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August 25, 2020
California Air Resources Board
1001 I Street Sacramento, California 95814

RE: Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments

Dear Chair Nichols and Members of the Board,

On behalf of our half million supporters, including nearly 50,000 Californians, the Union of Concerned Scientists (UCS) submit these comments to generally support the Heavy-duty Engine and Vehicle Omnibus Regulations ("Omnibus") proposed by the California Air Resources Board (CARB). This action is supported by a significant body of research and addresses a critical need to improve the air quality for California by driving down emissions from fossil-fueled trucks while accelerating the transition to an electrified heavy-duty fleet.

This rule represents a significant step forward in addressing pollution which disproportionately affects communities of color, but it can be further strengthened to promote the cleaner trucks needed to address the public health risk of heavy-duty vehicles while insuring the emissions reductions presented in staff analysis:

1) **CARB provided insufficient data to justify the proposed weakening of the 2027 heavy heavy-duty diesel engine target related to emissions control deterioration (from 0.02 to 0.035 g NO_x/bhp-hr). Moreover, the work at SwRI does not appear to support such a large reduction in stringency. This adjustment could undermine the anticipated benefit of CARB's extension of the warranty period and full-useful life. CARB staff should provide additional justification for any such adjustment prior to final adoption.**

2) **The proposed rule does not reflect the adoption of the Advanced Clean Trucks (ACT) standard—UCS believes that the rule's emission standards should be strengthened to reflect both the baseline requirements of the ACT standard and the availability of electrification as an emissions reduction strategy. The best way to do this is to increase stringency to reflect all achievable reductions—UCS calculates that ACT volumes warrant an increase in stringency from 0.05 to 0.045 g NO_x/bhp-hr in 2024 and from 0.02 (LHD/MHD) and 0.035 (HHD) to 0.013 (LHD/MHD) and 0.027 (HHD) g NO_x/bhp-hr in 2027. If an increase in stringency is not adopted, the proposed rule should be modified to better reflect the volumes of electric trucks required under ACT and minimize the potential for backsliding on diesel truck emissions due to double-counting of emissions reductions that are already required. We support use of the low NO_x rule to further incentivize progress towards the state's goal of widespread truck electrification, but credits for electric trucks should be awarded only once ACT volumes have been achieved.**

3) **The voluntary 50-state program allowing for higher emitting trucks (0.1 g NO_x/bhp-hr) to be sold in California is unnecessary and should be eliminated from the proposal. Nationwide adoption of cleaner emissions technology is important, but the research shows clearly that manufacturers can apply the technology needed to meet the 2024-2026 standards (0.05 g NO_x/bhp-hr) nationwide. Moreover, they already have ample flexibility and incentive within both the federal and California emissions programs to promote such deployment, and state adoption of California's standards under Section 177 of the Clean Air Act will further spur such progress, diminishing any justification for this voluntary program. Elimination of this voluntary option ensures that near-term progress on diesel emissions control is maximized, as envisioned by the technology-forcing requirements of the Clean Air Act.**

Rationale for these revisions as well as the need and support for the Omnibus package are detailed below.

Proposed revisions to the CARB proposal

Though CARB has put forth a strong proposal, there are three areas that need additional attention: 1) proposed adjustment to reflect changes to full-useful life; 2) inadequate attention to the volumes of electric trucks driven to market by the Advanced Clean Trucks standard; and 3) the voluntary 50-state framework.

1) Limit or clarify increases in emissions from control deterioration

While CARB has proposed a 0.02 g NO_x/bhp-hr standard for light and medium heavy-duty engines in 2027, the 0.02 g NO_x/bhp-hr standard for heavy heavy-duty engines is only applicable at 435,000 miles, rather than full useful life (FUL), a so-called "intermediate standard" which CARB staff indicate is "to account for deterioration."[1] Instead, CARB has increased the standard from 0.02 to 0.035 g/bhp-hr in 2027 and 0.040 g/bhp-hr in 2031 and beyond. However, such increases exceed any such increases assumed over a vehicle's lifetime under CARB's EMFAC and EPA's MOVES model, which include additional emissions owed to tampering, malmaintenance, and malfunction.[2]

While UCS does not dispute the fact that catalysts in emissions control systems deteriorate with age, CARB has not provided any data in support of the proposed reduction in stringency and specific numerical values for the 2027 and 2031 FUL HHD standard on the FTP cycle. Furthermore, as was noted earlier, there has been significant attention paid to the durability of modern catalysts, and (limited) data on aged catalysts shows only a moderate level of reduction in efficiency.[3] It is plausible that advances in catalysts in the timeframe of the rule will continue to reduce the amount of deterioration, resulting in a much weaker in-use standard than is appropriate and, as a result, increased NO_x emissions.

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[1] ISOR Table ES-2.

[2] CARB EMFAC2017, Volume III – Technical Documentation, p. 142. EPA Exhaust Emission Rates for Heavy-duty On-road Vehicles in MOVES2014 (EPA-420-R-15-015a), p. 163 (Appendix B).

[3] "Limited testing from several high use trucks suggests that the aftertreatment systems are capable of meeting current emission standards with 95% NOx conversion after approximately 700,000 miles of real-world operation," MECA 2020, p. 27.

<u>The data presented thus far by CARB as part of the SwRI work indicate substantially less deterioration than is presumed by its proposed FUL standard.</u> For example, the Phase 1/1b work showed that "degreened" parts achieved 0.008 g/bhp-hr on the composite FTP cycle, while fully aged parts achieved 0.023 g/bhp-hr[4]—rather than 0.035 and 0.040 g/bhp-hr at 600,000 and 800,000 miles, respectively, similar levels of deterioration would imply ~0.025-0.030 and ~0.030-0.035 g/bhp-hr, standards that are up to 25 percent more stringent than the proposed FUL standard. Similarly, preliminary Phase 3 data showed a drop in efficiency in NO_x conversion from 98.2 to 97.7 percent (Cold FTP) and 99.7 to 99.5 percent (Hot FTP) for degreened to fully-aged parts,[5] which would imply even less of an adjustment factor for deterioration than the Phase 1/1b results, to just 0.022 and 0.025 g/bhp-hr for 600,000 and 800,000 miles for an engine that met a 0.020 g/bhp-hr standard at 435,000 miles.

While it may be prudent to have to different relative useful life standards in order to accommodate differences in test procedures proposed by CARB, the data presented to date do not support such a large adjustment factor for deterioration.

