Attachment: Comments of the California Air Resources Board (CARB) in Response to the United States Environmental Protection Agency's (U.S. EPA) Requests for Comment on the "Advance Notice of Proposed Rulemaking (ANPRM): Control of Air Pollution from New Motor vehicles: Heavy-Duty Engine Standards," 85 Federal Register 3306 (January 21, 2020)

EPA–HQ–OAR–2019–0055

This document contains CARB staff responses to U.S. EPA requests for comment in the ANPRM. U.S. EPA's requests for comment from the ANPRM are shown below within quotes in blue in the same order they appear in the ANPRM. Relevant CARB staff responses follow each. In some instances, CARB staff's responses apply to more than one U.S. EPA request, and U.S. EPA's requests are grouped.

I. Introduction

"we will be looking to the following high-level principles to inform our approach to this rulemaking:

- Our goal should be to reduce in-use emissions under a broad range of operating conditions
- We should consider and enable effective technological solutions while carefully considering the cost impacts
- Our compliance and enforcement provisions should be fair and effective
- Our regulations should incentivize early compliance and innovation
- We should ensure a coordinated 50- state program
- We should actively engage with interested stakeholders

…We welcome comment on these principles"

CARB Comment: CARB staff is encouraged to see that one of the goals articulated in the ANPRM is to establish a coordinated 50-state program. CARB staff wholeheartedly supports that goal and encourages U.S. EPA in the Cleaner Trucks Initiative (CTI) to align with California's program toward that end. Although California's "Heavy-Duty Omnibus Low NOx Regulation" (HD Omnibus Regulation) will likely take effect ahead of the CTI with model year 2024, we encourage U.S. EPA to have the CTI take effect as early as possible, given federal lead-time constraints, preferably with the 2026 model year. To encourage manufacturers to make one set of 50-state clean vehicles, California's HD Omnibus Regulation may include compliance flexibilities to encourage manufacturers to voluntarily certify engines to harmonized state and federal standards.

We strongly encourage U.S. EPA to align with all elements of California's proposed HD Omnibus Regulation, including strict NOx standards that are about 90 percent lower than today's standards, a new low-load cycle, a revamped Heavy-duty In-use Testing

(HDIUT) program requiring broad in-use control, and longer useful life and emissions warranty provisions. As we describe further in the comments below, the research funded by U.S. EPA and CARB, as well as recent industry activities to commercialize relevant technologies, validate the technical feasibility of much lower-emitting heavy-duty trucks compared to today's new trucks. U.S. EPA aligning with California's HD Omnibus Regulation will provide a harmonized 50-state program and will provide emissions and public health benefits across the nation.

In addition to the principles articulated, CARB staff suggest U.S. EPA utilize the following principles as well in crafting the CTI:

- Achieve maximum feasible, cost-effective emission reductions in as timely a manner as possible; and
- Protect public health to the maximum extent possible.

II. Background

E. California's Heavy-Duty Highway Low NOx Program

"While we are not requesting comment on whether CARB should adopt these updates, we are requesting comment on the extent to which EPA should adopt similar provisions, and whether similar EPA requirements should reflect different stringency or timing."

CARB Comment: As summarized in the ANPRM, in the early 2010's, CARB embarked on a process of data gathering and planning to develop strategies that would significantly reduce oxides of nitrogen emissions (NOx) from on-road heavy-duty vehicles that operate in California. CARB kicked off the Low NOx Demonstration Program with Southwest Research Institute (SwRI) as the contractor[1] on October 16, 2013, with the goal of evaluating the feasibility of a 0.02 gram per brake horsepower hour (g/bhp-hr) tailpipe NOx standard on modern heavy-duty engines, representing a reduction of 90 percent below current levels. In October 2015, CARB published its technology and fuel assessments reports[2] for lower NOx heavy-duty diesel[3] and alternative fueled engines[4], which evaluated the current status and projected development over the next 5 to 10 years of technologies aimed at lowering NOx from heavy-duty diesel and alternative fueled engines. Subsequently, in May 2016, CARB

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[1] (Southwest Research Institute, 2017) "Evaluating Technologies and Methods to Lower Nitrogen Oxide Emissions from Heavy Duty Vehicles Final Report," Southwest Research Institute, April 2017. https://www.arb.ca.gov/research/apr/past/13-312.pdf

[2] (CARB, 2020) Technology and Fuels Assessment Reports, California Air Resources Board, Accessed February 19, 2020. https://ww2.arb.ca.gov/resources/documents/technology-and-fuels-assessments

[3] (CARB, 2015) "Draft Technology Assessment: Lower NOx Heavy-Duty Diesel Engines," California Air Resources Board, September 29, 2015. https://www.arb.ca.gov/msprog/tech/techreport/diesel_tech_report.pdf

[4] (CARB, 2015) "Draft Technology Assessment: Low Emission Natural Gas and Other Alternative Fuel Heavy-Duty Engines," California Air Resources Board, September 29, 2015. https://www.arb.ca.gov/msprog/tech/techreport/ng_tech_report.pdf

released the Mobile Source Strategy,[5] which laid out strategies to reduce emissions from mobile sources to meet air quality and climate goals.

Two of the measures included in the Mobile Source Strategy are a lower NOx heavy-duty engine standard that would reduce NOx emissions by approximately 90 percent below current levels and a lower in-use emission performance level to ensure heavy-duty vehicles continue to operate at their cleanest possible level in-use throughout their service life. The development of CARB staff's proposed HD Omnibus Regulation is currently in progress and is intended to implement these two measures.

Specifically, CARB staff expects the proposed HD Omnibus Regulation include:

- Significantly lower NOx emissions standards on existing certification cycles such as the Federal Test Procedure (FTP), the Supplemental Emission Test Ramped Modal Cycle (RMC), and idling test procedures,
- New NOx emissions standard on a new low load certification cycle (LLC) designed to control emissions that occur during cold start warm-up, idling, low load driving, and transient operations.
- Strengthened heavy-duty in-use testing procedures including revised in-use data analysis techniques and test procedures so that emissions over a broader range of the vehicle's operation are covered,
- Lengthened useful life and warranty periods to reflect the actual service lives of heavy-duty vehicles,
- Revised durability demonstration procedures to improve engine-aftertreatment system durability and reduce deterioration, and
- Revised warranty corrective action provisions.

To develop data driven requirements, CARB staff has been gathering data and funding research programs to demonstrate the technical feasibility and cost-effectiveness of the proposed requirements in the HD Omnibus Regulation. Specifically, CARB in partnership with the Manufacturers of Emission Controls Association (MECA), U.S. EPA, South Coast Air Quality Management District (SCAQMD), the Clean High Efficiency Diesel Engine VII Consortium (CHEDE VII managed by SwRI) with support from Volvo and Cummins, has funded over $5 million worth of research contracts with SwRI to demonstrate the feasibility of lower NOx emissions standards. The research contracts consisted of three phases referred to as SwRI Stages 1,[6] 1b, 2,[7] 3, and 3b Low NOx programs. Stages 1, 1b, and 2 have been completed and Stages 3 and 3b

[5] (CARB, 2016) "Mobile Source Strategy," California Air Resources Board, May 16, 2016. https://ww3.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf

[6] (SwRI, 2017) "Evaluating Technologies and Methods to Lower Nitrogen Oxide Emissions from Heavy Duty Vehicles Final Report," Southwest Research Institute, April 2017. https://www.arb.ca.gov/research/apr/past/13-312.pdf

[7] SwRI Stages 1b and 2 Low NOx programs have been completed and the final report will become available at: https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox

are currently nearing completion. Furthermore, staff also analyzed current NOx and CO2 certification data of modern engines to evaluate the level at which these engines are currently certified. CARB staff are also following the advanced technology demonstrations supported by California Climate Investments including advanced engine configurations, intelligent transportation systems level opportunities, and zero emission truck deployment.[8] To assess costs of emission control technologies, CARB has contracted with the National Renewable Energy Laboratory (NREL) to perform a cost analysis for emission control technologies and evaluated the cost analysis in the International Council of Clean Transportation's (ICCT) white paper[9] as well.

On April 18, 2019, CARB staff released a White Paper[10] that outlined staff's assessment regarding technical feasibility and cost-effectiveness of possible NOx reduction programs for 2022 and subsequent model year medium-duty diesel and heavy-duty diesel engines. The White Paper addressed feasibility assessments of the minor changes to the in-use testing program for 2022-2023 model year engines, NOx and PM emissions standards over the FTP, RMC-SET, idling, and a new LLC for 2024-2026 model year engines, and the introduction of a moving average window (MAW) technique for analysis of in-use testing data for 2024-2026 model year engines. Based on technical data collected so far, CARB staff expects to propose lower NOx standards for heavy-duty engines that would take effect in two steps: first for model years 2024-2026, and then a more stringent standard for 2027 and later model year engines, lengthening the warranty and useful life period for 2027 and later model year engines; a 3-bin moving MAW method for in-use testing data analysis, and revamped durability demonstration procedures beginning with the 2024 model year engines.

The first step of the standards for 2024 through 2026 model year engines are based on analysis of engine calibration and SCR aftertreatment strategies that provide exhaust thermal heat during cold start and low load operations without significantly changing the engine and aftertreatment architectures. MECA analysis shows the NOx reduction potential for best available catalyst coatings in the currently marketed aftertreatment

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[8] (CARB, 2020) Advanced Technology Demonstration Projects, California Air Resources Board, Accessed February 17, 2020. https://ww2.arb.ca.gov/our-work/programs/low-carbon-transportation-investments-and-air-quality-improvement-program-0

[9] (Posada et al., 2016) "White Paper: Costs of Emission Reduction Technologies for Heavy Duty Diesel Vehicles," F. Posada, S. Chambliss, and K. Blumberg, ICCT, February 2016. https://theicct.org/sites/default/files/publications/ICCT_costs-emission-reduction-tech-HDV_20160229.pdf

[10] (CARB, 2019) "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," California Air Resources Board, April 18, 2019. https://www.arb.ca.gov/msprog/hdlownox/white_paper_04182019a.pdf

configurations.[11] In addition, Cummins has been investigating a practical close coupled turbobypass/DEF doser/SCR catalyst unit for low load compliance (Cummins 2018).[12] Also, both Deutz (Deutz, 2020)[13] and Volkswagen have commercialized dual dosing SCR approaches in the heavy duty off road and light duty diesel sectors (VW 2020).[14]

Although CARB staff analysis is primarily based on an incremental aftertreatment-focused strategy, public discussion from industry and suppliers have pointed out two potential nontraditional aftertreatment configuration pathways for 2024 and subsequent model years as well. One such group of approaches emphasizes engine air handling (including cylinder deactivation (CDA), other variable valvetrain actuation techniques (VVA) and opposed piston engines) approaches, and the other group emphasizing mild hybridization with electric exhaust heating. Each of these, in addition to reducing NOx, also provides auxiliary user benefits of increased efficiency and, for the mild hybrids, increased electric power availability for many vehicle uses.

