propulsion system active	Vehicle	An indicator as to whether the powertrain is enabled by the driver such that the vehicle is ready to be used (e.g., vehicle is ready to be driven, ready to be shifted from "park" to "drive").
19	Odometer reading	Vehicle	Accumulated distance traveled by vehicle during its operation from the time it was new.
20	Engine family	Vehicle	Certification engine family name.
21	Hybrid/EV charging state	Hybrid/EV battery	An indicator of whether the hybrid/EV battery is in Charge Sustaining Mode or Charge Depletion Mode.
22	Hybrid/EV battery system voltage	Hybrid/EV battery	Voltage of the hybrid/EV battery system.
23	Hybrid/EV battery system current	Hybrid/EV battery	Electrical current in the hybrid/EV battery system.
24	Commanded/target fresh air flow	Engine	Air mass flow rate commanded by the engine control system.
25	Crankcase pressure sensor	CCV	The gauge pressure indicated by the pressure sensor inside the engine crankcase.
26	Crankcase oil separator rotational speed	CCV	The speed of a rotating (centrifugal) crankcase oil separator.
27	Evaporative system purge pressure sensor	Evaporative system	The pressure indicated by the purge pressure sensor in the evaporative system.

28	Vehicle speed limiter (VSL) speed limit	Vehicle	The speed limit to which the VSL is set.
29	Engine rated power	Engine	The rated net brake power output of the engine.
30	Engine rated speed	Engine	The engine speed that corresponds to the engine rated power.

In addition to making available key OBD parameters, ARB staff is proposing a simple and novel method to track NOx, fuel consumption, and a few other parameters. Parameter data would be stored as Active 100 Hour, Stored 100 Hour, and Lifetime Arrays (Table 2). Data would be stored in the Active 100 Hour Array until a total of 100 hours of engine operation has elapsed with both NOx sensors reporting NOx concentration data, as well as fuel consumption data. The stored data would then be moved to the Stored 100 Hour Array and a new block of Active 100 Hour Array data would begin to accumulate. All data stored in an array would be based on signals that are sampled at a rate of at least 1 Hertz. All tracked data would be required to be stored in a form of memory that is non-volatile. The proposal would require the stored data to not be lost in the event of loss of power to the controller(s) involved in tracking.

Table 2 ARB Staff proposal to track key emissions parameters from MY2022 and newer engines. Source: ARB ISOR

Parameter	Active 100 Hour Array	Stored 100 Hour Array	Lifetime Array	Lifetime Engine Activity Array[5]
NOx mass – engine out (g)[1]	x	x	x	n/a
NOx mass – tailpipe (g)[2]	x	x	x	n/a
Engine output energy (kWh)[3]	x	x	x	x
Distance traveled (km)	x	x	x	x
Engine run time (hours)	x	x	x	x
Vehicle fuel consumption[4] (liters)	x	x	x	x

1. Mass of NOx emitted by the engine upstream of the NOx emission control system.
2. Mass of NOx emitted by the engine which enters the atmosphere (downstream of the NOx emission control system).
3. Brake work output of the engine.
4. The amount of fuel consumed by the engine summed with the amount of fuel injected directly into the aftertreatment system.
5. Engine activity data are recorded regardless of NOx sensor status.

ICCT Recommendations

The ICCT supports the addition of these OBD stream parameters and data storage and tracking systems because they are critical for the real-world evaluation of aftertreatment systems performance and vehicle fuel consumption. The reasons for supporting such additions to the OBD regulatory framework are:

a. Data available from real-world emission testing of heavy duty vehicles in the US show that NOx emissions are consistently above certification values for a large number of vehicle models under driving conditions typical of urban and suburban driving. This high emission behavior seems to be the result of a combination of regulatory deficiencies found in the current in-use Not-To-Exceed regulation, and the inability of on-board sensors, that make up part of current OBD systems, to report high emission measurements.
b. Current OBD systems were originally designed to monitor and prevent high emissions vehicle operation due to emission control system malfunctions by alerting the driver of detected system failures. Though not designed for this purpose today, OBD systems have the inherent technical potential to monitor and prevent current high emissions of NOx and PM during a multiplicity of driving conditions. An OBD system capable of broadcasting emissions behavior under different driving conditions would increase the effectiveness of the HDV in-use monitoring program in California and at the national level.
c. Some of the listed parameters are already available as part of the current OBD data stream and are used for EPA's heavy-duty in-use test (HDIUT) program. However, some key parameters that would help understanding and solving high emissions behavior, are not open to regulators and research institutions. This makes high emissions analysis extremely onerous and time consuming as specialized tools must be developed to find the root causes of such behavior. Unaddressed high emissions over a long period of time results in uncontrolled elevated fleet emission and air-quality deterioration.
d. The data stream from fuel consumption can be used for tracking real world fuel consumption of the HDV fleet. There has been a consistent lack of publicly available detailed real world fuel consumption for HDVs. US EPA and CARB both have GHG/efficiency standards for HDVs. Having access to real world fuel consumption data would help to track the effectiveness of these programs and identify potential areas for improving upon existing standards.
e. The proposal for data binning and storage (100 hours for NOx and fuel consumption) would provide regulators and research organizations access to a wealth of data to better evaluate the emissions performance of vehicles under a wide set of driving conditions and duty cycles. This can help regulators at the

state and county level develop emissions and fuel consumption inventories and better plan for their air-quality mitigation actions. More importantly, this can be developed into a transparency tool for consumers to make the proper choice when evaluating new HDV purchases.

In summary, the HDV OBD regulation should be modified to add emission control and fuel consumption relevant parameters that help regulators, manufacturers, and the public in general reduce the environmental impact and operating cost of new HDVs.

High in-use emissions from MY2010 and newer HDVs

The ICCT has been studying the NOx emissions performance from HDVs in the US and Europe trying to better understand their general performance and how they compare to each other. Although these comments supporting the ARB staff proposal focus on HDVs manufactured for the US market, some figures include relevant data from HDVs of similar characteristics designed for the European market. They also serve as a reminder of how vehicle technology responds to regulatory requirements.

Data available from real-world emission testing of heavy-duty vehicles in the US shows that NOx emissions are consistently above certification values for a large number of vehicle models under driving conditions typical of urban and suburban driving. Data for the HDVs was obtained from publicly available data from US EPA heavy-duty in-use test (HDIUT) program,[2] while the EU data was purchased from research institutions in the European Union. All trucks are fitted with DOC, DPF and SCR aftertreatment systems. It should be noted that 6 of the 8 US trucks were compliant with the 0.2gNOx/bhp-h engine test limit and to the corresponding in-use 0.3 gNOx/bhp-h NTE limit; the two other trucks were certified under engine test family emission limits (FEL) of 0.35 gNOx/bhp-h.

Preliminary data analyzed by ICCT staff in 2018 shows that NOx emissions for HDVs certified to US EPA 2010 are generally below the standard not-to-exceed targets, but increase at speeds below 50 mph (80 km/h) (Figure 1). The $V < 40$ km/h (25 mph) bin does not include idle or operation below 2 km/h. Brake specific NOx emissions from this sample of US trucks more than quadruple in magnitude during urban driving conditions

[2] EPA Manufacturer-Run In-Use Testing Program Data for Heavy-Duty Diesel Engines. https://www.epa.gov/compliance-and-fuel-economy-data/manufacturer-run-use-testing-program-data-heavy-duty-diesel-3

(V < 25 mph), and are about 2.1 times higher during suburban driving operation. By contrast, highway driving emissions are about 55% of the average total route emissions.