2) Adjusting the proposal to account for the Advanced Clean Trucks standard

In its proposal, CARB has appropriately incorporated a new crediting procedure for plug-in electric vehicles, reflecting that electrification is one technological option for NO_x reduction. UCS supports the inclusion of a credit for zero-emission trucks in order to incentivize sales of electric trucks that exceed the volumes required under the Advanced Clean Trucks standard (ACT). However, <u>because CARB did not factored neither the required deployment of electric trucks nor their availability in setting the standard, adjustments are necessary to the proposal to limit backsliding on diesel truck emissions while continuing to incentivize the transition to electric trucks.</u>

ADJUST STRINGENCY TO REFLECT AVAILABLE TECHNOLOGIES

While CARB's proposed 0.05 g/bhp-hr and 0.02 g/bhp-hr standards are a substantial improvement over today's 0.2 g/bhp-hr standard, they represent only the technology potential of diesel engines, rather than the full suite of heavy-duty truck technology. Given the large penetration of zero-emission truck (ZET) volumes required under ACT (Table 1), <u>CARB should have incorporated electrification in assessing the potential stringency levels for heavy-duty NO_x reductions in order to maximize pollution reductions and better support its air quality mandate.</u>

In order to assess a technology-neutral stringency, our analysis assumes that the average diesel vehicle meets the standards proposed by CARB for 2024-2030, and that zero-emission trucks are credited as proposed. Electric truck volumes are considered proportional to ACT requirements and consistent with diesel truck sales, with one exception for Class 7-8 tractors—as CARB's ACT research noted, short-haul/drayage trucks are more likely to be electrified, and so the proportion of new Class 7 electric tractors is assumed to be higher as a fraction of tractor sales (40 percent) than Class 7 tractors are of the overall Class 7-8 tractor sales (20 percent).

[4] Christopher Sharp, "Update on Heavy-duty Low NO_x Demonstration Programs at SwRI," Presentation at Heavy-duty low NOx rulemaking workshop, Diamond Bar, CA, September 26, 2019.
[5] Personal communication with Chris Sharp, Southwest Research Institute.

Electric truck sales percentages under the Advanced Clean Trucks standard

Year	Class 2b-3	Class 4-8 straight trucks	Class 7-8 tractors
2024	5%	9%	5%
2025	7%	11%	7%
2026	10%	13%	10%
2027	15%	20%	15%
2028	20%	30%	20%
2029	25%	40%	25%
2030	30%	50%	30%
2031	35%	55%	35%
2032	40%	60%	40%
2033	45%	65%	40%
2034	50%	70%	40%
2035	55%	75%	40%

Table 1. *The Advanced Clean Trucks standard requires electric truck sales of 30 percent or more by 2030, which has a significant impact on the overall stringency of the Omnibus rule.*

While ACT requirements continuously increase year over year, NO_x standards are assumed to remain fixed for the 2024-2026 and 2027-2030 time periods, which will necessitate some credit averaging consistent with the averaging, banking, and trading (ABT) program under the Clean Air Act; however, UCS' analysis assumes no net accumulation of credits for the industry under the adjusted stringency. We also assume no credit trading between vehicle classes, consistent with the current ABT program.

In order to assess the appropriate stringency, our analysis precisely balances credits earned under baseline ZEV deployment with debits earned by diesel vehicles achieving the standards that CARB has identified as achievable (0.05 and 0.02/0.035 g NO_x/bhp-hr). Under the proposed standard, baseline deployment under ACT creates a bank of over 1800 metric tons of lifetime NO_x credits—this is such a substantial volume of credits that manufacturers could offset 100 percent of the required improvement for Class 8 vehicles in 2027-2030 simply by applying credits earned under baseline ACT compliance. In our analysis, a diesel vehicle in 2024 which achieves a 0.05 g/bhp-hr is actually a net credit debtor, requiring ZET sales at a 1:9 ratio to offset this debit.[6] This is, of course, consistent with the ACT deployment levels, which require 5 to 13 percent ZET deployment in 2024-2026, depending on vehicle class.

[6] Every ZET is credited based on the difference between the standard (0.045 g/bhp-hr in our analysis) and zero. Thus, each electric truck generates roughly 9 times the credits lost by a diesel vehicle that achieved the minimum level of improvement CARB identified achievable in this timeframe (0.05 g/bhp-hr, a 0.005 g/bhp-hr debit over the 0.045 g/bhp-hr standard). For 2027, the ratio is roughly 1:2 for LHD/MHD vehicles, and 1:4 for HHD vehicles, consistent with ACT requirements of 15 to 50 percent.

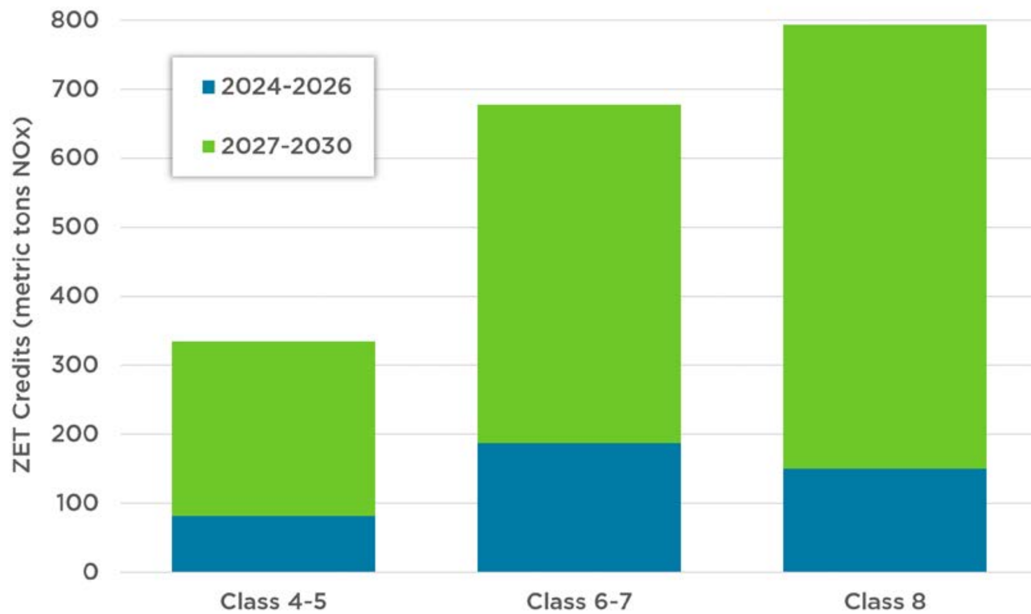

Figure 1. *Zero-emission trucks required under the Advanced Clean Trucks standard will generate a significant amount of credits under the proposed standard. Such credits can be used to offset emissions reductions from diesel trucks, reducing the net emissions reductions of the Omnibus relative to the status quo.*

To fully account for the deployment of electric trucks required by ACT, the NO_x FUL standard should be 0.045 g/bhp-hr in 2024, and 0.013 g/bhp-hr and 0.027 g/bhp-hr in 2027, for light/medium heavy-duty and heavy heavy-duty vehicles, respectively.

Correcting the stringency to drive the diesel emissions reductions identified as achievable and recognizing the electric truck deployment already required achieves a 15 percent reduction in lifetime NO_x emissions over the proposed Omnibus program for 2024-2030. ACT-mandated ZET credits should not be used in lieu of diesel emissions

reductions–adjusting the stringency explicitly recognizes the NO_x reductions which are already required to occur under the ACT standard and avoids the double-counting that allows for additional emissions from diesel vehicles.

ELIMINATE INTERCLASS TRADING FOR ELECTRIC TRUCKS

Under the current ABT program, credits earned under a particular vehicle class may only be used to offset debits within that class (HDO, LHDD, MHDD, and HHDD). However, CARB is proposing the introduction of a unique ZET bank, which could transfer credits to any class. This unnecessary flexibility creates a significant loophole for erosion of Class 8 truck requirements under the proposed standards.

