Proposal for a Multi-pollutant Heavy-duty Vehicle Standard

In the Phase 2 heavy-duty greenhouse gas (GHG) emissions program, EPA established the use of the Greenhouse gas Emissions Model (GEM) for both setting the stringency of the GHG program and establishing compliance with that program. Below, we detail an approach building upon that framework to establish a multi-pollutant heavy-duty vehicle emissions program that simultaneously regulates not just greenhouse gas emissions, but additional pollutants including nitrogen oxides (NOX) and particulate matter (PM).

Current Engine-based Standards for Non-GHG Pollutants

EPA recently established new standards for the emissions of pollutants including NO_X and PM from heavy-duty engines (88 FR 4296-4718. As part of these standards, EPA completely redesigned its in-use and off-cycle requirements on these engines (88 FR 4305-6). These performance requirements are meant to ensure that the emissions controls for engines are operating as intended over the life of the vehicle in real-world operation.

Similar to the Euro VI standard, EPA has established a “moving average window” (MAW) approach to assessing the performance of an engine through its off-cycle program. Data is collected via a portable emissions measurements system (PEMS) and is binned according to the engine’s CO_2 emissions (88 FR 4347-9). This binned data is then compared to a given emissions standard (TABLE 1).

Ignoring the ramifications of exclusions or adjustments that would further relax these standards, these off-cycle requirements generally establish on-road emissions limits that a manufacturer’s product would be expected to achieve in the real-world. Indeed, this is precisely how the Agency itself interpreted these off-cycle standards when establishing the impact of the recent standards on fleet emissions. EPA found (with only narrow exception) the binding target for manufacturers’ emissions to be the off-cycle standards (RIA, p. 238).

TABLE 1. Off-cycle standards for heavy-duty diesel engines for model years 2027 and later

Engine Class	NO_X, Bin 1 (g/hr)	NO_X, Bin 2 (mg/hp-hr)	HC, Bin 2 (mg/hp-hr)	PM, Bin 2 (mg/hp-hr)	CO, Bin 2 (g/hp-hr)
LHDD	10	58	120	7.5	9
MHDD	10	73	120	7.5	9
HHDD	10	73	120	7.5	9

HC = hydrocarbons; CO = carbon monoxide

Benefits of Heavy-duty Vehicle Standards

As noted above, current heavy-duty pollution standards for non-GHG emissions apply at the engine level, rather than the vehicle. This means that such standards do not apply to zero-emission vehicles such as battery-electric vehicles because they lack a conventional combustion engine-based powertrain. Thus, while these vehicles can eliminate tailpipe emissions of NO_X and PM entirely, they are currently not incentivized under the Agency's pollution control program.

Heavy-duty vehicle standards represent an opportunity to establish fleetwide emissions targets that would recognize the impact that vehicle design can have on emissions. It is not just full-vehicle electrification that can help reduce overall NO_X and PM emissions, for example—aerodynamic improvements that could reduce overall engine work over a vehicle's duty or start-stop technology that could reduce the use of an engine are vehicle-level technologies that should be incentivized as well.

The Agency has previously made clear that "EPA's overall program goal has always been to achieve emissions reductions from the complete vehicles that operate on our roads," while acknowledging that "the agency has often accomplished this goal for many heavy-duty truck categories through the regulation of heavy-duty engine emissions" (76 FR 57111). Given the advent of more vehicle-based solutions to the challenge of truck pollution, it is an appropriate time to move beyond engines to whole-vehicle solutions, just as it has for GHGs.