The average NOx emissions for US and EU HDVs by power bin is presented in Figure 2. Power bins are defined here as percentage of maximum rated power for each engine. Similar to what was found under the speed bin analysis, the European vehicles emit lower levels of NOx for every power bin. The emission rates exhibit a consistent behavior for both datasets, with lower NOx at the mid power ranges, higher NOx at the upper power bin range and the highest at the low power bind end. The average brake specific emission value for EU HDVs is below the 0.3 g/bhp-h (US NTE Std) for all bins except for the 10% power bin. A comparison with route NOx shows that power bin values are consistent across regions in relative terms for bins above 30% power. Below 30% max power, NOx emissions increase quicker for the US trucks, while the EU trucks maintain good performance until 20% max power. Note the effects of power exclusions in the per-bin emissions performance for both regions. As the US NTE protocol excludes all data below 30% max power, the performance for those bins degrades significantly. This effect is also shown for EU HDVs, but a much smaller scale.

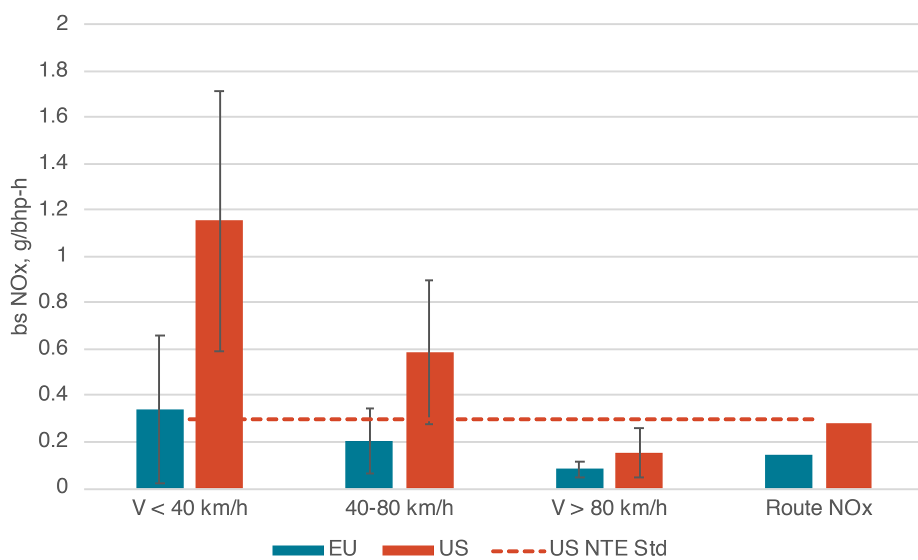

Figure 1 NOx emissions by speed bin for European and US HDVs. Grey bars show confidence intervals at 95% (CI95).