While the ability to "trade up" NO_x credits (from a lower weight class to a higher weight class) is somewhat limited by the differences in useful life for each weight class, this is offset by the substantially higher sales volume of lighter vehicle classes (Figure 1). As noted above, the net credits earned under baseline compliance with ACT are sufficient to offset the entire difference in stringency between the 2024-2026 and 2027-2030 programs for Class 8 vehicles, if that is how manufacturers chose to apply these credits.

Given the breadth of operating conditions for heavy-duty vehicles, it is critical that advances in emissions control technology penetrate each and every vehicle class, whether that is advanced diesel emissions controls or electrification. In order to ensure NO_x reductions for every community affected by heavy-duty trucks, whether that is a community located along a freeway freight route or near a warehouse district or port, it is prudent to limit trading of all credits to those within a particular service class, regardless of technology.

In addition to addressing potential disparities between truck vocation/route and emissions reductions, retaining the prohibition on trading credits between service classes limits the adverse impact of the current proposal by reducing the fungibility of ZET credits earned under baseline ACT adoption. Prohibiting the transfer of credits between classes would eliminate 60 percent of the credits available to offset Class 8 tractors, the class of vehicle likely to have the highest cost of compliance under the proposed Omnibus, something which significantly reduces the potential for abuse under the current proposal.

LIMITING ZERO-EMISSION TRUCK CREDIT WINDFALL

Should CARB decline to adjust the stringency to reflect the deployment of ZETs to meet ACT, CARB should limit the availability of ZET credits to the volume of vehicles in exceedance of a manufacturer's required deployment under ACT. While UCS' preferred option is for the stringency of the NO_x rule to reflect the ACT requirements for electric truck deployment, if the stringency is not further adjusted, additional steps must be taken to limit the availability of ZET credits, which could substantially offset the emissions requirements for diesel trucks and thus fail to drive the improvements needed in Californian communities suffering from truck pollution.

One simple change CARB could make to respond to this issue is to add a qualifier to the "sales" term in the ZET credit formula, restricting it to "sales above ACT requirements." This would reduce the number of credits available to offset diesel vehicle emissions and focus the incentive on manufacturers that were investing heavily in electrification to reduce truck pollution above and beyond ACT requirements.

3) Eliminate the 50-state voluntary compliance program

While UCS acknowledges CARB's desire for all trucks operating in the state of California to fall under the same set of standards, UCS does not support the 0.1 g NO_x/bhp-hr voluntary program.

First and foremost, the technologies that CARB has identified as applicable in 2024 are applicable at national scale. Research at SwRI itself showed that today's engines are capable of meeting less than a 0.1 g/bhp-hr standard using engine calibration alone.[7] Thus, such a 50-state program would drive virtually no technology improvement whatsoever. Furthermore, to the extent that manufacturers are able to adopt the technology to achieve the 0.05 g/bhp-hr standard in California, it is likely such technology will already spill over to trucks sold outside the state of California—manufacturers have a strong interest in selling a single product across

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[7] Staff White Paper, California Air Resources Board Staff Current Assessment of the Technical Feasibility of Lower NOx Standards and Associated Test Procedures for 2022 and Subsequent, Model Year Medium-Duty and Heavy-Duty Diesel Engines Prepared by Staff of the Mobile Source Control Division Mobile Source Regulatory Development Branch April 18, 2019

the country, particularly in order to build up a credit bank to meet more stringent EPA standards likely to be phased in in 2027. While there is the possibility for differences related to emissions warranties, for example, it is not desirable for manufacturers to create an entirely separate program for the 2024-2026 time period, so it is unlikely for a manufacturer to develop a California-only truck. This spillover to national sales inherently diminishes the potential benefit of any voluntary program under the guise that all out-of-state trucks will be operating under 2010 standards, rather than California's more stringent 2024 standard.

In addition to the lack of a technological need for a weaker standard, there are concerns again about equity and fairness. For example, CARB already identified that 2024 will introduce a significant disparity between vehicles which are chassis-certified (such as medium-duty pickups) and those that are engine-certified[8]—the voluntary 50-state program could see similar disparities arise between manufacturers specializing in light heavy-duty vehicles compared to those with a greater share of heavy heavy-duty vehicles, owing to the substantially different power demands for different vocations. Since all communities in the state should expect to benefit from this rule, any such disparities raise concerns about allowing specific classes of vehicle the option of meeting a weaker standard, particularly one which is unlikely to advance emissions control design and investment.

The need to reduce truck pollution

California air quality and heavy-duty trucks

As the Board is well aware, California continues to remain home to the worst air quality in the nation.[9] Even with the numerous actions undertaken by virtually every level of government, the South Coast and San Joaquin Valley continue to struggle with air quality that falls short of federal requirements for both ozone and particulate pollution, pointing to the need for continued progress. While smog formation is a complex process, in these two regions in particular, it is limited largely by the emissions of nitrogen oxides (NO_x),[10] the greatest source of which is heavy-duty trucks.[11] Heavy-duty trucks also remain a tremendous source of particulate pollution ($PM_{2.5}$), both through primary emissions from the tailpipe, and through the secondary formation as a result of the emissions of nitrogen and sulfur oxides. For both the South Coast and San Joaquin Valley, secondary $PM_{2.5}$ is the greater cause of days in exceedance of federal

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8 ISOR II-25

9 American Lung Association, "State of the Air," 2020. Online at http://www.stateoftheair.org/key-findings/ozone-pollution.html

10 San Joaquin Valley Unified Air Pollution Control District, "Draft 2016 Plan for the 2008 8-Hour Ozone Standard, Chapter 4: Scientific Foundation and Ozone Modeling Results," March 22, 2016. Online at http://www.valleyair.org/workshops/postings/2016/03-22-16_Ozone/Chapter4.pdf. South Coast Air Quality Management District, "VOC Controls Whitepaper," September 2015. Online at https://www.aqmd.gov/docs/default-source/Agendas/aqmp/white-paper-working-groups/wp-voc-draftfinal.pdf

11 San Joaquin Valley Unified Air Pollution Control District, "2016 Plan for the 2008 8-Hour Ozone Standard, Appendix B: Emissions Inventory," June 16, 2016. Online at http://valleyair.org/Air_Quality_Plans/Ozone-Plan-2016/b.pdf. South Coast Air Quality Management District, "2016 Air Quality Management Plan: Appendix III, Base and Future Year Emissions Inventory," March 2017, p. 172. Online at http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2016-air-quality-management-plan/final-2016-aqmp/appendix-iii.pdf?page=172.