The proposed 2027 and subsequent model year standards would require engine technologies that provide both NOx and CO2 reductions such as the aforementioned air handling techniques, and the close coupling of light-off catalysts in split SCR systems with dual dosing.

The proposed concepts have been shared and discussed extensively with stakeholders through workgroup meetings, public workshops, and dozens of individual meetings and presentations.[15] Staff is preparing to bring a proposal to the Board for a comprehensive well-integrated HD Omnibus Regulation incorporating all the aforementioned elements later in 2020. Staff has recently completed the Standard Regulatory Impact Analysis (SRIA)[16] for the proposed HD Omnibus Regulation, which is an economic assessment

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[11] (MECA, 2019) "Technology Feasibility for Model Year 2024 Heavy-Duty Diesel Vehicles in Meeting Lower NOx Standards," Manufacturers of Emission Controls Association, June 2019. http://www.meca.org/resources/MECA_MY_2024_HD_Low_NOx_Report_061019.pdf

[12] (Cummins, 2018) Cummins Unveils the Future of Diesel with Low NOx and Low CO2 Emissions Technology During IAA Commercial Vehicles Show, Cummins, Sept. 19, 2018. https://www.cummins.com/news/releases/2018/09/19/cummins-unveils-future-diesel-low-nox-and-low-co2-emissions-technology

[13] (Deutz, 2020) TCD12.0/16.0, Deutz, Accessed February 19, 2020. https://dieselengines.centraldieselinc.com/Asset/Deutz-12-0-16-0-Series-T4F.PDF

[14] (VW, 2020) Twin dosing reduces emissions, Volkswagen, Jan 31, 2020. https://www.volkswagen-newsroom.com/en/stories/twin-dosing-reduces-emissions-5750

[15] CARB staff workshop presentations on proposed concepts can be accessed at: https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox/heavy-duty-low-nox-meetings-workshops

[16] (CARB, 2019) "Proposed Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments: Standard Regulatory Impact Assessment (SRIA)," California Air Resources Board, August 8, 2019. http://www.dof.ca.gov/Forecasting/Economics/Major_Regulations/Major_Regulations_Table/documents/CARB%20SRIA%20Heavy%20Duty%20Engine%20Standards.pdf

of the regulatory proposal. We anticipate staff's proposal will be released via an Initial Statement of Reasons in April 2020.

Recommendations: We encourage U.S. EPA to align its proposed CTI provisions with CARB's proposed HD Omnibus Regulation, to the greatest extent possible. We encourage U.S. EPA staff to consult the demonstration work and ongoing commercialization cited above to justify technical feasibility and other sources mentioned above to help estimate costs. California's air quality is heavily impacted by emissions from federally certified heavy-duty vehicles sold outside of California and as such federal requirements that are as stringent as California's are critical to help California meet its air quality attainment goals. Nationally harmonized requirements would also reduce the cost of compliance to the industry and improve the cost-effectiveness of U.S. EPA's CTI. CARB staff recognizes that because of statutory lead time issues U.S. EPA may not be able to implement the proposed requirements as early as California's program timeline which begins with the 2024 model year. However, CARB encourages U.S. EPA to recognize the significant engineering and commercialization investment being made to comply with California 2024 to 2026 standards that will be available for U.S. EPA to leverage in their initial program implementation in 2026. Overall, CARB staff believes that there is enough lead time for technology development from now until 2025 and encourages U.S EPA to start implementation of the proposed requirements early in 2026 rather than in 2027.

III. Potential Solutions and Program Elements

"Although our focus in this rulemaking is primarily on future model years, we also seek comment on the extent to which the technologies and solutions could be used by state, local, or tribal governments in reducing emissions from the existing, pre-CTI heavy-duty fleet."

CARB Comment: For the years when California's heavy-duty emission standards are stricter than U.S. EPA's, which appears to be likely at least for model years 2024 to 2025, we encourage U.S. EPA to provide incentivizes such as credits for manufacturers to certify nationally to the California standards. We also encourage other states to opt into the California standards as allowed by Section 177 of the Clean Air Act and to fund accelerated turnover to trucks meeting the stricter California standards.

CARB recommends U.S. EPA recognize the substantial efforts of federal, state and local entities to promote the roll out of zero and near-zero emission technologies including the incentive programs described above. CARB recommends U.S. EPA structure their CTI to encourage additional rollout and fleet penetration of these technologies beyond the volumes already mandated or that are already funded by state and local and federal agency actions.

In California, CARB manages a broad portfolio of heavy-duty incentives to help reduce emissions from a range of sources. There are three main ways that incentives help to meet our emission reductions goals: they help to increase the volume of lower emission vehicles and equipment in the overall fleet; they help to advance the technologies for both zero- and near zero-emission vehicles and equipment; and they are targeted for some of the most impacted areas of the State with priority given to incentive funding in low-income and disadvantaged communities. CARB's incentive programs include traditional scrap and replace programs; incentives to fund the incremental cost differential between standard and advanced technology engines; demonstration and pilot projects that help advance the state of zero-and near zero-emission vehicles and equipment; and loan programs that help fleets comply with current regulations. All of CARB's programs are available to state, local, and tribal governments throughout California. Currently, California offers incentive funding to purchase engines certified to our optional 0.02 g/bhp-hr NOx standard. To date, CARB alone has awarded approximately 2,400 vouchers totaling $65 million for optional NOx engines through Clean Truck and Bus Vouchers under California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP).

A. Emission Control Technologies

"We request comment on each of the technologies discussed. Commenters are encouraged to address all aspects of these technologies including: Costs, emission reduction effectiveness, impact on fuel consumption/CO2 emissions, market acceptance factors, reliability, and the feasibility of the technology being available for widespread adoption in the 2027 and later timeframe. We also welcome comments on other technologies not discussed here. Finally, to the extent emission reductions will be limited by the manufacturers' engineering resources, we encourage commenters to address how we should prioritize or phase-in different requirements."

1. Diesel Engine Technologies Under Consideration

"We welcome comment including any available data on the cost, effectiveness, and limitations of the SCR and other emission control systems considered. We also request comment, including any available data, regarding the technical feasibility and cost of commercializing emerging technologies expected to enter the heavy-duty market by model year 2027."

"We welcome comment on the current adoption of passive thermal management strategies, including any available data on the cost, effectiveness, and limitations."

"We welcome comment on active thermal management strategies, including any available data on the cost, effectiveness, and limitations, as well as information about its projected use for the 2024 to 2030 timeframe."

"We welcome comment on CDA and LIVC strategies for NOx reduction, including any available data on the cost, effectiveness, and technology limitations."

"We request comment on the extent to which advanced catalyst formulations can be used to lower emissions further, and whether they would have any potential impact on CO2 emissions."

"We request comment, including any available data, on the appropriateness and costs of requiring closed crankcases for all heavy-duty compression-ignited engines."

CARB Comment: As mentioned above, CARB has been evaluating strategies and technologies that significantly reduce NOx emissions from heavy-duty vehicles without or with minimal CO2 impacts. In SwRI Stages 1[17] and 1b, SwRI evaluated advanced aftertreatment technologies such as NOx adsorbers (PNA) and SCR coated-on filters (SCRF) and demonstrated reductions of approximately 90 percent below current NOx standards on two engines: a diesel-fueled 13-liter Volvo turbocompound engine and a natural gas-fueled 11.9-liter Cummins engine. Furthermore, in 2015, CARB conducted and released an extensive review of technology and fuels in several technology assessment reports[18] that assessed the current state of technology and expected near-term advances for low NOx strategies for heavy-duty diesel and natural gas engines, as well as heavy-duty hybrid, fuel cell and battery electric trucks and buses. Moreover, since then, a number of new strategies and technologies have been identified that provide improved exhaust thermal management and significantly reduce NOx emissions without CO2 penalties.