Designing a Multi-pollutant Heavy-duty Vehicle Rule

Alignment with Current Regulations

Because there already exist both a vehicle-based program for reducing GHG emissions from heavy-duty trucks as well as an engine-based program for non-GHG pollutants, an ideal regulatory framework would be built upon the foundation of those two programs. The structure of the off-cycle standards provides exactly that opportunity:

$$m_{CO2,norm,testinterval} = \frac{m_{CO2,testinterval}}{e_{CO2FTPFCL} \cdot P_{max} \cdot t_{testinterval}}$$

$$e_{[emissions],offcycle} = \frac{m_{[emission]}}{m_{CO2}} \cdot e_{CO2FTPFCL}$$

$$\bar{\dot{m}}_{NOx,offcycle,bin1} = \frac{\sum_{i=1}^{N} m_{[emission],testinterval,i}}{\sum_{i=1}^{N} m_{CO2,testinterval,i}} \cdot e_{CO2FTPFCL}$$

$$e_{[emissions],offcycle,bin2} = \frac{\sum_{i=1}^{N} m_{[emission],testinterval,i}}{\sum_{i=1}^{N} m_{CO2,testinterval,i}} \cdot e_{CO2FTPFCL}$$

(40 CFR § 1036.530, Equations 2-5).

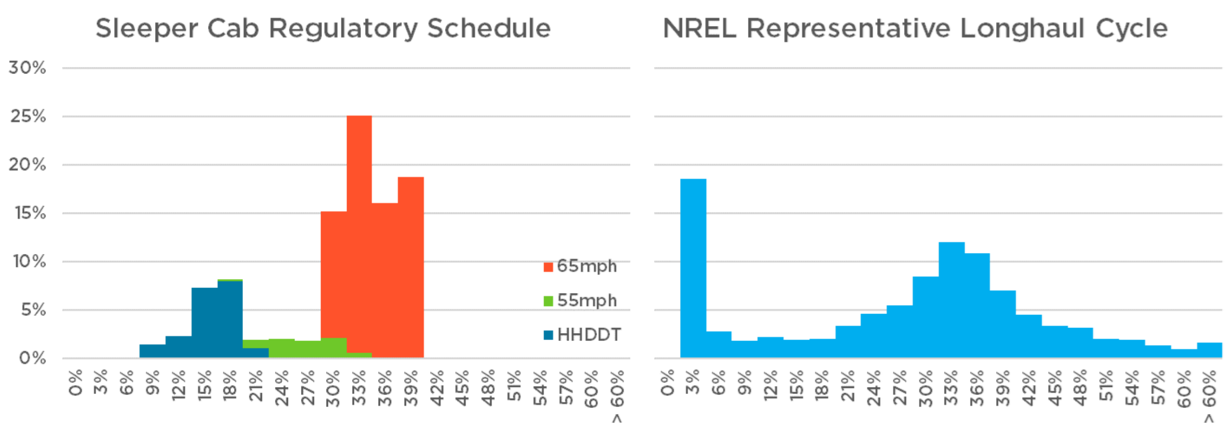
The off-cycle program requires that emissions rates for pollutants achieve a given level in real-world operation. This is tested in what is called a "moving average window" (MAW), where a vehicle is fitted with a PEMS at a 1-Hz or better rate. This data is then collected into *N* 300-second windows. These windows are then collected into either an idle bin (Bin 1) or a use bin (Bin 2) based on the average CO_2 emitted during the test interval (300 seconds), as compared to the FTP certified test level of the engine ($e_{CO2FTPFCL}$) and its maximum power (P_{max}). Note that this structure frames the required NO_X limits entirely around CO_2 emissions.

The GEM model is already designed to estimate well a vehicle's CO_2 emissions. By subjecting this simulated vehicle to the MAW off-cycle program, it is possible to establish the required emissions rates that the virtual vehicle would be expected to achieve over the duty cycle modeled. By assuming that the off-cycle program's limits represent the limiting emissions factor, as EPA did in its RIA, it is possible to reverse the equations above to estimate the mass of a pollutant over the modeled duty cycle: $\bar{m}_{NOX,offcycle,bin1}$ and $e_{NOX,offcycle,bin2}$ are the off-cycle program requirements for Bin 1 and Bin 2, respectively; $e_{CO2FTPFCL}$ is the certification level of the engine installed in the vehicle, which is already provided by manufacturers to GEM; and $m_{CO2,testinterval}$ would be calculated via GEM simulation.