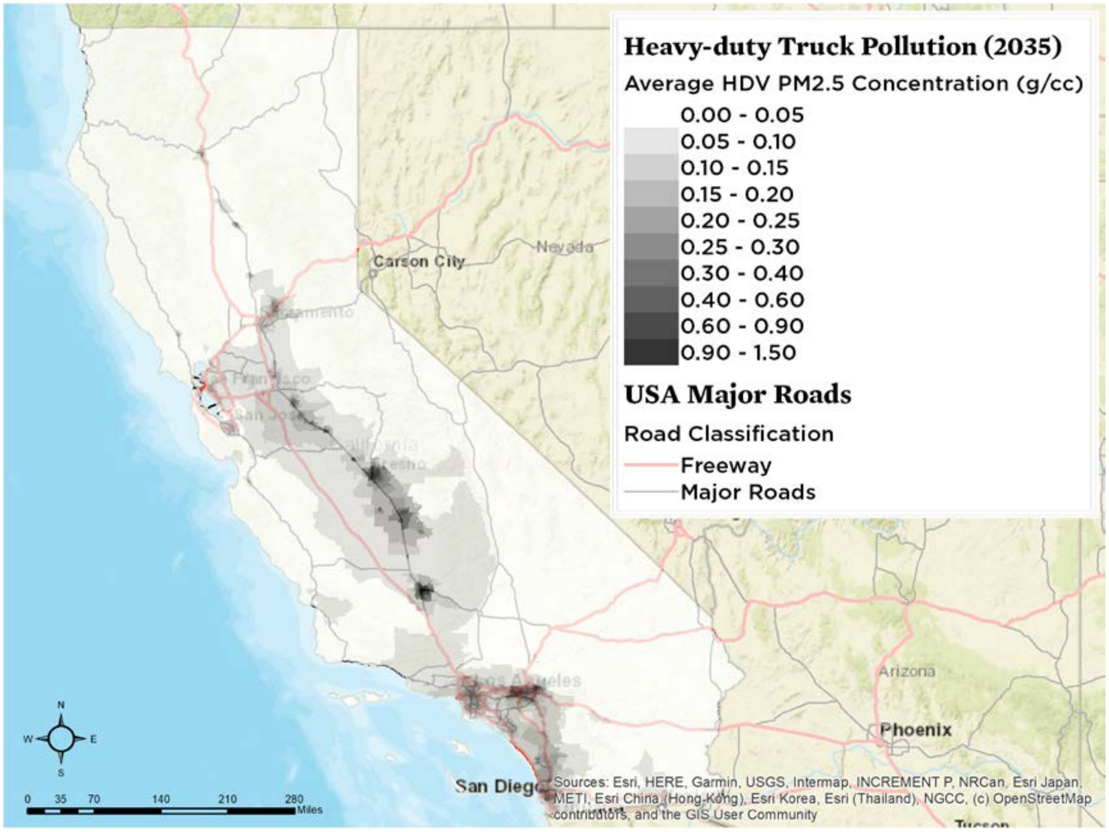

Figure 2. *Average particulate matter pollution in 2035 from heavy-duty trucks in California, including both primary and secondary emissions, is concentrated along freight corridors.* (UCS analysis, modeled in InMAP)

standards.[12] Thus, reducing NO_x emissions from heavy-duty trucks provides an opportunity to simultaneously address both ozone and particulate non-compliance.

Inequitable health impacts of heavy-duty vehicles

The air quality impacts of heavy-duty trucks do not affect Californians uniformly. Analysis by UCS shows pollution from heavy-duty trucks is concentrated in freight corridors (Figure 2), and communities of color are disproportionately likely to be located in these areas (Figure 3), owing at least in part to a history of systemically racist land-use policies, including redlining.

The San Joaquin Valley (including Bakersfield and Fresno) is most impacted along Highway 99, particularly among communities which are disproportionately non-White, including large Latinx and Southeast Asian populations. In Southern California, the areas along the I-10 freeway from LA to Riverside, and the area bounded by the I-605 and I-110 freeways from the

[12] San Joaquin Valley Unified Air Pollution Control District, "2018 Plan for the 1997, 2006, and 2012 PM2.5 Standards, Appendix: San Joaquin Valley $PM_{2.5}$ SIP," November 15, 2018, p. 29. Online at https://www.valleyair.org/pmplans/documents/2018/pm-plan-adopted/2018-Plan-for-the-1997-2006-and-2012-PM2.5-Standards.pdf#page=1291, South Coast Air Quality Management District, "2016 Air Quality Management Plan," March 2017, p. 2-26. Online at http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2016-air-quality-management-plan/final-2016-aqmp/final2016aqmp.pdf?page=100.

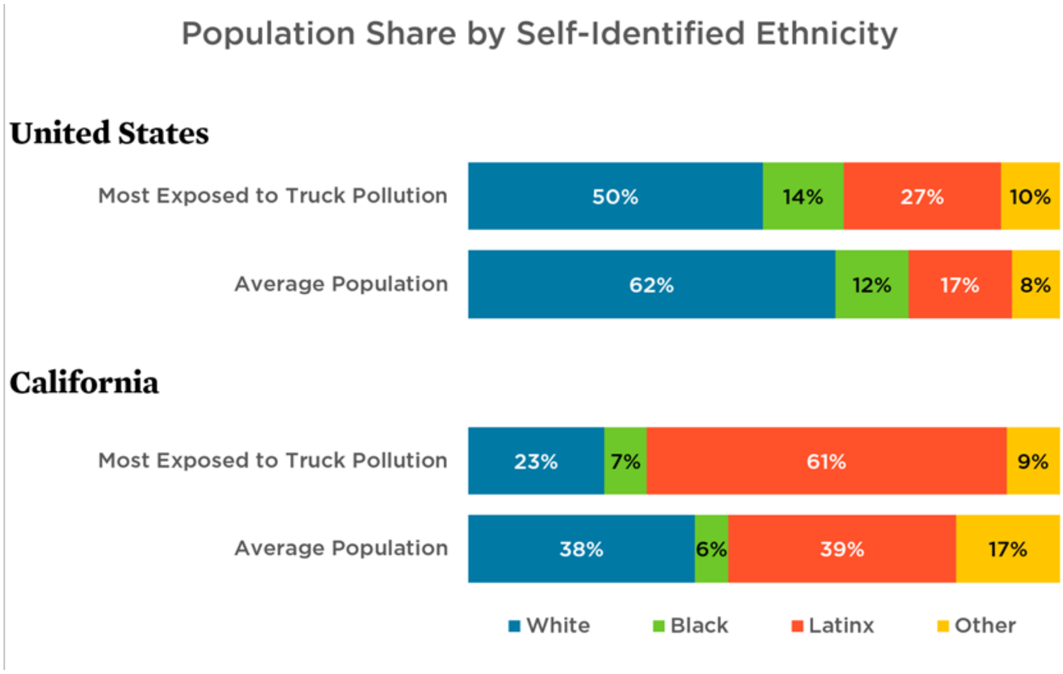

Figure 3. ***While truck pollution is a broad nationwide issue affecting everyone, Black and Latinx communities represent a disproportionate share of the communities exposed to the highest levels of truck pollution.*** **(UCS Analysis. "Truck pollution" includes both primary and secondary $PM_{2.5}$ emissions. "Most exposed" represents the 99^{th} percentile of census tracts, based on truck pollution.)**

Port of Long Beach through LA are most affected, including communities like Lynwood and Huntington Park, which are virtually devoid of non-Hispanic White residents.