Some of these low NOx strategies are currently being evaluated and demonstrated in Stage 3 and 3b of the SwRI program, which include evaluation of engine technologies such as cylinder deactivation, EGR cooler bypass, and turbocharger bypass, as well as aftertreatment technologies such as insulated exhaust systems and advanced twin SCR systems with dual dosing. With model-based Diesel Exhaust Fluid (DEF) dosing, exhaust insulation, a hydrothermally aged twin SCR system with a close-coupled light-off catalyst, a zone coated catalyzed soot filter and cylinder deactivation, SwRI demonstrated significant NOx emission reductions down to approximately 0.019 g/bhp-hr on the FTP and 0.036 g/bhp-hr on the LLC[19]. For further information regarding

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[17] (SwRI, 2017) "Evaluating Technologies and Methods to Lower Nitrogen Oxide Emissions from Heavy Duty Vehicles Final Report," Southwest Research Institute, April 2017. https://www.arb.ca.gov/research/apr/past/13-312.pdf

[18] (CARB, 2020) Technology and Fuels Assessment Reports, California Air Resources Board, Accessed February 19, 2020. https://ww2.arb.ca.gov/resources/documents/technology-and-fuels-assessments

[19] (CARB, 2019) "Workshop presentation: Heavy-Duty Low NOx Program - Proposed Heavy-Duty Engine Standards," California Air Resources Board, September 26, 2019 https://ww3.arb.ca.gov/msprog/hdlownox/files/workgroup_20190926/staff/01_hde_standards.pdf

technologies such as SCR, improved thermal management, cylinder deactivation and advanced catalysts, CARB staff recommends U.S. EPA staff consult SwRI's reports on the Stage 1 and 1b work[12] and the reports on the Stage 2, Stage 3, and Stage 3b work once they are available later in 2020. CARB is also sponsoring[20] demonstration of a promising advanced engine architecture, the Achates multi-cylinder opposed-piston engine, which is aimed at achieving low NOx performance[21] at lower GHG[22] with engine dynamometer testing and vehicle integrated testing. This architecture has control of exhaust flows and temperatures that can potentially enable smaller catalyst sizes.[23]

CARB staff encourages U.S. EPA to consider the substantial work in the literature from OEMs, suppliers and researchers examining the range of Low NOx technologies for reducing NOx by about 90 percent from today's levels, as well as related light-duty and off-road diesel studies. Overviews of GHG and NOx issues and approaches include those contributed by Cummins[24], AVL[25], TNO[26], FEV[27,28], IAV[29], and Michigan

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[20] (California Climate Investments, 2020) "Opposed Piston Engine Class 8 Heavy-Duty On-Road Demonstration," California Climate Investments, Accessed February 19, 2020. https://ww3.arb.ca.gov/msprog/lct/pdfs/opposedpiston.pdf

[21] (Patil et al., 2018) "Cold Start HD FTP Test Results on Multi-Cylinder Opposed-Piston Engine Demonstrating Rapid Exhaust Enthalpy Rise to Achieve Ultra Low NOx," Patil, S., Ghazi, A., Redon, F., Sharp, C. et al., SAE Technical Paper 2018-01-1378, April 3, 2018. https://doi.org/10.4271/2018-01-1378

[22] (Abani et al., 2016) "Developing a 55+ BTE Commercial Heavy-Duty Opposed-Piston Engine without a Waste Heat Recovery System", Dr. Neerav Abani, Michael Chiang, Isaac Thomas, Nishit Nagar, Rodrigo Zermeno, 11th International MTZ Conference, 2016 Heavy-Duty, On- and Off-Highway Engines. November 22-23, 2016 Ulm, Germany.

[23] (Patil et al., 2019) "Cold-Start WHTC and WHSC Testing Results on Multi-Cylinder Opposed-Piston Engine Demonstrating Low CO2 Emissions while Meeting BS-VI Emissions and Enabling Aftertreatment Downsizing," Patil, S., Sahasrabudhe, A., Youngren, D., Redon, F. et al., SAE Technical Paper 2019-26-0029, January 9, 2019, https://doi.org/10.4271/2019-26-0029

[24] (Eckerle et al., 2017) "Future Challenges for Engine Manufacturers in View of Future Emissions Legislation," Eckerle, W., Sujan, V., and Salemme, G., SAE Technical Paper 2017-01-1923, May 10, 2017. https://doi.org/10.4271/2017-01-1923

[25] (Walter et al., 2017) "Impact of GHG-Phase II and Ultra Low NOx on the Base Powertrain," Walter, L., Toth, A., Hasenbichler, G., Theissl, H. et al., SAE Technical Paper 2017-01-1925, May 10, 2017, https://doi.org/10.4271/2017-01-1925

[26] (Seykens et al., 2018) "Towards Ultra-Low NOx Emissions within GHG Phase 2 Constraints: Main Challenges and Technology Directions," Seykens, X., Kupper, F., Mentink, P., and Ramesh, S., SAE Technical Paper 2018-01-0331, April 3, 2018, https://doi.org/10.4271/2018-01-0331

[27] (Dahodwala et al., 2018) "Strategies for Meeting Phase 2 GHG and Ultra-Low NOx Emission Standards for Heavy-Duty Diesel Engines," Dahodwala, M., Joshi, S., Koehler, E., Franke, M. et al., SAE Int. J. Engines 11(6):1109-1122, April 3, 2018, https://doi.org/10.4271/2018-01-1429

[28] (Deppenkemper et al., 2019) "Super Ultra-Low NOX Emissions under Extended RDE Conditions - Evaluation of Light-Off Strategies of Advanced Diesel Exhaust Aftertreatment Systems," Deppenkemper, K., Ehrly Ing, M., Schoenen, M., and Koetter, M., SAE Technical Paper 2019-01-0742, April 2, 2019, https://doi.org/10.4271/2019-01-0742

[29] (Rauch et al., 2018) "Holistic Development of Future Low NOx Emission Concepts for Heavy-Duty Applications," Rauch, H., Rezaei, R., Weber, M., Kovacs, D. et al., SAE Technical Paper 2018-01-1700, September 10, 2018, https://doi.org/10.4271/2018-01-1700

Technological University[30]. More individual technology oriented reports include various methods of introducing externally supplied exhaust heat using electric heat[31,32] and fuel[33], cylinder deactivation practical considerations[34,35,36,37,38,39,40,41], close coupling

[30] (Chundru et al., 2020) "A Modeling Study of an Advanced Ultra-low NOx Aftertreatment System," Chundru, V., Johnson, J., and Parker, G., SAE Int. J. Fuels Lubr. 13(1):2020, January 9, 2020. https://doi.org/10.4271/04-13-01-0003.

[31] (Continental, 2015) "Continental Electrically Heated Catalyst Supports Low-CO2 48 Volt Hybrid Strategies," Continental, September 10, 2015. https://www.continental.com/en/press/press-releases/2015-08-20-volt-e-kat-102146

[32] (Culbertson et al., 2018) "Exhaust Heating System Performance for Boosting SCR Low Temperature Efficiency," Culbertson, D., Khair, M., Zha, Y., and Diestelmeier, J., SAE Technical Paper 2018-01-1428, April 3, 2018. https://doi.org/10.4271/2018-01-1428

[33] (Harris et al., 2019) "Modeling of Aftertreatment Technologies to Meet a Future HD Low-NOx Standard," Harris, T. and Gardner, T., SAE Technical Paper 2019-01-0043, January 15, 2019. https://doi.org/10.4271/2019-01-0043

[34] (Lu et al., 2015) "Impact of cylinder deactivation on active diesel particulate filter regeneration at highway cruise conditions," Lu X., Ding C., Ramesh A. K., Shaver G. M., Holloway E., McCarthy J. Jr., Ruth M, Koeberlein E and Nielsen D Frontiers in Mechanical Engineering, August 24, 2015 https://doi.org/10.3389/fmech.2015.00009

[35] (Neely et al., 2019) "Simultaneous NOX and CO2 Reduction for Meeting Future CARB Standards Using a Heavy-Duty Diesel CDA-NVH Strategy," Neely, G., Sharp, C., Pieczko, M., and McCarthy, J., SAE Int. J. Engines 13(2):2020. December 10, 2019.

[36] (Archer et al., 2018) "Quantification of Diesel Engine Vibration Using Cylinder Deactivation for Exhaust Temperature Management and Recipe for Implementation in Commercial Vehicles," Archer, A. and McCarthy Jr, J., SAE Technical Paper 2018-01-1284, April 3, 2018. https://doi.org/10.4271/2018-01-1284

[37] (Gosala et al., 2017) "Cylinder deactivation during dynamic diesel engine operation," Gosala, D., Allen, C., Ramesh, A., Shaver, G., McCarthy, J., Stretch, D., Koeberlein, E., Farrell, L., International Journal of Engine Research, February 1, 2017. https://doi.org/10.1177/1468087417694000

[38] (Ramesh et al., 2017) "Utilizing low airflow strategies, including cylinder deactivation, to improve fuel efficiency and aftertreatment thermal management," Ramesh, A. K., Shaver, G. M., Allen, C. M., Nayyar, S., Gosala, D. B., Caicedo Parra, D., Nielsen, D., International Journal of Engine Research, 18(10), 1005–1016, March 14, 2017. https://doi.org/10.1177/1468087417695897

[39] (Vos et al., 2019) "Impact of Cylinder Deactivation and Cylinder Cutout via Flexible Valve Actuation on Fuel Efficient Aftertreatment Thermal Management at Curb Idle," Vos K. R., Shaver G. M., Ramesh A. K., and McCarthy J. Jr., Frontiers in Mechanical Engineering 5:52, August 21, 2019. https://doi.org/10.3389/fmech.2019.00052

[40] (Halbe et al., 2017) "Oil Accumulation and First Fire Readiness Analysis of Cylinder Deactivation," Halbe M., Pietrzak B., Fain D., Ramesh A., Shaver G., McCarthy J. E. Jr., Ruth M. and Koeberlein E., Frontiers in Mechanical Engineering 3:1, March 6, 2017. https://doi.org/10.3389/fmech.2017.00001

[41] (Gehm, R., 2018) "Jacobs employs cylinder deactivation in HD engines to lower CO2, Nox," Ryan Gehm, SAE, September 24,2018. https://www.sae.org/news/2018/09/jacobs-cylinder-deactivation-heavy-duty-engines

locations for split SCR systems with dual dosing[42], and catalyst shapes for tight packaging[43], low exhaust temperature DEF dosing[44,45,46,47].

MECA has also published two white papers that describe the technical feasibility of CARB staff's proposed low NOx standards for 2024 to 2026 and 2027 and later model year engines. For the proposed 2024 to 2026 model year engines standards, MECA in its White Paper[11] identifies technologies that retain exhaust heat over a long period of time such as air gap or ceramic filter insulated double-walled exhaust pipes and canning/packaging of SCR systems in a one-box system. The second White Paper[48] deals with the technical feasibility of CARB staff's proposed 2027 model year engine standards and associated costs with and without extended warranty and useful life periods. Technologies identified in this paper include engine hardware technologies such as cylinder deactivation, advanced turbocharger, 48-volt mild hybrid systems, and advanced aftertreatment catalyst substrates and architectures.