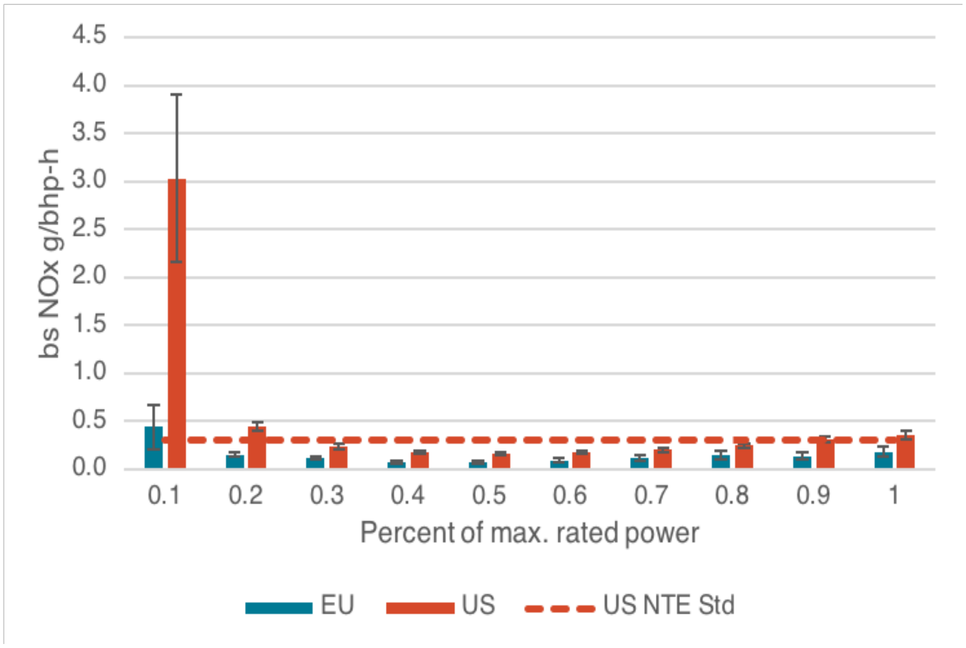

Figure 2 NOx emissions by power bin for European and US HDVs. Grey bars show confidence intervals at 95% (CI95).

Our preliminary findings also coincide with data published by EPA staff after analysis of hundreds of thousands of hours of PEMS data collected from 121 US HDV trucks certified after 2010.[3] It was concluded that MY2010 and newer trucks present higher emission rates than what is indicated by the standards. Also, significant variability exists between engine families and trucks with the same engine. It was concluded that driving and duty cycle were a key contributor to high emission values.

[3] Gurdas Sandhu, Darrel Sonntag, James Sanchez (2017) In-use emission rates for MY2010+ Heavy Duty Diesel Vehicles. 27th CRC real World Emissions Workshop, March 26-29, 2017, CA, USA.

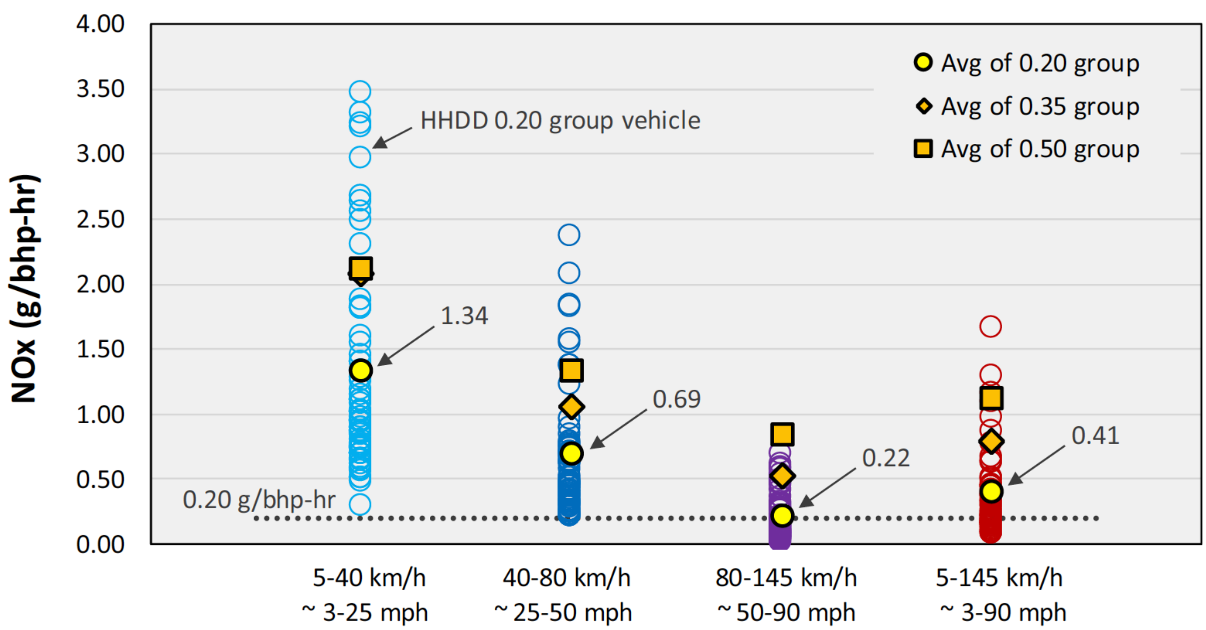

Figure 3 EPA's summary of 121 US HDDT vehicles certified to EPA MY2010+ standards. Source: Sandhu et al. (2017)