Representative Duty Cycle

As noted above, it is possible to utilize the new program design of the off-cycle, in-use 2027 NO_X requirements to estimate the emissions for a virtual vehicle using the same GEM model as is currently used for compliance with the HDV GHG emissions program. However, the difference between the in-use duty cycle requirements and the current GHG regulatory test cycles are stark. For example, the longest single component of the regulatory cycle is the heavy-duty diesel transient cycle developed by the California Air Resources Board (CARB HHDDT), at just 668 seconds—in-use data must be collected in the field for a minimum of 6,000 seconds of Bin 2 operation and 2,400 seconds of idling, a substantial increase over GEM's regulatory program.

FIGURE 1. The share of bin-averaged, normalized GHG emissions for regulatory and representative Class 8 Sleeper Cabs



It is not just the length of the duty cycle that suggests the use of non-regulatory cycles to estimate a vehicle's emissions, but the quality of the data. The regulatory cycles were designed to be carried out in the lab environment, which necessarily limits the range of operating conditions that can be reasonably carried out on a dynamometer. Because we are proposing to piggyback on the GEM virtual environment for compliance with the rule, there is no such necessary limitation. Thus, it makes sense to take advantage of a wider range of data that can provide a fuller picture of the operating conditions.

While both the EPA regulatory cycle and NREL test cycle based on Fleet DNA data show a substantial peak at high power cruise, the regulatory cycle lacks any idle bin (Bin 1) windows, while there is a significant share in the real-world data. Moreover, the representative cycle shows a smooth distribution of engine powers, including at even higher power where the regulatory cycle lacks any data.

An example of the benefit of using a more representative test cycle can be seen in FIGURE 1. While the regulatory cycle spans a reasonable range of power operation (shown here through the surrogate for the off-cycle program, normalized GHG emissions), it lacks any data whatsoever at high- and low-power, and it shows a markedly more peaked range of operation than the representative cycle.

Given the large range of EPA classes covered by its HDV GHG emissions program, it may seem daunting to determine representative duty cycles for all vehicle types. However, through its Fleet DNA program, NREL has developed a number of representative cycles already and has collected additional data on some specific vocational cycles covered by EPA's custom chassis program.[1] This data could be readily developed into additional representative data cycles to ensure that every class of truck currently covered by the GHG program would be adequately covered by a multipollutant program.

The duty cycles provided in TABLE 2 are meant to be illustrative assignments to regulatory categories, rather than prescriptive. Given NREL's systematic process for developing representative duty cycles ([Zhang et al. 2021]), there is ample opportunity for the Agency to work directly with researchers on developing duty cycles for use in GEM specifically to cover a range of operational conditions spanning the appropriate regulatory categories for use in a multipollutant rule.

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[1] Much of this work is part of its DriveCAT program: NREL DriveCAT - Chassis Dynamometer Drive Cycles. 2023. National Renewable Energy Laboratory. www.nrel.gov/transportation/drive-cycle-tool. Some of the duty cycles published are incomplete (may not end at zero) due to data being removed for privacy concerns or being the end of the dataset. The methodology and drive cycles have been peer-reviewed: Zhang, C., et al. 2021. "Development of heavy-duty vehicle representative driving cycles via decision tree regression," *Transp. Res. D* 95, 102843. https://doi.org/10.1016/j.trd.2021.102843.

TABLE 2. Possible representative test cycles for a multipollutant rule covering the span of EPA HDV GHG regulatory categories