As noted above, CARB has contracted with NREL to estimate costs associated with the HD Omnibus Regulation technologies. NREL's preliminary cost estimates are referenced in CARB's Standardized Regulatory Impact Analysis (SRIA) for the HD Omnibus Regulation, which is available on the California Department of Finance's

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[42] (Harris et al., 2019) "Modeling of Close-Coupled SCR Concepts to Meet Future Cold Start Requirements for Heavy-Duty Engines," Harris, T.M., Mc Pherson, K., Rezaei, R., Kovacs, D. et al., SAE Technical Paper 2019-01-0984, April 2, 2019, https://doi.org/10.4271/2019-01-0984

[43] (Continental, 2019) "Clean and Cost-Effective Exhaust Aftertreatment for Construction Machinery of the Future," Continental, OEM Off-Highway, March 20, 2019. https://www.oemoffhighway.com/engines/filtration/emissions-control-exhaust-systems/press-release/21060606/continental-clean-and-costeffective-exhaust-aftertreatment-for-construction-machinery-of-the-future

[44] (Wilson & Hargrave, 2018) "Analysis of a Novel Method for Low-Temperature Ammonia Production Using DEF for Mobile Selective Catalytic Reduction Systems," Wilson, J. G. and Hargrave, G., SAE Technical Paper 2018-01-0333, April 3, 2018, https://doi.org/10.4271/2018-01-0333

[45] (Larsson et al, 2019) "NOx-Conversion Comparison of a SCR-Catalyst Using a Novel Biomimetic Effervescent Injector on a Heavy-Duty Engine," Larsson, P., Ravenhill, P., and Tunestal, P., SAE Int. J. Advances & Curr. Prac. in Mobility 1(1):278-283, January 15, 2019. https://doi.org/10.4271/2019-01-0047

[46] (Okada et al., 2019) "Study on Improvement of NOx Reduction Performance at Low Temperature Using Urea Reforming Technology in Urea SCR System," Okada, Y., Hirabayashi, H., Sato, S., and Inoue, H., SAE Technical Paper 2019-01-0317, April 2, 2019. https://doi.org/10.4271/2019-01-0317

[47] (Continental Automotive, 2020) Universal Decomposition Pipe, Continental Automotive, Accessed February 19, 2020. https://continental-automotive.com/en-gl/Passenger-Cars/Products-and-Solutions/Powertrain/Combustion-Technologies/Combustion-Technologies-for-Agriculture/Exhaust-Management-After-treatment/Catalysts/Universal-Decomposition-Pipe

[48] (MECA, 2020) "Technology Feasibility for Model Year 2027 Heavy-Duty Diesel Vehicles in Meeting Lower NOx Standards," Manufacturers of Emission Controls Association, February 2020. http://www.meca.org/resources/MECA_2027_Low_NOx_White_Paper_FINAL.pdf

website.[49] For cost information, CARB staff recommends U.S. EPA staff consult NREL's final report once it is available later in spring 2020. In addition, CARB staff recommends U.S. EPA consult ICCT's white paper[50] costs of emission reduction technologies for heavy-duty diesel vehicles, as well as MECA's February 2020 white paper.[48]

As noted in the ANPRM, a number of manufacturers are currently certifying heavy-duty engines with closed crankcase ventilation indicating that manufacturers have developed systems that route the blowby gases to the engine without negatively impacting the turbocharger. CARB staff supports U.S. EPA considering requiring closed crankcase ventilation for all compression-ignition heavy-duty engines to prevent blowby emissions from being vented to the directly to the atmosphere.

The ANPRM lists all of the above technologies (and others) that have been demonstrated to not only provide significant NOx emissions reductions, but also have little or no impact on fuel economy and greenhouse gas (GHG) emissions. Some technologies such as cylinder deactivation even improve fuel economy. CARB staff recommends that U.S. EPA evaluate technologies that provide maximum technically feasible and cost-effective emissions reductions in establishing the stringency of the CTI program.

i. Fuel quality –

> "EPA requests comment on concerns regarding metal and water contamination in highway diesel fuel and on the potential role of biodiesel in this contamination. EPA seeks data on the levels of these contaminants in fuels, including the prevalence of contamination, and on the associated degradation and failure of engines and aftertreatment function."

CARB staff has evaluated sulfur and metals levels in today's fuel supply for diesel engines versus the needs of the aftertreatment that staff projects to meet the new engine standards expected in the HD Omnibus Regulation.

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[49] (CARB, 2020) "Proposed Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments: Proposed Amendments to the Exhaust Emissions Standards and Test Procedures for 2024 and Subsequent Model Year Heavy-Duty Engines and Vehicles, Heavy-Duty In-Use Testing Program, Emissions Warranty Period and Useful Life Requirements, Emissions Warranty Information and Reporting Requirements, In-Use NOx Emissions Data Reporting Requirements, and Phase 2 Heavy-Duty Greenhouse Gas Regulations and Powertrain Test Procedures - Standardized Regulatory Impact Assessment (SRIA)," California Air Resources Board, Accessed February 19, 2020. http://www.dof.ca.gov/Forecasting/Economics/Major_Regulations/Major_Regulations_Table/documents/CARB%20SRIA%20Heavy%20Duty%20Engine%20Standards.pdf

[50] (Posada et al., 2016) "White Paper: Costs of Emission Reduction Technologies for Heavy Duty Diesel Vehicles," F. Posada, S. Chambliss, and K. Blumberg, ICCT, February 2016. https://theicct.org/sites/default/files/publications/ICCT_costs-emission-reduction-techHDV_20160229.pdf

To better understand sulfur content and variability in the California fuel supply for diesel engines, CARB-collected over 400 fuel samples from California producers, importers and distribution terminals during 2017 to 2019 calendar years. These samples included diesel and some biodiesel and renewable diesel blends with maximum sulfur content observed of 13 parts per million (ppm) and an average sulfur content 4 ppm with a standard deviation of 3 ppm (without any applied corrections for volumes represented or market share of producers.) Appendix A to this Attachment includes a summary of a the 2017 to 2019 California sampling campaign for sulfur content in diesel fuel. Based on the system performance in demonstrations funded by CARB and data on current fuel sulfur levels, CARB staff have concluded that sulfur levels in current ULSD are adequate, and changes to the sulfur standards are likely not needed.

For metals, an OEM has raised concern regarding risks from lifetime exposures to trace metals, particularly sodium, potassium, magnesium and calcium (Na, K, Mg, and Ca) in biodiesel. The four (4) California-sourced fuel samples in the OEM's dataset contained both biodiesel as well as levels of metals that if attributed solely to a B100 blend stock, would be sufficient to put such a blend stock at or beyond the ASTM specification limits.[51]

Staff believes the metals levels the OEM has reported may have large associated analytical uncertainties inconsistent with the OEM's own demonstrated analytical capabilities [52] and the fuel sampling protocol may not be representative of the general fuel pool. In response to the OEM concerns, CARB staff arranged for the collection and analysis of 437 diesel and biodiesel blend samples collected at the retail pump across California in 2019. Appendix B to this Attachment summarizes the findings of the 2019 California sampling campaign. As discussed in detail in Appendix B, the phosphorus and metal contents of biodiesel were significantly lower than current ASTM limits, and overall, staff does not expect the impact of biodiesel metals and phosphorus on the full useful life durability of diesel exhaust aftertreatment systems to be in excess of expectations based on current fuel specifications. As U.S. EPA staff is aware, CARB staff also arranged for analysis of 27 EPA collected B100 samples collected from biodiesel production facilities nationally and again did not identify metals contamination problems to corroborate the OEM claims. This finding is generally consistent with trends

[51] (Recker, 2019) "Fuel Contaminants, Effects on Aftertreatment, and Their Limits on NOx Stringency and Extended Useful Life," Alissa Recker, Presentation at University of Wisconsin, Engine Research Center 2019 Symposium, June 6, 2019. https://erc.wisc.edu/publications/Fuel-Contaminants-Effects-on-Aftertreatment-and-Their-Limits-on-Nox-Stringency-and-Extended-Useful-life/

[52] (Trick et al., 2016) "Determination of Trace Sodium in Diesel and Biodiesel Fuel," Joachim Trick, Cornelia Wanner, Detlef Jensen, and Holger Kurth, Thermo Scientific, 2016. http://tools.thermofisher.com/content/sfs/brochures/CAN-118-IC-Trace-Sodium-Diesel-Biodiesel-Fuel-AN71197-EN.pdf

seen in national biodiesel fuel surveys conducted by NREL[53,54,55, 56,57,58,59, 60] as well as the performance seen in survey history from the European biodiesel market[61, 62].

A number of studies have looked at today's 0.2 g/bhp-hr NOx engines performance and fuel metal exposure, including studies run to full useful life on fuels at the metals limit. As noted above, many fuel surveys indicate typical metal concentrations are much less than the recommended limit. Deutz points out that they do not find metals accumulating in their SCRs at the full rate one would calculate from the maximum allowable biodiesel limit concentrations and also indicate that biodiesel derived metal exposures could be comparable or less than engine lubricant derived metal sources[63].

Studies at NREL have examined emissions control performance and other parameters after a Full Useful Life worth of metal exposure equivalent to continuous fueling with

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[53](McCormick et al., 2005) "Survey of the Quality and Stability of Biodiesel and Biodiesel Blends in the United States in 2004," R.L. McCormick, T.L. Alleman, M. Ratcliff, L. Moens and R. Lawrence, Technical Report NREL/TP-540-38836, National Renewable Energy Laboratory, October 2005. https://www.nrel.gov/docs/fy06osti/38836.pdf

[54] (Alleman et al., 2007) "2006 B100 Quality Survey Results Milestone Report," T.L. Alleman, R.L. McCormick, and S. Deutch, Milestone Report NREL/TP-540-41549, National Renewable Energy Laboratory, May 2007. https://www.nrel.gov/docs/fy07osti/41549.pdf

[55] (Alleman et al., 2008) "Results of the 2007 B100 Quality Survey," T. L. Alleman and R. L. McCormick, Technical Report NREL/TP-540-42787, National Renewable Energy Laboratory, March 2008. https://www.nrel.gov/docs/fy08osti/42787.pdf

[56] (Barnitt et al., 2008) "St. Louis Metro Biodiesel (B20) Transit Bus Evaluation," R. Barnitt, R.L. McCormick, and M. Lammert, Technical Report NREL/TP-540-43486, National Renewable Energy Laboratory, July 2008. https://www.nrel.gov/docs/fy08osti/43486.pdf

[57] (Alleman et al., 2010) "Analysis of Biodiesel Blend Samples Collected in the United States in 2008," T.L. Alleman, L. Fouts, and R.L. McCormick, Technical Report NREL/TP-540-46592, National Renewable Energy Laboratory, Revised December 2010. https://www.nrel.gov/docs/fy11osti/46592.pdf

[58] (Alleman et al., 2013) "Quality Parameters and Chemical Analysis for Biodiesel Produced in the United States in 2011," Teresa L. Alleman, Lisa Fouts, and Gina Chupka, Technical Report NREL/TP-5400-57662, National Renewable Energy Laboratory, March 2013. https://www.nrel.gov/docs/fy13osti/57662.pdf

[59] (Alleman et al., 2019) "Metals Analysis of Biodiesel Blends," Teresa L. Alleman, Lisa Fouts, and Earl D. Christensen, Technical Report NREL/TP-5400-72341, National Renewable Energy Laboratory, May 2019. https://www.nrel.gov/docs/fy19osti/72341.pdf.