There is no single action which can remedy the *cause* of the longstanding injustices faced by these communities; however, policies like those proposed by CARB targeting reductions in pollution from heavy-duty trucks will disproportionately benefit these communities and help to remedy, in part, a *symptom* of this injustice.

General support for the CARB proposal

Stringency under current engine test procedures

<u>There is significant evidence for manufacturers' ability to meet a 0.02 g/bhp-hr standard on the heavy-duty federal test procedure (FTP) and ramp modal cycle (RMC).</u> In addition to the exceptionally detailed body of evidence put together by CARB and the team at the Southwest Research Institute (SwRI), there has been a decade of progress on the technology to go beyond the current combination of selective catalytic reduction (SCR) systems required under the 2007/2010 rules. Importantly, many of the strategies for achieving even lower soot and smog-forming emissions go hand in hand with strategies to reduce global warming emissions from these trucks as well. Detailed examples of three different, complementary strategies manufacturers can utilize to reduce emissions are described below in greater detail in order to emphasize the diversity of options available to meet the stringency laid out in CARB's proposed targets.

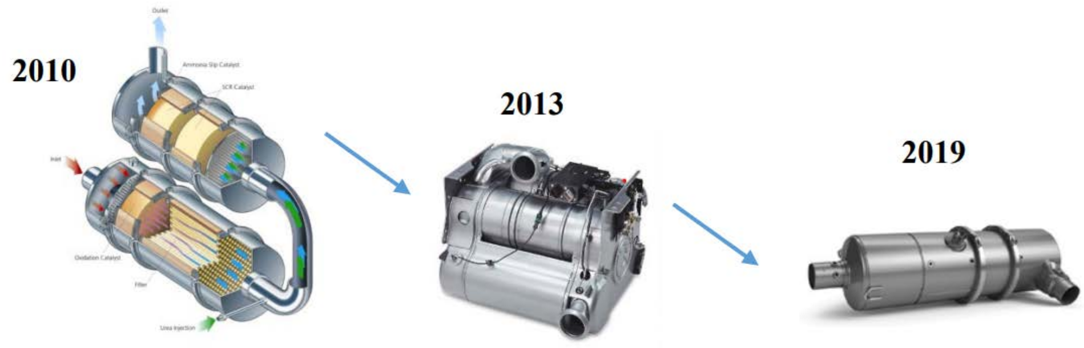

Figure 4. ***Packaging of SCR systems has changed dramatically over the past decade, moving to a much more compact configuration that is 60% smaller, 40% lighter, and significantly less expensive. This more compact design allows for novel strategies for future aftertreatment systems, including close-coupled dual-SCR.*** **(Source: MECA)**

AFTERTREATMENT SYSTEMS

In a recent study, the Manufacturers for Emissions Controls Association (MECA) found that improving the catalyst alone from 2014 to 2019 technology cut hot-start FTP NO_x emissions by two-thirds, even while using the same emissions control design.[13] Improvements enabled by next-generation catalysts (including the potential for a second, smaller, upstream SCR system) were able to further reduce the hot-start NO_x emissions below 0.02 g/bhp-hr, while also significantly reducing N_2O, a greenhouse gas. Additional progress is also being made regarding durability of the catalyst, something which strongly supports CARB's extension of the useful life and warranty of emissions systems. For example, a second- generation Cu-zeolite SCR showed less than a 10 percent deterioration in performance after accelerated aging at high temperatures, as compared to a 40 percent deterioration in performance in the current generation catalyst.[14]

On top of the progress in catalyst performance, the aftertreatment packaging shows tremendous levels of potential. Packaging of SCR systems has changed dramatically over the past decade, moving to a much more compact configuration that is 60% smaller, 40% lighter, and significantly less expensive (Figure 4). This evolution in packaging has been enabled through improvements to catalyst substrate design which allow for improved catalyst loading, efficiency, and durability, as mentioned above. Because of the substantial progress to date, there is room in the vehicle for an evolutionary step to more sophisticated systems.

The next generation of aftertreatment systems is aligned not just with CARB's 0.02 g/bhp-hr target but is also supportive of improved performance on the proposed low-load cycle. Reducing the thermal mass of the SCR systems and better insulation of the exhaust system can help reduce the warm-up time and maintain the temperature of the system through transient operation, an example of passive thermal management. Additionally, there are alternative approaches, such as heating the catalyst itself, which can improve reactivity to such an extent that the system can be reduced in volume by 50 percent while seeing an improvement on the FTP cycle of 60 percent, again supportive of multiple elements of CARB's strong proposal.[15]

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[13] Manufacturers of Emissions Controls Association (MECA), "Technology feasibility for MY2024 HDD vehicles in meeting lower NOx standards," June 2019. http://www.meca.org/resources/MECA_MY_2024_HD_Low_NOx_Report_061019.pdf.
[14] *Ibid.*
[15] Bruck, R., M. Presti, O. Holz, A. Geisselmann, and A. Scheuer, A. "The Way to Achieve 'CARB post 2023' Emission Legislation for Commercial Vehicles," Presentation at the 39th International Vienna Motor Symposium 26th - 27th April 2018. Vienna.

Finally, a dual-SCR configuration combines the underlying ideas behind both active and passive thermal management with a smaller SCR unit that is both more closely coupled thermally to the engine and has reduced thermal mass, allowing it to achieve light-off temperature much more quickly than a traditional SCR system.[16] A dual-SCR system requires more complex controls strategies but improves aftertreatment efficiency, particularly at low load, and has shown both reduced impact on greenhouse gases and achieved nearly a 0.02 g/bhp-hr standard on the FTP cycle.[17]

ENGINE-BASED STRATEGIES

In addition to upgrades to the aftertreatment system, it is possible to reduce NO_x emissions at the source by driving improvements to the engine itself. These systems changes are complementary to different aftertreatment designs and are a key approach to reducing greenhouse gas and NO_x emissions simultaneously.

As noted in the Phase 1 SwRI work, turbocompounding can be a useful technology for meeting future greenhouse gas targets;[18] however, it also has the challenge of reducing the temperature of the exhaust gas, which would thus increase the challenges of low-load operation of aftertreatment systems. However, modern advances in turbocharger design can compensate for this, allowing for both improved emissions controls and reduced global warming emissions. Directly routing the exhaust gases to the aftertreatment system, bypassing the turbo under cold-start conditions, can yield nearly a 50°C increase in temperature for the aftertreatment system within the first 100 seconds of cold-start operation, allowing the system to operate at 60 percent NO_x conversion and, again, supporting real-world emissions reductions at lower load.[19] Alternatively, decoupling boost from exhaust gas recirculation allows for more independent control of emissions and efficiency. One such system going into production in 2021 can contribute to a 20 percent reduction in NO_x emissions, while another approach utilizing an exhaust gas recirculation pump can be used in other advanced engine strategies to simultaneously reduce NO_x and CO_2 emissions, including with complementary 48V electrification and variable valve actuation (VVA).[20]

VVA has been used for decades to reduce fuel use from light-duty vehicles, but recent advances have allowed for heavy-duty vehicles to develop novel diesel valve control that can fine-tune intake/exhaust valve timing to reduce emissions and fuel use at the same time. With such advanced controls in place, VVA can be used to compensate for any fuel penalty from early

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[16] Light-off temperature is the temperature at which more than half the exhaust gas is catalyzed by the SCR system. In practice, many systems are not operational until a higher temperature than this due to concerns about urea crystallization, which can contaminate the catalyst.