Note that having only overall (total NOx divided by total distance or total work) does not provide a clear picture of the emission performance of the vehicle. Overall route emissions are shown in Figures 1 and 3 in the right column group. **The emission behavior is extremely dependent on driving condition (speed and power demand). The overall route emission value does not reflect the emission performance at low speed (Figures 1 and 3) and even less at low loads (Figure 2). This highlights the need for storing data under a binning methodology. Thus, the ICCT encourages the board to support ARB staff proposal to require storage of data by a bin system.**

OBD systems have the inherent technical potential to monitor and prevent current high emissions of NOx and PM during a multiplicity of driving conditions

These high emissions values at low speed and power conditions, as reported above, are not the product of emission control system malfunctions—none of the trucks reported OBD malfunctions during the data collection process. As a matter of fact, it is required in the text of the regulation that no OBD light be active for HDIUT PEMS testing. These high emission values are the byproduct of regulatory deficiencies that fail to incentivize proper emission control at mid-to-low speed and load conditions. The current NTE design does not allow for proper emissions evaluation of NOx during nonhighway driving conditions. Results from ICCT's analysis show that urban driving accounts for about 30% of all mass of NOx emitted during HDV operation. This is the result of regulatory data exclusion for low power, torque and exhaust temperatures. **This suggests the importance of extending the OBD monitoring function beyond diagnostics of failures and moving into emissions monitoring.**

The data shows that many of those trucks are emitting **like** vehicles with high-emission malfunctions. At low power demands (i.e., operating below 30% of maximum rated power)**, the average US HDV is emitting more than 100 times its NOx certification emission limit**. At low speeds, some of those vehicles are emitting 10 times or more the certification value. That emission behavior would be considered equivalent to the behavior of a high-emitter, and would be addressed as such, if there were an Inspection and Maintenance program that would have the technical capacity to sense, collect, and report those high emission periods. As a matter of fact, the authority has no recourse to measure and test in-use HDVs for high emissions of NOx, only for soot (a component of PM). The ARB staff proposal opens that option for NOx and PM emissions in-use monitoring, with sensors that are already built into the vehicles.

Key emission control parameters are already available through OBD while others require special equipment for their capture

The poor emission behavior shown by some of those trucks under urban and suburban driving conditions is measurable with sophisticated and expensive portable emission measurement systems (PEMS), but it is extremely difficult to capture with current inspection and maintenance tools—OBD loggers. Moreover, even with expensive PEMS data, it is extremely difficult to understand the reason behind such behavior.

Going beyond plain emissions measurement and moving into answering the basic research question of what are the root causes of high emission behavior, can only be performed by developing and applying specialized tools to track key engine and aftertreatment systems parameters. Information such as engine-out NOx, urea injection rates, or EGR activity and flowrate, help elucidate the reasons behind such increases in emissions at low speed and loads. Unfortunately, those key parameters are not available from the OBD datastream, increasing the complexity, cost, and timeline for solving the issue of high emissions from the fleet.

The proposed addition of data stream parameters would facilitate the identification of challenges for newly certified engines and would reduce the chance of sales and operation of vehicles that would not deliver on the expected low emissions performance set by the current and future standards. **ARB staff proposed additions would provide the technical framework for inexpensive and early identification of conditional high emitters and to issue the corresponding enforcement actions to address the problem, e.g., via recalls.**

Access to SCR relevant data, parameter items 1 to 8 in Table 1, would allow for better understanding of how SCR systems are responding under different driving conditions. Urban driving emissions reduction for SCR systems is a challenge today, as shown by HDIUT data analysis (Figures 1 to 3). Providing regulators and research institutions access to those parameters, especially Commanded DEF dosing and NOx mass emission rates would help identify potential shortcomings of the SCR system of target vehicles. EGR operation is critical at low load conditions, as SCR systems present lower NOx conversion efficiencies at exhaust temperatures below 250°C, typical of urban and low load driving conditions. High NOx emissions can be identified early and addressed by recalibrating the operational range of the EGR system.