[60] (Lopes et al., 2013) "Review of 2013 U.S. Retail Biodiesel Blends Quality Survey," Shailesh Martin Lopes, Pat Geng, and Anke Konzack, SAE paper 2014-01-1379, April 1, 2014. http://papers.sae.org/2014-01-1379

[61] (EBB, 2020) "EBB European Biodiesel Quality Report (EBBQR)" European Biodiesel Board, Accessed February 19, 2020. https://www.ebb-eu.org/EBBQR.php

[62] (AGQM, 2020) Biodiesel Quality Reports in Germany, AGQM - The Association Quality Management Biodiesel e.V., Accessed February 19, 2020. https://www.agqm-biodiesel.com/en/downloads/reports

[63] (TW, 2011) "A short study to assess the metal, phosphorus and sulfur content in biodiesel," Thomas Wilharm and Hendrik Stein, UFOP project No. 540/104 Final report ASG Analytik-Service GmbH, August 2011. https://www.agqm-biodiesel.de/application/files/7613/2999/1435/20110825_Abschlussbericht_ENG_pdf.pdf

biodiesel at the maximum allowable metals limit. These studies have included light duty truck)[64, 65] and heavy heavy-duty[66, 67] diesel engine applications.

Although the aforementioned data and studies are reassuring, because advanced aftertreatment has not been tested on biodiesel out to the longer useful lives recommended, and because current biodiesel blend stock recommendations are less protective than current DEF standards, CARB staff plans to continue to seek information on lifetime exposure/emissions impact relationships, prevailing fuel metals levels and to evaluate the potential need for future changes to biodiesel standards.

2. Gasoline Engine Technologies Under Consideration

"We request comment on the need for more stringent PM standards for heavy-duty gasoline engines."

"We request comment on EPA expanding our ORVR requirements to incomplete heavy-duty vehicles. We are particularly interested in the challenges of multiple manufacturers to appropriately implement ORVR systems on the range of gasoline-fueled vehicle products in the market today. We also seek comment on refueling test procedures, including the appropriateness of engineering analysis to adapt existing test procedures that were developed for complete vehicles to apply for incomplete vehicles."

CARB Comment: As mentioned in the ANPRM, gasoline-fueled or stoichiometric spark-ignited (SI) engines use three-way catalysts (TWC) to reduce emissions of NOx, carbon monoxide, and hydrocarbons. The SwRI Stage 1 program demonstrated a 0.010 g/bhp-hr NOx level on the FTP and a 0.008 g/bhp-hr NOx level on the RMC on a 12-liter Cummins natural gas engine using a close-coupled TWC, an underfloor TWC, and improved air-fuel ratio controls. Furthermore, since 2016, a number of gasoline,

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[64] (Williams et al., 2013) "Impact of Fuel Metal Impurities on the Durability of a Light-Duty Diesel Aftertreatment System," Aaron Williams, Jonathan Burton and Robert L. McCormick, Todd Toops, Andrew A. Wereszczak, Ethan E. Fox and Michael J. Lance, Giovanni Cavataio, Douglas Dobson and Jim Warner, Rasto Brezny, K. Nguyen and D. William Brookshear, SAE paper 2013-01-0513, April 8, 2013. https://doi.org/10.4271/2013-01-0513

[65] (Williams et al., 2016) "Effect of Accelerated Aging Rate on the Capture of Fuel-Borne Metal Impurities by Emissions Control Devices" Aaron Williams and Robert McCormick, Michael Lance, Chao Xie, and Todd Toops, Rasto Brezny, SAE paper 2014-01-1500, April 1, 2014. https://doi.org/10.4271/2014-01-1500

[66] (Williams et al., 2011) "Impact of Biodiesel Impurities on the Performance and Durability of DOC, DPF and SCR Technologies," Aaron Williams, Jon Luecke and Robert L. McCormick, Rasto Brezny, Andreas Geisselmann, Ken Voss and Kevin Hallstrom, Matthew Leustek, Jared Parsons and Hind Abi-Akar, SAE paper 2011-01-1136, April 12, 2011. https://doi.org/10.4271/2011-01-1136

[67] (Lance et al., 2016) "Evaluation of Fuel-Borne Sodium Effects on a DOC-DPF-SCR Heavy-Duty Engine Emission Control System: Simulation of Full-Useful Life," Michael Lance, Andrew Wereszczak, Todd J. Toops, Richard Ancimer, Hongmei An, Junhui Li, Leigh Rogoski, Petr Sindler, Aaron Williams, Adam Ragatz, and Robert L. McCormick, SAE paper 2016-01-2322, October 17, 2016. https://doi.org/10.4271/2016-01-2322

natural gas, and propane-fueled heavy-duty Otto cycle engine families have been certified to CARB's optional low NOx standards of 0.02 g/bhp-hr and are currently commercially available in the market for applications in urban buses, garbage trucks, and other vocational vehicles.[68]

CARB staff supports U.S. EPA in addressing the discrepancy in emissions control between engine certified and chassis certified heavy-duty gasoline engines, in particular those that occur during sustained idle or stop-and-go city driving and at high loads. We are encouraged to see U.S. EPA considering further reductions of PM and evaporative emissions from gasoline engines. CARB staff will monitor U.S. EPA's efforts to further reduce emissions from on gasoline engines. Although U.S. EPA's work will not be complete until after CARB's HD Omnibus Regulation is considered by the Board, CARB staff supports consideration of more stringent PM and on-board refueling vapor recovery (ORVR) requirements and will likely follow-up with another rulemaking proposal to take advantage of U.S EPA's findings.

3. Emissions Monitoring Technologies

"We encourage commenters to submit information to help us project whether the state of NOx sensor technology in the 2027 timeframe would be sufficient to enable such programs. We also request comment on the durability of NOx sensors, as well as specific maintenance or operational strategies that could be considered to substantially extend the life of these components and any regulatory barriers to implementing these strategies."

CARB Comment: CARB staff is closely following the development of NOx sensor technology and the use of telematics systems in the trucking industry. CARB staff is having discussions with NOx sensor manufacturers on the state of NOx sensor technology development and is following the work of the NOx Sensor Task Force within the Engine Emissions Measurement & Testing Committee (EMTC) of the Truck and Engine Manufacturers Association (EMA).

In general, CARB staff is supportive of the use of NOx sensor data collection and telematics reporting to enhance and streamline the durability certification and in-use testing requirements. The importance of this strategy would be even more critical in the post-2027 model year period, for which CARB staff expects to propose increasing the useful life of heavy-duty engines. In fact, CARB has already adopted the REAL (Real Emissions Assessment Logging) program that requires the collection of onboard data using existing OBD sensors and other vehicle performance parameters that will bin data to allow the assessment of real world over the road emission performance relative to laboratory performance beginning in the 2022 model year.

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[68] See list of engines certified to CARB's optional NOx standards at https://ww3.arb.ca.gov/msprog/onroad/optionnox/optionnox.htm

Although advances in NOx sensors are promising and CARB staff anticipates a strong role for NOx sensors in future heavy-duty in-use compliance programs, it is important to note, however, NOx sensors alone cannot replace the failure prevention and repair assistance functionality of a comprehensive on-board diagnostics (OBD) system.

"We request comment on the prevalence of telematics, the range of information that can be shared over-the-air, and limitations of the technology today."

CARB Comment: Observation of the telematics market shows a substantial growth in this industry. For example, there has been a continuous increase in manufacturer-equipped vehicle telematics over the past few years. Sources suggest that telematics would be embedded in more than half of all manufactured vehicles in North America by 2023.[69] It should be noted that the above projection only accounts for original equipment manufacturer (OEM) equipped telematics and does not include vehicles in heavy-duty fleets that use aftermarket telematics providers to assist in fleet logistics/management efforts.

A broad range of information available on vehicles' onboard computer can be accessed and shared via telematics. Vehicle location, speed, diagnostics fault codes, and measured data by the onboard sensors are among the collected information. The data can be used in a variety of applications, including but not limited to: fleet management, road safety, vehicle maintenance and repair, and demonstrating compliance with federal and state regulations (for example, Department of Transportation's Federal Motor Carrier Safety Administration's Electronic Logging Device [ELD] Rule).

Many OEMs already take advantage of remote data transmission through telematics to monitor data coming from their vehicles. Transmission of vehicle data to government entities for the purpose of vehicle compliance demonstration would be a logical next step. CARB is currently in the developmental stages of a HD inspection and maintenance (I/M) program that may rely on remote transmission of emissions-related OBD data either directly from an OEM telematics system or third party telematics system installed on the vehicle. Remote vehicular data transmission could potentially not only allow for a quick and cost-effective way for vehicle owners to demonstrate compliance with an I/M program, but also allow provide OEMs with a cost-effective method to provide data for in-use compliance programs.