EPA Regulatory Class	Representative Multipollutant Test Cycle
Class 8 Sleeper Cab – Low Roof Class 8 Sleeper Cab – Mid Roof Class 8 Sleeper Cab – High Roof	Fleet DNA Long-Haul Representative
Class 8 Day Cab – Low Roof Class 8 Day Cab – Mid Roof Class 8 Day Cab – High Roof Heavy-Haul Tractor	Fleet DNA Regional-Haul Representative
Class 7 Day Cab – Low Roof Class 7 Day Cab – Mid Roof Class 7 Day Cab – High Roof	Fleet DNA Drayage Representative
Heavy Heavy-duty Vocational – Regional Medium Heavy-duty Vocational – Regional Light Heavy-duty Vocational – Regional Custom Chassis – Coach (Intercity) Bus Custom Chassis – Motor Home	Fleet DNA Local Delivery Maximum Trip Distance
Heavy Heavy-duty Vocational – Multi-purpose Medium Heavy-duty Vocational – Multi-purpose Light Heavy-duty Vocational – Multi-purpose Heavy Heavy-duty Vocational – Urban Medium Heavy-duty Vocational – Urban Light Heavy-duty Vocational – Urban Custom Chassis – Cement Mixer Custom Chassis – Emergency Vehicle	Fleet DNA Local Delivery Representative
Custom Chassis – School Bus	Duran and Walkowicz (2013)
Custom Chassis – Transit Bus	Fleet DNA Transit Bus Representative
Custom Chassis – Refuse Truck	Dembski et al. (2005)

Establishing Stringency

Under § 202(a)(3) of the Clean Air Act, EPA is required to set pollution standards for NO_X, PM, and other non-GHG emissions from heavy-duty vehicles and engines that are technology-forcing (i.e., that "reflect the greatest degree of emission reductions achievable"). This represents an important opportunity for the Agency to consider in establishing multipollutant standards that would complement the GHG emissions standards adopted under § 202(a)(1). Here EPA can directly consider technology packages representing the maximum achievable reductions in the time-frame of consideration for all relevant pollutants.

While there may not be a significant difference in the GHG impacts of different technology pathways, there may be significant differences in the impacts such packages have on non-GHG emissions. Thus, in setting a multipollutant standard, EPA may base its rule on a narrower set of technologies in its rulemaking, and the technology-forcing authority of Clean Air Act § 202(a)(3) could justify advancing technologies beyond those considered available for the GHG rulemaking. This iterative approach would be used to reduce GHGs in a feedback loop designed to maximum the reductions of all pollutants simultaneously.

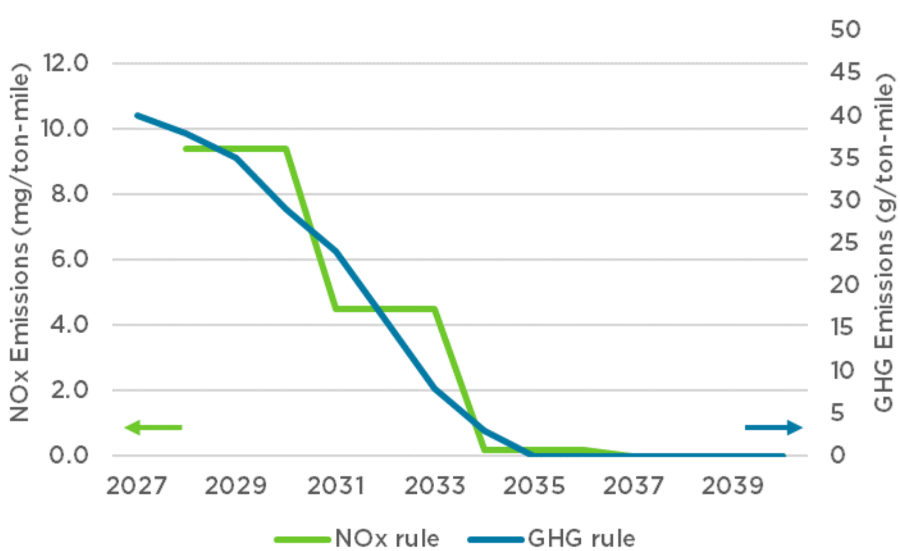
Because these rules could remain technology neutral, such a multipollutant approach does not necessarily exclude any individual technologies, and alternatives may be developed that the Agency had not considered, as has frequently occurred. However, by ensuring manufacturers must simultaneously meet targets for all pollutants, any of these unforeseen pathways would be required to deliver on both GHG and non-GHG emissions reductions.