The OBD system, in principle, is designed to notify of high emissions from malfunctions in in-use vehicles. OBD systems were born of the need to control in-use emissions when the main source of high emissions was malfunction of the gasoline vehicle catalytic converter and oxygen sensor, and misfire.

Current OBD system requirements for diesel vehicles are falling short of their design principle. Controlling NOx and PM to levels that are adequate for maintaining proper air-quality levels is pushing manufacturers and regulators to develop highly complex systems that, under some driving conditions, can deliver very low emissions rates. It is precisely because of this level of complexity that the current OBD system should not be tasked only with diagnosing malfunctions, but should expand into looking at emission rates (e.g.. gNOx/s) and key parameters that explain emissions performance (e.g., urea injection rates in g/s) as a cost-effective method for early identification and correction of high emission behavior areas.

The need to control diesel in-use emissions includes all the conditions that may result in higher emissions which are derived from calibration strategies that do not fully cover the operating envelope of the engine. Emission control system strategies are developed under FTP engine cycle conditions and tailored to meet the in-use not-to-exceed (NTE) requirements. The NTE requirements, however, have been designed to focus on highway driving evaluation, leaving wide areas of the engine and vehicle operating envelope exposed to uncontrolled emissions.

Today, engines have OBD-like systems to prompt the driver to refill the urea tank with a quality product, or face reductions in engine torque or speed output. The system that controls those warning and engine output deratings feeds from the same sensor and data stream as the OBD. The proposed monitoring requirements for the HDV OBD system can be understood as a tool that, based on the OBD data stream, would help prompt manufacturers and regulators to address the calibration and design requirements of operating a vehicle that emits as little NOx and PM as indicated by the certification document under the vast majority of driving conditions—not just under highway driving—or face potential recalls and fines.

The data stream from fuel consumption is key for regulators and more importantly for HDV operators

This proposal is in-line with efforts made in the European Union and China to track and report real-world fuel consumption. In order to ensure an effective implementation of the upcoming (proposed) CO_2 standards for heavy-duty vehicles in the European Union and to address the risk of an increasing gap between type-approval and real-world emissions of CO_2, the European Commission has proposed to mandate the collection, publication, and monitoring of real-world fuel consumption data reported by manufacturers, based on mandatory standardized fuel consumption meters.[4] China has also implemented "administrative measures for dynamic supervision of road transportation vehicles,"[5] which is in effect since 2014 and applies for trucks above 12t and fleets of 50 or more vehicles. The measure mandates installation of monitoring platforms (telematic systems) and reporting to a centralized public platform.

Systematic data collection with consistent procedures to keep track of reported fuel consumption levels would help ensuring that the level of ambition of current and upcoming GHG regulations is seen in the real world, adding transparency and verifiability. Besides regulatory efforts, more transparency on the fuel consumption performance of HDVs positively affects the market as it would enable better informed purchasing decisions to be made to ensure fuel savings and also would foster competition among OEMs based on real-world performance.

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[4] http://ec.europa.eu/clima/policies/transport/vehicles/heavy_en

[5] http://www.global-regulation.com/translation/china/159246/administrative-measures-for-dynamic-monitoring-of-road-transport-vehicles.html

The accurate reporting of fuel consumption would also help to maintain a connection between GHGs and criteria pollutants, such as NOx. Known trade-offs between NOx and CO2 emissions could be exploited as manufacturers might decide to calibrate their engines favoring compliance with NOx standards at the expense of CO2 emissions.

NOx emissions and fuel consumption data transparency would become a game changer for national and local inventories and transport planning

As shown before, the overall NOx emissions performance is not representative of the emissions observed at specific driving conditions. This has important ramifications for county and state air quality mitigation implementation plans (i.e., SIP and FIPS). Repeating from a previous item, the emission behavior is extremely dependent on the driving condition (speed and power/load demand). The overall route emission value does not reflect the emission performance at low speed (Figure 1 and 3) and even less at low loads (Figure 2). This highlights the need for storing data under a binning methodology.