Some of the potential limitations of using telematics can include, but may not be limited to, service subscription costs, fraud, difficulties in transmitting collected data in areas with poor cellular network coverage, issues regarding data ownership, and cybersecurity/privacy concerns. However, CARB staff believes the benefits of using telematics potentially outweigh its existing limitations, which are not viewed as insurmountable. Furthermore, due to the increasing application of telematics in

[69] Sherry Calkins, Melissa Hoffman & Kristie Lightfoot, "Geotab Integrated Solution for GM: What it is and what is coming", Geotab Connect 2020.

vehicles, it seems reasonable to anticipate OEMs and telematics providers will offer more affordable, robust, and secure products and services in near future.

> "Finally, we request comment on whether and how improved communication systems could be leveraged by manufacturers or in state, local, or tribal government programs to promote emission reductions from the heavy-duty fleet."

CARB Comment: Using improved communication systems such as telematics would result in accessing a broad range of vehicle information in real-time. This would further enable manufacturers to track the status of onboard emission control monitors, identify the existing emissions related faults early, and take appropriate actions to fix the problem. States and local governments could use telematics in their vehicle I/M programs to meet their emission reduction goals. CARB staff potentially sees remote data submission application programs as a quick and effective way to confirm vehicle compliance, while minimizing both cost and downtime for both vehicle owners and OEMs. The entire process of data submission and verification could be done automatically with little to no human interaction. However, confirmatory testing and/or other safeguards would need to be set up to minimize fraudulent activity.

4. Hybrid, Battery-Electric, and Fuel Cell Vehicles

"We are interested in whether a hybrid powertrain test procedure addresses concerns with certifying the full range of heavy-duty hybrid products, or if other options might be useful for specific products, such as mild hybrid systems."

CARB Comment: CARB staff is planning to propose amending California powertrain testing procedures to provide heavy-duty hybrid vehicle manufacturers an option to certify hybrid powertrains to demonstrate compliance with criteria pollutants emission standards. The proposed amendments would allow heavy-duty hybrid vehicle manufacturers a voluntary option for powertrain-based (as opposed to engine-based, or chassis dynamometer-based) certification. The powertrain testing procedure would align with federal procedures for powertrain testing and is based on the U.S. EPA Phase 2 GHG technical amendments.

Under the proposed amendments, the complete hybrid powertrain, including the combustion engine, the hybrid system, and exhaust aftertreatment systems, would be required to be tested as a unit on a powertrain dynamometer. The CARB certification value for a heavy-duty hybrid powertrain would be determined through emissions measurements and calculations using powertrain dynamometer test results. Once certification requirements are satisfied, an Executive Order would be issued to the entity that applied for certification. All hybrid powertrains intended for use in heavy-duty hybrid vehicles certified using the proposed

powertrain testing procedure would need to comply with all certification requirements for heavy-duty engines and vehicles, as applicable, including, but not limited to, useful life, emissions warranty, durability demonstration, and OBD requirements.

CARB staff believes that the proposed powertrain test procedure would be sufficiently flexible to allow it to be used for testing different hybrid powertrain architectures, including mild hybrid systems. Based on discussion with industry, as well as communication with U.S. EPA staff, the proposed powertrain test procedure can be used to test both plug-in and non-plug-in hybrids, from strong hybrids to mild hybrids, as well as range extender hybrids. Because the procedure allows for the creation and testing of generic vehicle configurations, including options for simulating vehicle and transmission parameters, it provides for a robust testing process that should be able to cover a wide range of hybrid architecture.

"We are also aware that current OBD requirements necessitate close cooperation between engine and hybrid system manufacturers for certification, and the process has proven sufficiently burdensome such that few alliances have been pursued to-date. We are interested in better understanding this potential barrier to heavy-duty hybrid systems, and any potential opportunities EPA could consider to address it."

CARB Comment: Close cooperation is certainly required to implement OBD systems on heavy duty hybrids to robustly detect emission related malfunctions. CARB recognizes the significant challenges this creates for introducing hybrids. In 2016, CARB created and adopted the Innovative Technology Regulation (ITR) with significant short term certification flexibility on the OBD requirements to encourage development and introduction of hybrid technologies. The ITR was crafted with significant input from the relevant stakeholders. To date, no hybrid certifications have used this flexibility in the ITR which suggests the impediment may be broader than OBD. U.S. EPA's comment may be interpreted to imply that OBD requirements are the reason there are so few HD hybrids, which may not be the case.

It might be helpful to research the reasons why HD hybrids have not flourished. Is it because of OBD challenges or is it customer acceptance? Thus far, HD hybrids have made some headway into the transit bus market, but transit agencies have a unique business model with different funding sources and often more stringent greenhouse gas requirements due to local commitments or mandates. For the larger truck market, it is worth investigating what the true potential benefit from HD hybrids actually is and whether this benefit justifies the cost of the technology. While the

familiar LD hybrid can get an attractive 50 percent improvement in fuel economy relative to a conventional powertrain, we cannot automatically expect similar gains in the HD sector. The HD truck's duty cycle and far lower power-to-weight ratio could mean that HD hybrid benefits will always be dramatically less than their LD counterparts. Because of this, the cost of HD hybrids may make them intrinsically unattractive to truck owners regardless of OBD requirements.

CARB's experience shows that the incremental burden of OBD for HD hybrids relative to conventional trucks is not large, but the burden has been significant because it is borne mostly by hybrid system manufacturers that are new to OBD. While engine manufacturers have years of experience with OBD, hybrid system manufacturers often have to start from the beginning. Early hybrid system hardware and software were not originally designed with OBD requirements in mind, and this resulted in challenges with subsequent attempts to implement even the most basic OBD requirements. Recognizing this, the OBD requirements and CARB's program implementation provided manufacturers additional years to come up to speed with OBD. The hybrid manufacturers that have been through this process now design components with OBD requirements in mind, which significantly reduces the difficulty of OBD compliance relative to the early years. As for the actual diagnostic requirements that hybrid system manufacturers need to satisfy, they are in fact much simpler than engine diagnostics which are often emissions-correlated and require extensive and iterative emissions testing. Hybrid system manufacturers have a relatively small fraction of the normal testing burden that engine manufacturers have for conventional and hybrid engines alike. From this, it seems much of the true burden in HD hybrid OBD comes from the lack of an integrated business structure and not the OBD requirements themselves. If the business structure for HD hybrids were more akin to that of LD hybrids, in which one company with OBD experience develops the entire system, OBD requirements for HD hybrids would be much easier to satisfy.

Despite the challenges facing HD hybrids that come from a horizontally integrated business model, ensuring a well-integrated finished product needs to remain a priority. CARB's experience is that emissions and OBD performance could be significantly compromised relative to a conventional powertrain if the engine and hybrid systems are not carefully integrated to ensure good emissions control performance and good OBD performance. As such, there is value in maintaining the current requirements.

Currently, manufacturers are certifying fully integrated HD hybrid vehicles which are fully compliant with the OBD requirements. These manufacturers work with the engine OEMs and perform a significant level of on-road testing to ensure the two systems (i.e., engine and hybrid

powertrains) work together without causing adverse impacts on emissions or the OBD system. This is a resource intensive effort and requires a high level of experience and expertise from both the engine and hybrid manufacturers. The risk of weakening OBD requirements to allow less experienced hybrid manufacturers into the market is that the emissions control system and/or OBD system could be negatively impacted which could lead to higher average in-use emissions (i.e., off the certification test cycle) or a failure to illuminate the MIL when emission related components are malfunctioning.

"Since battery-electric and hydrogen fuel cell vehicles do not have ICEs, they have zero tailpipe emissions of NOx. We request comment on whether, and if so how, the CTI should project use of these more advanced technologies as NOx reduction technologies."

"EPA requests comment on the likely market trajectory for advanced powertrain technologies in the 2020 through 2045 timeframe. Commenters are encouraged to provide data supporting their perspectives on reasonable adoption rates EPA could use for hybrid, battery-electric, and fuel cell heavy-duty vehicles relative to the full heavy-duty vehicle fleet in specific time periods (e.g., early 2020s, late 2020s, 2030, 2040, 2050)."

CARB Comment: CARB is in the process of adopting and implementing aggressive measures to bring about a transformation to zero-emission heavy-duty vehicles wherever feasible and hence has gathered and compiled a great deal of relevant information concerning zero-emission heavy-duty technologies. For example, as described further below, CARB in 2018 adopted the Innovative Clean Transit regulation, requiring transit fleets in California to transition to a fully zero-emission transit fleet by roughly 2040. CARB staff in December 2019 proposed the Advanced Clean Truck (ACT) regulation, which would require manufacturers to meet aggressive heavy-duty zero-emission vehicles (ZEV) sales requirements (CARB, 2019c).[70]

In response to the ANPRM queries above, CARB staff provides information concerning zero-emission heavy-duty technologies grouped into the four sections below:

- Declining Technology Costs;
- Zero-Emission Vehicle Cost Competitiveness;
- Regulatory and Policy Drivers in California; and
- Market Trajectory Analyses.