Timeframe Constraints

Heavy-duty emissions standards for NO_X and a number of other pollutants are authorized under § 202(a)(3) of the Clean Air Act, which means that they are subject to a lead-time requirement of four years and so-called stability requirement of three years (42 USC § 7521(a)(3)(C)). While EPA has previously also established GHG rules under a three-year stabilization, there is no such limitation on the design of the GHG program, and it may be desirable to establish year-upon-year standards to accelerate the transition to zero-emission technologies. However, such differences are not necessarily incompatible.

For simplicity, let's consider a fleet-average standard predicated on the broad deployment of just two types of vehicles, a heavy-duty diesel vehicle achieving a maximum fuel economy for its class and meeting exactly the relevant engine pollution

FIGURE 2. Example rules for 2027+/2028+ for greenhouse gas emissions and NO_X emissions, respectively, for heavy-duty trucks



standards for NO_X in 2027 and beyond, and an electric truck achieving zero tailpipe emissions of all pollutants. A mock-up of what those standards could look like is shown in FIGURE 2.

A NO_X rule for heavy-duty vehicles requiring "three-year stability" is compatible with GHG standards that vary year-over-year. The steps required for stability (for example, the fixed standard for 2028-2030) can be based on the average NO_X emissions for a fleet meeting the GHG standards over that same time period.

In this example, the target has been set based on average standards over a time period rather than a target matching the first year of such stability period in order to encourage the deployment of technology as rapidly as possible, taking advantage of the averaging, banking, and trading provisions we anticipate would be similar to those currently in effect. However, this is not prescriptive, and we imagine that nuances of such program components would be determined through the upcoming rulemaking process, thus making it important EPA formalize information requests around a multipollutant rule strategy in its notice of proposed rulemaking.

While it should be noted that the second step of a multi-pollutant rule could, if finalized by the end of 2023, align with the 2031 timetable already set by strong state standards for heavy-duty engines, it should also be emphasized that there is nothing magical or unique about the alignment of a particular three-year period. Heavy-duty engine and vehicle product cycles generally extend well beyond a three-year period, and manufacturers add and update features on a business cycle that reflects many different concerns. A three-year window provides manufacturers the certainty needed to plan around changes as befits their business, but it should not be used to stifle or inhibit EPA's ambition in living up to its mandate to limit emissions reductions from heavy-duty trucks.

Miscellany

Given the complexity of a rulemaking, there are nuances about the exact design of this program that may need further consideration and specification. Below, we walk through a few of the technical considerations that may need to be dealt with, with some suggested remedies where appropriate.

SPARK-IGNITION ENGINES

Unlike compression-ignition (CI) engines, EPA did not set comparable new off-cycle requirements for spark-ignition (SI) engines, though the Agency did leave open the possibility of setting such standards in the future (EPA-420-R-22-036, p. 442). However, this does not mean that these vehicles should be omitted from a multipollutant rule, as doing so could create incentives for manufacturers to product shift to unregulated classes, and zero-emission options are not defined by engine class but duty class.

EPA based its decision not to set off-cycle standards in part on new lab test procedures meant to ensure SI engines achieve emissions reductions over a broader range of operation, including the addition of a new supplemental emissions test (SET) and new requirements on idle control (EPA-420-R-22-036, p. 442). Since the standards between the new SET and the current FTP are identical for nearly all pollutants, this sets a reasonable expectation for the emissions from these vehicles.

In its Heavy-duty Omnibus rulemaking, CARB applied MAW in-use standards to SI engines, using a single bin and comparing that to the FTP standard for the engine after applying a multiplier.[2] Similarly, for the in-use process for verifying emissions controls deterioration factors, a manufacturer compares PEMS results on the engine to its duty cycle standards, applying a 1.5 multiplier (88 FR 4384, fn. 383). For these reasons, we think it is reasonable to apply the same GEM-based MAW approach used to establish emissions from vehicles CI engines to vehicles with SI engines, with $e_{\text{[emission],offcycle}} = 1.5 \times e_{\text{[emission],FTP}}$.