[17] Kasab, J. M. de Monte, K. Hadl, H. Noll, S. Mannsberger, G. Graf, H. Theissl, and A. Arnberger. Using close-coupled SCR to meet ultra-low NOx requirements. (Presentation). 2019 CLEERS Workshop, Ann Arbor, MI, September 17-19, 2019. Online at *https://cleers.org/wp-content/uploads/formidable/3/2019CLEERS_Kasab_Web.pdf*. Sharp, C.A., "Heavy-duty Engine Low-load Emission Control Calibration, Low-load Test Cycle Development, and Evaluation of Engine Broadcast Torque and Fueling Accuracy During Low-load Operation, Low NOx Demonstration Program—Stage 2 Final Report," Prepared for California Air Resources Board, May 6, 2020.

[18] Southwest Research Institute, "Evaluating Technologies and Methods to Lover Nitrogen Oxide Emissions from Heavy-Duty Vehicles: Final Report," prepared for California Air Resources Board, April 2017.

[19] MECA, "Technology feasibility for heavy-duty diesel trucks in achieving 90 percent lower NOx standards in 2027," February 2020. Online at *http://www.meca.org/resources/MECA_2027_Low_NOx_White_Paper_FINAL.pdf*.

[20] Abuelsamid, S. "Garrett electric turbochargers headed to production in 2021." *Forbes*, October 17, 2019. Online at *https://www.forbes.com/sites/samabuelsamid/2019/10/17/garrett-electric-turbochargers-headed-to-production-in-2021/*. Eaton, "TVS applications: Diesel engine EGR pump" (product description). Online at *https://www.eaton.com/us/en-us/products/engine-solutions/superchargers/TVS-technology-applications/tvs-diesel-egr-pump.html*.

exhaust valve opening through improved efficiency, such as early and late intake valve closing (EIVC, LIVC). Such a strategy can even be used to implement Miller cycle operation in the diesel engine, as noted in an analysis from the Volvo SuperTruck program which shows that Miller cycle operation can enable reduced NO_x emissions without compromising efficiency.[21] CARB's work with SwRI utilized another VVA strategy, cylinder deactivation (CDA), which helps both reduce fuel and address low-load emissions. CDA has already been proven effective and durable in light-duty vehicles, but recent research shows the strong benefits of CDA in heavy-duty diesel vehicles as well. CDA essentially allows the engine to be downsized in real time—this has the effect of dramatically increasing temperature of low load operation (about 100°C in an MHD engine) while improving overall fuel efficiency.[22] Importantly, this study found fuel savings (3.2 to 7.8 percent) and NO_x reduction (33 to 86 percent) over a range of real-world driving cycles emphasizing low load operation, without any modification to the production aftertreatment system. Even at low-load operation and idle conditions, heavy-duty CDA saw increases of 60-80°C with fuel savings of 8 to 28 percent.[23]

ADVANCED POWERTRAINS

Some of the same advances made in light-duty electrification are proving transferrable to heavy-duty vehicles, including mild 48V hybridization and plug-in electric vehicles. Full-hybrid electric trucks have been in the heavy-duty market for quite some time, both fully integrated by the OEM (e.g., Eaton, BAE Systems) and in the aftermarket (e.g., XL Hybrids, Odyne). This technology has been strongly promoted by CARB under various regulatory programs, and the proposal's inclusion of new test procedures will help continue to promote these extremely efficient hybrid-electric strategies for heavy-duty vehicles. However, mild hybridization offers a lower cost opportunity, particularly with a movement towards 48V electrification, and many of the emissions control strategies mentioned above would benefit from complementary 48V mild hybridization—for example, a 48V electrical system is an enabler for devices like an electrically driven turbocharger, an electrically heated catalyst, or an electrified EGR pump.[24]

As will be discussed in greater detail below, the Advanced Clean Trucks (ACT) rule established quite clearly the ability for electrification to be adopted at high volumes in the heavy-duty fleet at high volume. Electric trucks will be on the market and are critical to meeting our long-term climate and air quality goals, and CARB's proposed stringency targets should reflect the availability of this NO_x-reduction strategy.

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[21] Garcia, E., V. Triantopoulos, A. Boehman, A., M. Taylor, and J. Li. 2020. "Impact of Miller Cycle Strategies on Combustion Characteristics, Emissions and Efficiency in Heavy-Duty Diesel Engines." *SAE Technical Paper* 2020-01-1127. Online at *https://saemobilus.sae.org/content/2020-01-1127/*.

[22] McCarthy, J. "Simultaneous CO2 and NOx Reduction for Medium & Heavy- Duty Diesel Engines Using Cylinder Deactivation," Presentation at 16th SAE Brasil forum on diesel and alternative technologies for commercial and off-road vehicles, September 4, 2019.

[23] McCarthy, J. "Meeting Future Low Load Emissions Using Cylinder Deactivation and EGR Pumps to Achieve Simultaneous NOx and CO2 Reduction," Presentation at Emissions 2019 Conference, Livonia, MI, June 5, 2019.

[24] MECA 2020, McCarthy Emissions 2019 Presentation, and Dorobantu, M., "Commercial Vehicle Powertrains in the Era of Simultaneous NOx and CO2 Reduction," Presentation at the 16th SAE Brasil forum on diesel and alternative technologies for commercial and off-road vehicles, September 4, 2019.

	2024			2027		
	FTP standard	Real-world improvement	LLC/FTP ratio	FTP standard	Real-world improvement	LLC/FTP ratio
w/o LLC	-75%	-75%	9X	-90%	-90%	6X
w/ LLC	-75%	-80%	4X	-90%	-93%	2X

Table 2. ***Improving emissions on a low-load cycle (LLC) better captures real-world emissions reductions not represented on the federal test procedure (FTP) cycle. While reducing emissions on the FTP cycle results in commensurate real-world reduction, instituting additional requirements on low-load operation will yield additional real-world emissions reductions. Engines meeting the 2024 and 2027 FTP standards could see up to 9 times and 6 times the amount of emissions under low-load conditions, respectively—implementing the low-load cycle helps close this gap, resulting in additional real-world reductions because of improved regulation of cold and warm operating conditions not properly captured by the FTP by itself.*** **(UCS analysis. Percentages are relative to 2010 standards and reflect CARB's proposal. Real-world improvement reflects UCS estimate of g/mi for long-haul combination tractor-trailers.)**

Support for a low-load test cycle

According to EPA's in-use data, emissions under low speed operations (< 25 mph) are 7 times higher than those at high speed (> 50 mph) and represent a disproportionate share of NO_x emissions compared to fuel use.[25] This is in large part due to two, related factors: 1) trucks spend a much higher share of idling in the real world than is captured in the current tests, and 2) the long idle times and pattern of low-load use means that low-load operations spend a disproportionately large share of time at sub-optimal catalyst temperatures.