[70] (CARB, 2019c) "Public Hearing to Consider the Proposed Advanced Clean Trucks Regulation – Staff Report: Initial Statement of Reasons," California Air Resources Board, October 22, 2019. https://ww3.arb.ca.gov/regact/2019/act2019/isor.pdf

Declining Technology Costs

Batteries are the largest cost component for battery-electric vehicles. Per Bloomberg New Energy Finance, the price of batteries has dropped dramatically over the last decade from $1,100/kWh (dollar per kilowatt hour) in 2010 to $156/kWh in 2019 (BNEF, 2019a).[71] This decline can be attributed to numerous factors including increasing order size, growth in battery-electric vehicle sales, continued penetration of high energy density cathodes, increasing levels of cell and battery standardization, and improved manufacturing equipment. Bloomberg forecasts further battery price reductions and projects that batteries will cost $96/kWh by 2025 and $70/kWh by 2030 (Bloomberg, 2019).[72]

Fuel cell technology for transportation has also seen a marked decline in costs. The Department of Energy estimates that the cost of transportation fuel cells produced at high volume has declined 60 percent since 2006 (DoE, 2018).[73] Strategic Analysis estimates that fuel cell costs for medium- and heavy-duty vehicles can decline to $81/kWh at high production volumes as opposed to the current cost of $325/kWh at low production volume (Strategic Analysis, 2018).[74]

This emerging heavy-duty ZEV market segment is being supported by technology transfer from other, more developed markets. Manufacturers including Volvo and Proterra have developed electric powertrains in the transit bus sector which will soon be utilized in Class 8 trucks and school buses (Volvo, 2019)[75], (Proterra, 2018)[76]. Navistar's upcoming electric school bus has been designed using technology from Volkswagen light-duty passenger cars (Trucks.com, 2018)[77]. Daimler is leveraging its light-duty battery investments to power its Mitsubishi Fuso eCanter truck (CARB,

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[71] (BNEF, 2019a) "Battery Pack Prices Fall As Market Ramps Up With Market Average At $156/kWh In 2019," Bloomberg, December 3, 2019. https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/

[72] (Bloomberg, 2019) "Better Batteries," Bloomberg, Updated on October 11, 2019. https://www.bloomberg.com/quicktake/batteries

[73] (DoE, 2018) "Fact of the Month April 2018: Fuel Cell Cost Decreased by 60% since 2006," Department of Energy, Accessed on February 11, 2020. https://www.energy.gov/eere/fuelcells/fact-month-april-2018-fuel-cell-cost-decreased-60-2006

[74] (Strategic Analysis, 2018) "2018 DOE Hydrogen and Fuel Cells Program Review: Fuel Cell Systems Analysis," Strategic Analysis, June 15, 2018. https://www.hydrogen.energy.gov/pdfs/review18/fc163_james_2018_o.pdf

[75] (Volvo, 2019) "Heavy-Duty Class 8 Electrification Roadmap: Regional Distribution and Short Haul Applications," Volvo Technology of North America.

[76] (Proterra, 2018) "Proterra Closes $155 Million Investment from Daimler, Tao Capital Partners, G2vp And Others," Proterra, September 19, 2018. https://www.proterra.com/press-release/proterra-closes-155-million-investment-from-daimler-tao-capital-partners-g2vp-and-others/

[77] (Trucks.com, 2018) "Navistar Brings an Electric School Bus to the Streets," Trucks.com, May 17, 2018. https://www.trucks.com/2018/05/17/navistar-electric-school-bus-streets/

2017)[78]. Motiv is using batteries from the BMW i3 in some of its commercial trucks (Motiv, 2019)[79]. Tesla is using electric motors and other components from the Model 3 in its demonstration tractor and Toyota is using two Mirai fuel cells in its demonstration tractor (Tesla, 2019)[80], (Toyota, 2019)[81]. These synergies drive down costs and enable greater economies of scale as electrification expands into the trucking market.

Zero-Emission Vehicle Cost Competitiveness

Zero-emission vehicles are anticipated to cost more than their combustion-powered counterparts for the foreseeable future. However, zero-emission vehicles also have lower operational costs due to less expensive fuel and reduced maintenance needs. Numerous studies have assessed the total cost of ownership for the different available technology options.

Over the past years, a number of organizations including CARB, ICF International, the International Council on Clean Transportation (ICCT), Lawrence Berkeley National Laboratory (LBNL), and the North American Council on Fuel Efficiency (NACFE) have released reports assessing the total cost of ownership for electric trucks. While these reports differ in their assumptions and methodology, they all come to similar conclusions: while battery-electric vehicles cost more today, by the mid-2020s they are projected to have lower total cost of ownership than their diesel counterparts (CARB,

[78] (CARB, 2017) "Proposed Fiscal Year 2017-2018 Funding Plan for Clean Transportation Incentives," California Air Resources Board, November 9, 2017. https://ww3.arb.ca.gov/msprog/aqip/fundplan/proposed_1718_funding_plan_final.pdf

[79] (Motiv, 2019) "Motiv Power Systems to Offer BMW Batteries on Electric Chassis for Commercial Vehicles," Motiv, last accessed February 11, 2020. https://www.motivps.com/motivps/pressreleases/motiv-power-system-to-offer-bmw-batteries-on-electric-chassis-for-commercial-vehicles/

[80] (Tesla, 2020) "Press Kit – Semi," Tesla, last accessed on February 11, 2020. https://www.tesla.com/presskit#semi

[81] (Toyota, 2019) "Toyota Mirai fuel cell stack propels ten zero-emission trucks," Toyota, January 17, 2019. https://blog.toyota.co.uk/toyota-mirais-hydrogen-fuel-cell-trucks

2019a[82];.ICF, 2019[83]; ICCT, 2017[84]; ICCT, 2019[85]; LBNL, 2019[86]; NACFE, 2018a[87]; NACFE, 2018b[88]; NACFE, 2019a[89]; NACFE, 2019b[90]). As shown in the two figures below from the Union of Concerned Scientists 2019 report, "Ready for Work", three different cost comparisons come to similar conclusions (UCS, 2019).[91] The first figure is for Class 6 delivery trucks, and the second is for Class 8 short-haul/drayage trucks, and both show battery-electric vehicles by 2030 having lower total cost of ownership than their diesel counterparts.

[82] (CARB, 2019a) "Advanced Clean Trucks Total Cost of Ownership Discussion Document", California Air Resources Board, February 22, 2019. https://ww2.arb.ca.gov/sites/default/files/2019-02/190225tco_0.pdf
[83] (ICF, 2019) "Comparison of Medium- and Heavy-Duty Technologies in California," ICF International, December 2019. https://caletc.com/comparison-of-medium-and-heavy-duty-technologies-in-california/
[84] (ICCT, 2017) "Transitioning to Zero-Emission Heavy-Duty Vehicles," International Council on Clean Transportation, September 2017. https://theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf
[85] (ICCT, 2019) "Estimating the Infrastructure Needs and Costs for the Launch of Zero-Emission Trucks," International Council on Clean Transportation, August 2019. https://theicct.org/sites/default/files/publications/ICCT_EV_HDVs_Infrastructure_20190809.pdf
[86] (LBNL, 2019) "Clean truck standards consistent with carbon neutrality are economically and environmentally compelling," Lawrence Berkeley National Laboratory, last accessed on February 11, 2020. https://www.arb.ca.gov/lists/com-attach/108-act2019-WzoHYIInVSsCZ1U6.zip
[87] (NACFE, 2018a) "Electric Trucks – Where They Make Sense," North American Council for Freight Efficiency (NACFE), May 2018. https://nacfe.org/future-technology/electric-truck
[88] (NACFE, 2018b) "Medium-Duty Electric Trucks: Cost of Ownership," North American Council for Freight Efficiency (NACFE), October 2018. https://nacfe.org/future-technology/medium-duty-electric-trucks-cost-of-ownership/
[89] (NACFE, 2019a) "Amping Up – Charging Infrastructure for Electric Trucks," North American Council for Freight Efficiency (NACFE), March 2019. https://nacfe.org/future-technology/amping-up-charging-infrastructure-for-electric-trucks/
[90] (NACFE, 2019b) "Viable Class 7/8 Alternative Vehicles," North American Council for Freight Efficiency (NACFE), last accessed December 2019. https://nacfe.org/future-technology/viable-class-7-8/
[91] (UCS, 2019) "Ready For Work: Now Is the Time for Heavy-Duty Electric Vehicles," Union of Concerned Scientists, December 2019. https://www.ucsusa.org/sites/default/files/2019-12/ReadyforWorkFullReport.pdf

FIGURE 8. Total Cost Comparisons, Class 6 Delivery Trucks

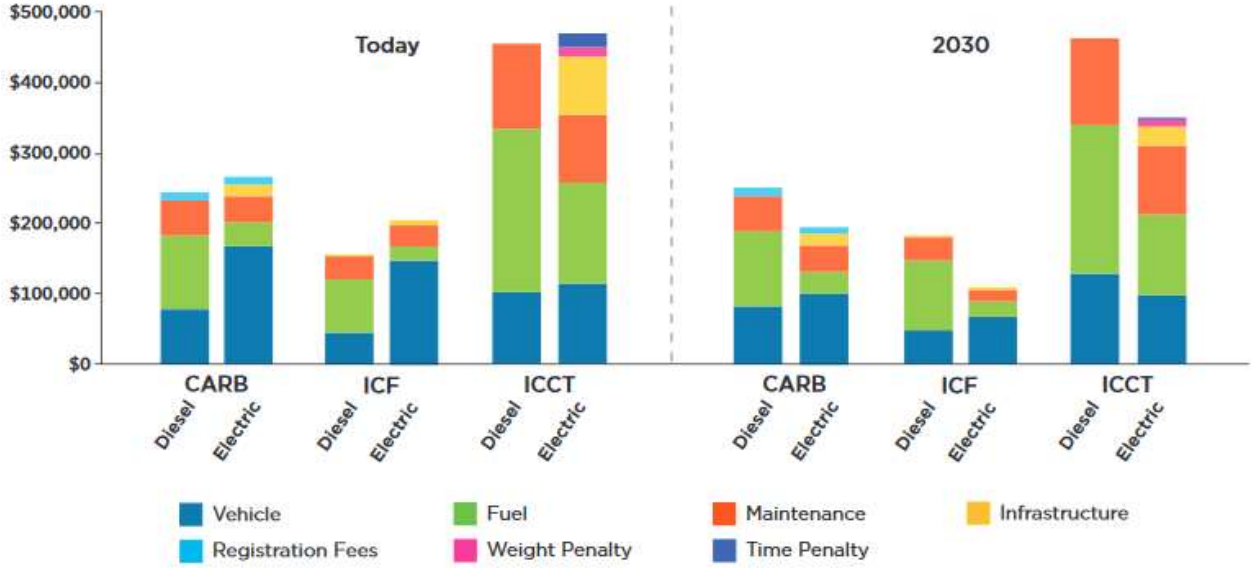
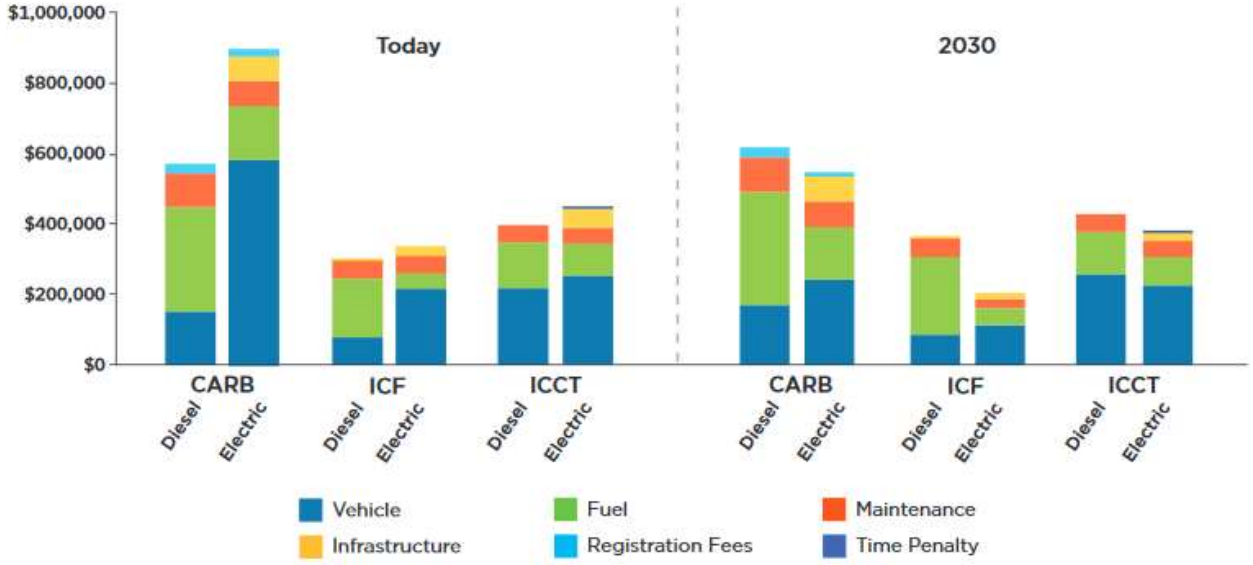