STOP-START AND AUTOMATIC ENGINE SHUTOFF

Two of the technologies most likely to be encouraged for SI- and CI-engine-powered heavy-duty vehicles through a multipollutant vehicle standard are stop-start and automatic engine shut-off (AES), both of which shuts off the engine at idle. For the purposes of the GEM model and therefore the multipollutant rule, the simulated in-use emissions should be treated in the same manner as a tamper-proof start-stop or AES system—in that case, the emission rate for all pollutants is set to zero when the AES and/or stop-start system is active (88 FR 4347). Consistent with that approach, these data would still be included in the MAW process, which ensures that the simulated duty cycle reflects the ability for such technologies to reduce real-world emissions.

CUSTOM CHASSIS

As part of the Phase 2 GHG regulations, EPA utilized a simplified GEM model in expanding its custom chassis program. This optional program targets specific vocational applications that were identified by the agency as potentially needing a simpler set of technology options for various reasons, including small business manufacturers and unique duty cycles.

Certification through the custom chassis program uses default inputs for a number of critical vehicle components, most notably the engine. This means that any such simulations would not actually well represent the certified vehicle's emissions. This is particularly concerning given that many of these applications like school buses and refuse trucks are some of those most ripe for vehicle-based non-GHG emissions reducing technologies like hybridization and electrification.

While overall EPA finds that these vehicles are generally a small share of the total new heavy-duty population and annual emissions (81 FR 73688), it will be critical to

[2] See § 86.1370.B.1 of the "California Exhaust Emission Standards and Test Procedures for 2004 and Subsequent Model Heavy-Duty Diesel Engines and Vehicles," as incorporated by reference in title 13, CCR, section 1956.8(b).

develop a multipollutant approach that incentivizes the deployment of emissions reductions while recognizing some of the unique characteristics of the vocational applications relevant to this voluntary program. Placing limits on the use of the simplified custom chassis certification process may be one strategy, and there are already limits on averaging, banking, and trading of credits that when applied to non-GHG pollutants could effectively limit the degree to which the program disincentivizes emissions reductions of non-GHG pollutants. Again, however, such details would likely be considerations in a rulemaking process.

RANGE OF POLLUTANTS

The heavy-duty engine standards for non-GHG pollutants cover NO_X, $PM_{2.5}$, hydrocarbons, and carbon monoxide. However, only NO_X has in-use requirements across the entire use phase—the other pollutants have no low-power/idle in-use requirements. At the same time, these are certainly critical pollutants to consider and control at the vehicle level.

In order to set standards for pollutants other than NO_X, one strategy could be to grade the emissions on a curve based on a baseline vehicle—for example, if only 75 percent of the duty cycle for the baseline truck would fall into Bin 2, the Bin 2 emissions assigned by the standards are scaled up by a factor of 1/0.75. This would preserve incentives designed to reduce engine power through stop-start or hybridization, which would necessarily reduce the number of events contributing to Bin 2. This would also ensure that the Bin 1 data, which cannot be assigned an in-use emissions value, does not contribute significant weight to the emissions profile (say, if it were characterized as 0 mg/ton-mile).

Alternatively, if the primary vehicle-based technologies to reduce non-GHG emissions are simply reducing power/operation of the engine, through hybridization or electrification, this could potentially be driven solely with a NO_X vehicle standard. While it would remain important to reduce $PM_{2.5}$, there would not necessarily be additional technology forced to market through a vehicle $PM_{2.5}$ standard in this case beyond what would already be driven by the NO_X standard and so perhaps a NO_X vehicle standard would be sufficient to maximize the reductions of all non-GHG pollutants.

Conclusion

Emissions controls technologies exist beyond those already incentivized by EPA's non-GHG emissions standards from heavy-duty engines. A vehicle-based multipollutant rule could ensure these technologies are deployed, resulting in non-GHG emissions reductions beyond those which may have otherwise occurred as the result of a strong GHG rule. Such a multipollutant rule can be designed taking advantage of the compliance tools, procedures, and standards already used by the agency and the regulated parties. It is therefore critical that EPA incorporate a multipollutant strategy in its upcoming rulemaking to be consistent with its authority under the Clean Air Act to drive the maximum emissions reductions possible.