UCS is strongly supportive of CARB's inclusion of a new low-load cycle (LLC) to better ensure that reductions measured in the test protocol for new vehicles result in lasting, robust real-world emissions reductions.

While there is some significant range of operating conditions,[26] even data on line-haul trucks show significant time spent with the catalyst well below light-off temperatures. Analysis of these impacts show that moving forward, low-load emissions are anticipated to become a greater and greater share of the overall emissions from heavy-duty trucks,[27] signifying a need for heavy-duty test procedures to better capture real-world operation.

Using simulated data on catalyst temperature on the FTP, data on catalyst efficiency versus temperature and EPA heavy-duty in-use data,[28] UCS has estimated cold- and hot-start

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[25] Badshah, H., F. Posada, and R. Muncrief. "Current state of NOx emissions from in-use heavy-duty diesel vehicles in the United States. Whitepaper of the International Council on Clean Transportation (ICCT)," November 26, 2019. Online at *https://theicct.org/publications/nox-emissions-us-hdv-diesel-vehicles*.

[26] Boriboonsomsin,K., et al. "Real-world exhaust temperature profiles of on-road heavy-duty vehicles equipped with selective catalytic reduction." *Sci. Total Environ.* **634**, 909-921. Online at *http://dx.doi.org/10.1016/j.scitotenv.2018.03.362*.

[27] Yoon, S., et al. "In-use emissions from 2010-technology heavy-duty trucks: Impacts on air quality planning in California." *TRR: J. of the Transp. Res. Board* **2627** (1), 1-8. Online at *https://doi.org/10.3141%2F2627-01*.

[28] Salehi, R., and A.G. Stefanopoulou. "Optimal exhaust valve opening control for fast aftertreatment warm up in diesel engines." *Proceedings of ASME 2018 Dynamic Systems and Control Conference, Vol. 2.* DSCC2018-9178, V002T26A003. Online at *https://doi.org/10.1115/DSCC2018-9178*. Boriboonsomsin, et al. 2018. Sandhu, G.S., and D. Sontag. 2016. "Update to running exhaust criteria pollutant emission rates for model year 2010+ heavy-duty diesel vehicles," Presentation at FACA MOVES Review Work Group, Ann Arbor, MI, December 7, 2016. Online at *https://www.epa.gov/sites/production/files/2017-01/documents/running-exhaust-cri-pollutant-emission-rates-my-2010-hd-vehicles.pdf*.

performance on the FTP cycle for different operating modes, which was then used to estimate behavior under CARB's proposed low-load cycle. Comparing engines which nominally reduce the FTP cycle only to those which not just reduce FTP cycle emissions but also close the gap between hot- and cold-start emissions reduces the disparity between the FTP and LLC tests and results in additional real-world emissions reductions (Table 2).

Based on a national profile of truck travel and emissions, implementing the LLC yields an additional 14 percent reduction in real-world NOx emissions in 2035 by forcing more reduction under the low-load operation responsible for a disproportionate share of NO_x emissions.

Support for improving in-use testing and requirements

Replacing the "not-to-exceed" (NTE) process with a moving average window (MAW) approach as outlined in the proposal better ensures that CARB's test procedures result in real-world reductions and allow for better monitoring and enforcement of tampering and mal-maintenance of emissions equipment. The current heavy-duty in-use testing (HDIUT) requirements are woefully inadequate—the vast majority of data are discarded due the very narrow NTE window and limits on aftertreatment temperature, which all but neglect low-load operations, where aftertreatement systems are frequently operating below light-off conditions. It is critical that any HDIUT program accurately reflect the typical range of operating conditions that a truck undergoes, in order to ensure the lab certification tests continue to drive the anticipated emissions reductions.

UCS concurs with CARB's MAW strategy to include *all* data, rather than adopt in full the Euro VI method. Furthermore, UCS believes that the decision to set the boundary between the low-load bin and idle bin below the average operating condition of the LLC helps reduce the chance that too much low-load operation is inadvertently shifted to the idle bin, which would artificially ease requirements under low-load conditions, precisely the emissions which CARB's new HDIUT requirement is targeting.

Support for increasing warranty and useful life requirements

Heavy-duty diesel engines last well beyond the current useful lifetime, with 90 percent of engines lasting nearly double the current regulatory requirement, and 50 percent of Class 8 engines nearly triple (Figure 5). This extends to the warranty period, where the standard 100,000-mile warranty requirement is only a very small fraction of the expected lifetime of the engine (e.g., B10 and B50 miles, which indicate the mileage at which 10 percent and 50 percent of engines will need a major overhaul or replacement) and is well behind typical warranties and extended warranties of 250,000 and 500,000 miles.[29]

[29] CARB, "Proposed heavy-duty vehicle (HDV) warranty period amendments," Presentation at Heavy-duty low NOx rulemaking workshop, Diamond Bar, CA, July 12, 2017. Online at *https://ww3.arb.ca.gov/msprog/hdlownox/files/workshop071217/warrantyws_presentation.pdf*.

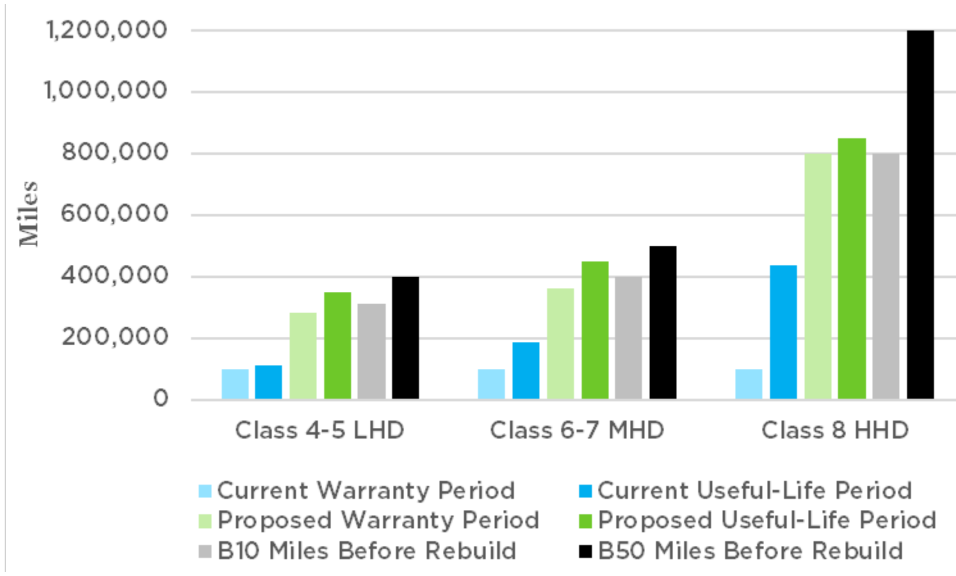

Figure 5. ***Heavy-duty engines can last up to 1.2 million miles before a rebuild, yet the current warranty extends to just 100,000 miles, and the useful-life period is only 435,000 miles. The CARB proposed changes to the warranty and useful-life periods for heavy-duty vehicles more closely mirrors the real-world operation of these engines and would help maintain working emissions controls while diminishing any costs incurred by the operators.*** **(B10 and B50 indicate the mileage at which 10 percent and 50 percent of engines will need a major overhaul or replacement, respectively.)**

The useful life is critical to ensure adequate testing such that emissions controls are functional for the life of the engine. The warranty period, however, is more important to minimize tampering or disrepair and shifts the cost of failures onto the manufacturer rather than the driver. Repair costs and downtime can be a significant burden for drivers, and survey data has shown that there is a significant interest in coverage that better reflects the operational lifetime of the vehicle.[30] Nearly one-quarter of respondents already opt for an extended warranty, with a substantial share of those respondents choosing warranties that exceed the current useful-life requirements of the engine. A majority of owner-operators suggested future warranty coverage should meet or exceed 500,000 miles, well above the current minimum.