Having access to updated NOx emissions data by overall fleet of vehicles, by model year, and even by manufacturer and engine family, can open the possibility to tailoring state and county plans for fleet purchases and environmental related actions. It would reduce the cost of developing the inputs for emission factors for ozone and would increase the accuracy of modelling results. As an example, the EPA presented a comparison of the emission factors by vehicle specific power operating mode. The original NOx emission factors from the MOVES model were compared against NOx data captured with expensive PEMS equipment (Figure 4). The analysis shows a systematic underestimation of NOx emissions (by almost 3 times) by engine mode, especially at urban speed conditions (modes 11–16) and suburban driving conditions (modes 22–30). In summary, the information gathered by the ARB staff binning storage proposal could be directly used to update the MOVES model annually, and better inform future regulatory decision making processes.

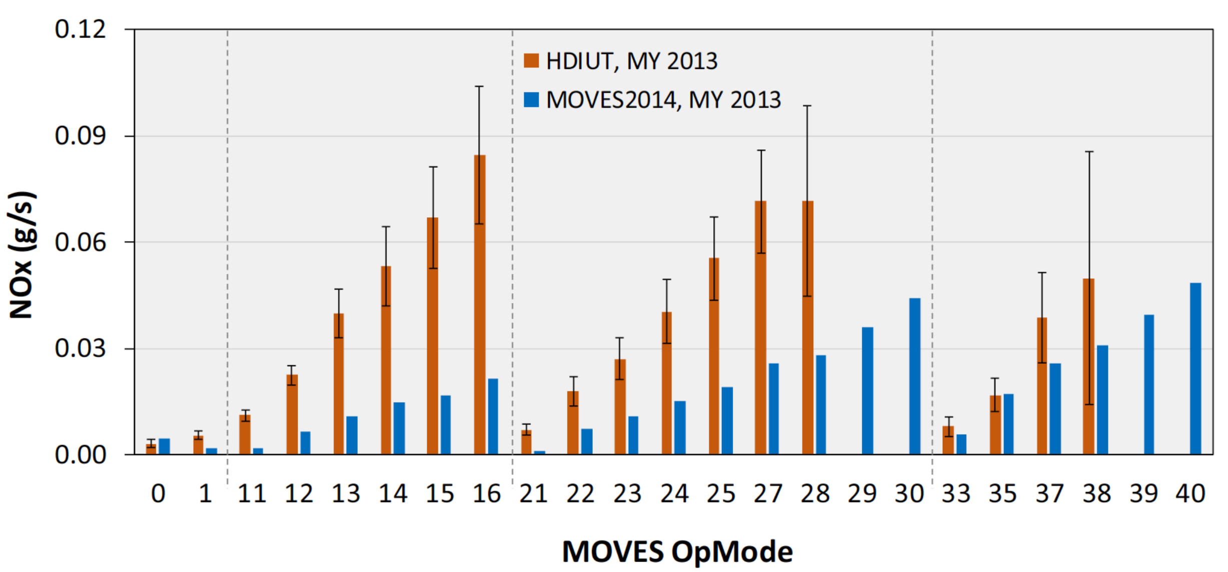

Figure 4 Comparison of HHDD vehicles NOx emission rates for PEMS testing and values predefined in MOVES2014. Source: Sandhu et al. (2017)

Another potential benefit of making those values transparent to regulators and operators of HDVs is that it can help reduce the cost of planning for public transit projects. Urban fleet managers are faced with the need to evaluate technology purchase options, in terms of pollution control and fuel consumption, and the associated operating costs. Having a reliable source of data that research institutions can collect and summarize into different operating conditions could be a supporting action to better inform their decision process. This covers not just fuel consumption, but also NOx emissions.