CARB's proposal helps ensure that more of the cost burden for cleaning up the diesel fleet is shifted to manufacturers, which will in turn helps reduce mal-maintenance and tampering from drivers. UCS strongly support the proposed increased of the full useful life and extended warranty. However, we are disappointed implementation is delayed until 2031 and ask ARB to reconsider implementing these requirements starting in 2027.

Support for reducing the $PM_{2.5}$ standard for all heavy-duty engines

Diesel particulate filters (DPFs) have allowed for manufacturers to reduce $PM_{2.5}$ emissions well below the current regulatory target. Furthermore, work at SwRI shows the potential for even

[30] Kerschner, B., and D. Barker. 2017. Survey and analysis of heavy-duty vehicle warranties in California (15MSC009). Prepared by the Institute for Social Research for the California Air Resources Board, December 2017. Online at *https://ww3.arb.ca.gov/regact/2018/hdwarranty18/apph.pdf*.

further reductions in PM2.5 emissions.[31] Some manufacturers may choose to reduce backpressure on the engine by reducing the size/efficiency of the DPF, particularly in response to more stringent NO_x regulations. It is imperative that as part of its proposal that CARB reduce the current engine target for $PM_{2.5}$ as well as NO_x, so that EPA does not inadvertently allow the industry to backslide, increasing the direct tailpipe emissions of $PM_{2.5}$.

<u>The vast majority of engine families today have certified test values of 0.005 g/bhp-hr or better,[32] so CARB can reduce the current $PM_{2.5}$ certification value with little impact on the industry, while limiting backsliding.</u> UCS is concerned that CARB did not adequately explore the potential for a particle count standard and does not appear to have discussed this threat as part of their rulemaking—current Euro VI standards also include a particle number limit as part of their test procedures, and the unique health ramifications of ultrafine particles in addition to the impacts that black carbon particle size has on climate suggest that there is a current need for the regulation of particle number in addition to mass.[33] However, the most important point for the $PM_{2.5}$ standard is to minimize backsliding, and there may be additional opportunities to reduce black carbon as part of a future greenhouse gas rule for 2030 and beyond.

<u>It is appropriate for CARB to adopt an equally stringent $PM_{2.5}$ standard for gasoline engines.</u> Gasoline particulate filters (GPFs) are available today and would be able to achieve the same level of reductions found today with DPFs.[34] GPFs are already being deployed in the light-duty vehicle fleet in order to comply with more stringent European regulations[35]—in the spirit of technology neutrality, and with no technological barrier, it is appropriate to set a PM standard for gasoline engines equivalent to their diesel counterparts.

Support for reducing the idle standard

Beginning in 2008, California required new trucks sold in the state to meet a "Clean Idle" standard. There are two means by which a truck can be certified to the standard, either by having an automatic shut-off that cuts the engine after five minutes of idling, or by meeting a 30 g NO_x/hr idling standard. All heavy-duty engines in 2019 and 2020 comply with the standard by meeting the 30 g/hr requirement.[36] Though this standard was implemented only in California, it

[31] "CARB staff current assessment of the technical feasibility of lower NOx standards and associated test procedures for 2022 and subsequent model year medium-duty and heavy-duty diesel engines." Prepared April 18, 2019. Online at *https://ww3.arb.ca.gov/msprog/hdlownox/white_paper_04182019a.pdf*.

[32] EPA. Heavy-duty highway gasoline and diesel certification data (Model years: 2015-present). Online at *https://www.epa.gov/sites/production/files/2020-01/heavy-duty-gas-and-diesel-engines-2015-present.xlsx*.

[33] Rodriguez, F., and F. Posada. "Future heavy-duty emission standards: An opportunity for international harmonization." White paper of the International Council on Clean Transportation (ICCT). November 2019. Online at *https://theicct.org/sites/default/files/publications/Future%20_HDV_standards_opportunity_20191125.pdf*. Matsui, H., D.S. Hamilton, and N.M. Mahowald. 2018. "Black carbon radiative effects highly sensitive to emitted particle size when resolving mixing-state diversity." *Nature Communications* 9, 3446. Online at https://www.nature.com/articles/s41467-018-05635-1.

[34] MECA, "Ultrafine particulate matter and the benefits of reducing particle numbers in the United States," July 2013. Online at *http://www.meca.org/resources/MECA_UFP_Report_0713_Final.pdf*.

[35] Giechaskiel, B., A. Joshi, L. Ntziachristos, and P. Dilara. "European regulatory framework and particulate matter emissions of gasoline light-duty vehicles: A review." *Catalysts* 9, 586 (2019). Online at *http://dx.doi.org/10.3390/catal9070586*.

[36] CARB, "Heavy-Duty Engines and Vehicles, including Urban Buses, and Engines Used in Diesel or Incomplete Medium-Duty Vehicles of 8,501-14,000 Pound GVWR Executive Orders – 2020." Online at *https://ww3.arb.ca.gov/msprog/onroad/cert/mdehdehdv/2020/2020.php*.

has driven 50-state improvements, with EPA's in-use data showing that the vast majority of diesel engines meet the 30 g/hr threshold.[37]

Because in-use data shows a higher fraction of idling than current test procedures, and because CARB's idling standard has already proven to drive idling emissions downward, CARB is appropriately proposing to reduce the idling standard to 10 g/hr in 2024 and 5 g/hr in 2027. However, even this reduced standard does not currently reflect the increased availability of stop-start and zero-emission technologies, which CARB's idle rule was initially anticipated to promote.[38] As stop-start and zero-emission technologies become more ubiquitous, we would expect CARB to continue to ratchet down idling emissions.

Conclusion

CARB staff have drafted a technically sound policy to reduce emissions from new heavy-duty trucks sold in the state. This proposal will help address air quality issues, particularly in communities of color that are disproportionately exposed to truck pollution. This proposal can be strengthened by increasing stringency to reflect the adoption of electric trucks, limiting the presumed headroom related to emissions control deterioration, and eliminating the 50-state voluntary program. UCS hopes the Board moves swiftly to adopt this critical policy, with the recommended corrections.

Sincerely,

Dave Cooke
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Union of Concerned Scientists

[37] Badshah et al. 2019, Figure 13.
[38] Chen, D. "California's heavy-duty vehicle idling regulations," Presentation to NCSL (conference call), January 28, 2008. Online at *https://www.ncsl.org/print/energy/dchenidling07.pdf*.