FIGURE 9. Total Cost Comparisons, Class 8 Short-Haul/Drayage Trucks



iii. **Regulatory and Policy Drivers in California**

Zero-emission vehicles are an emerging technology and future ZEV penetration is difficult to project, especially in the heavy-duty market which is earlier in development as compared to light duty. This is further complicated since there are two potential zero-

emission solutions coming to market – battery-electric and fuel cell electric. Zero-emission penetration is expected in California due to a combination of regulations, policy drivers, and based on the positive economics of zero-emission vehicles.

Innovative Clean Transit Regulation

In December 2018, CARB adopted the Innovative Clean Transit regulation which aims to transition California's transit fleet to 100% zero-emission by 2040 (CARB, 2018).[92] The regulation requires transit agencies to purchase a portion of their sales as zero-emission starting in 2023 ramping up to 100 percent of purchases being zero-emission by 2029. Beyond the Innovative Clean Transit rulemaking, transit agencies representing more than half of the state's transit fleet have committed to transitioning to zero-emission prior to 2040.

Zero-Emission Airport Shuttle Bus Regulation

In July 2019, CARB adopted the Zero-Emission Airport Shuttle Bus Regulation which regulates public and private shuttle bus fleets serving California airports (CARB, 2018b).[93] Regulated fleets must be 33 percent zero-emission by 2027, 66 percent zero-emission by 2031, and 100 percent zero-emission by 2035.

Assembly Bill 739

AB 739, passed in 2017, requires California's state fleet to purchase 15 percent of their Class 6-8 vehicles as zero-emission starting 2025, increasing to 30 percent starting in 2030 (California State Legislature, 2017).[94]

Advanced Clean Trucks Regulation

As part of the 2016 Mobile Source Strategy and State Implementation Plan, CARB staff recently proposed a "Last Mile Delivery" regulation which would accelerate the penetration of zero-emission technologies into the heavy-duty sector. After a three year public process, CARB presented the proposed Advanced Clean Trucks regulation to the Board in December 2019 (CARB, 2019c).[70] The proposed regulation would require that

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[92] (CARB, 2018) "Public Hearing to Consider the Proposed Innovative Clean Transit Regulation – Staff Report: Initial Statement of Reasons, California Air Resources Board, August 7, 2018. https://ww3.arb.ca.gov/regact/2018/ict2018/isor.pdf

[93] (CARB, 2018b) "Public Hearing to Consider the Proposed Zero-Emission Airport Shuttle Regulation," California Air Resources Board, December 31, 2018. https://ww3.arb.ca.gov/regact/2019/asb/isor.pdf

[94] (California State Legislature, 2017) "Assembly Bill 739 (2017)," California State Legislature, October 10, 2017. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB739

medium- and heavy-duty manufacturers sell a portion of their California sales as zero-emission vehicles. This regulation is anticipated to result in reduced NOx, PM, and GHG emissions, especially in disadvantaged communities disproportionately impacted by freight emissions.

The proposed regulation would require that beginning in the 2024 model year, manufacturers must sell an increasing percentage of their Class 2b through 8 sales as zero-emission as displayed in the table below. Zero-emission technologies that earn full credit include battery-electric, fuel cell electric, and catenary powered vehicles. Hybrid electric vehicles meeting a minimum all-electric range requirement are defined as "near-zero-emission vehicles" and are eligible for partial credit.

Table: Advanced Clean Truck Requirements Proposed in the Staff Report

Model Year	Class 2b-3*	Class 4-8	Class 7-8 Tractors
2024	3%	7%	3%
2025	5%	9%	5%
2026	7%	11%	7%
2027	9%	13%	9%
2028	11%	24%	11%
2029	13%	37%	13%
2030 and beyond	15%	50%	15%

*Note: Class 2b and 3 pickups are excluded from requirements until 2027 MY

At the December 2019 Board hearing, the Board directed staff to reassess the rule and identify ways to increase the number of zero-emission trucks deployed, as well as identify specific sectors that can be accelerated to 100 percent zero-emission. Staff plans to release changes to the Advanced Clean Trucks rule in the upcoming months and anticipates returning with a final proposal for Board consideration in May 2020. If approved, the Advanced Clean Trucks rule would represent a minimum floor for how many zero-emission medium- and heavy-duty vehicles must be sold into California.

In addition to California's actions, the states of Connecticut, Maine, Massachusetts, New Jersey, Oregon, Rhode Island and Vermont as well as the District of Columbia have signed a Statement of Intent to support accelerated deployment of zero-emission medium- and heavy-duty vehicles (NESCAUM, 2019).[95] This builds on a previous Memorandum of Understanding signed by California and nine other states to accelerate consumer adoption of zero-emission passenger cars and trucks. Increased medium- and heavy-duty ZEV adoption across multiple states will generate greater economies of

[95] (NESCAUM, 2019) "Multi-State Medium- and Heavy-Duty Zero Emission Vehicle Initiative: Statement of Intent," Northeast States for Coordinated Air Use Management, December 12, 2019. https://www.nescaum.org/documents/nescaum-press-release_12-12-19.pdf/

scale benefiting manufacturers and fleets while greater emissions reductions will benefit all individuals negatively affected by truck emissions.

San Pedro Bay Ports' Clean Air Action Plan

The San Pedro Bay Ports, consisting of the Port of Los Angeles and the Port of Long Beach, released their Clean Air Action Plan Update in 2017 (San Pedro Bay Ports, 2017).[96] This plan sets a goal of 100% zero-emission drayage trucks by 2035. The Ports aim to achieve this through a number of actions including conducting large scale pilots of zero-emission trucks and a truck rate program which would charge a fee for non-zero-emission drayage trucks entering the Ports. Drayage trucks servicing the Ports often operate within and travel through disadvantaged communities near warehouses and highways and have been identified by the state as a key sector to electrify. As roughly 11,000 to 18,000 drayage trucks frequent the San Pedro Bay Ports, the Ports represent a major early market for zero-emission tractor trailer adoption (San Pedro Bay Ports, 2019).[97]

Los Angeles's Green New Deal pLAn

In 2019, the City of Los Angeles released its "L.A.'s Green New Deal: Sustainable City pLAn" (City of Los Angeles, 2019).[98] This action plan seeks to use the City of Los Angeles's resources and leadership position to drive change on climate action, environmental justice and equality, and green jobs. The plan contains the following actions:

- Increase the percentage of zero-emission vehicles in the city to 25% by 2025; 80% by 2035; and 100% by 2050
- 2021: All vehicle procurement will follow a "zero-emission first" policy for City fleets
- 2026: Electrify 100% of paratransit shuttles
- 2028: Convert all City fleet vehicles to zero-emission where technically feasible
- 2028: 100% zero-emission school buses in Los Angeles
- 2028: Ensure that 100% of medium-duty trash and recycling trucks are zero-emission
- 2030: Electrify 100% of Metro and LADOT buses by 2030

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[96] (San Pedro Bay Ports, 2017) "Clean Air Action Plan 2017: Final Clean Air Action Plan Update," San Pedro Bay Ports, November 2017. https://cleanairactionplan.org/documents/final-2017-clean-air-action-plan-update.pdf/

[97] (San Pedro Bay Ports, 2019) "2018 Feasibility Assessment for Drayage Trucks," San Pedro Bay Ports, April 2019. https://cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/

[98] (City of Los Angeles, 2019) "L.A.'s Green New Deal: Sustainable City pLAn - 2019," City of Los Angeles, last accessed February 11, 2020. https://plan.lamayor.org/sites/default/files/pLAn_2019_final.pdf

- 2030: 100% zero-emission cargo handling equipment
- 2035: 100% of urban delivery vehicles are zero-emission
- 2035: 100% zero-emission on-road drayage trucks

Los Angeles is nation's second largest city, meaning actions taken by the city will lead the way for other cities across the nation to identify pathways to transition fleets to zero-emission.

Market Trajectory Analyses

Numerous studies and reports have projected the uptake of zero-emission heavy-duty vehicles into the 2020s and beyond.

Advanced Clean Trucks Market Segment Analysis

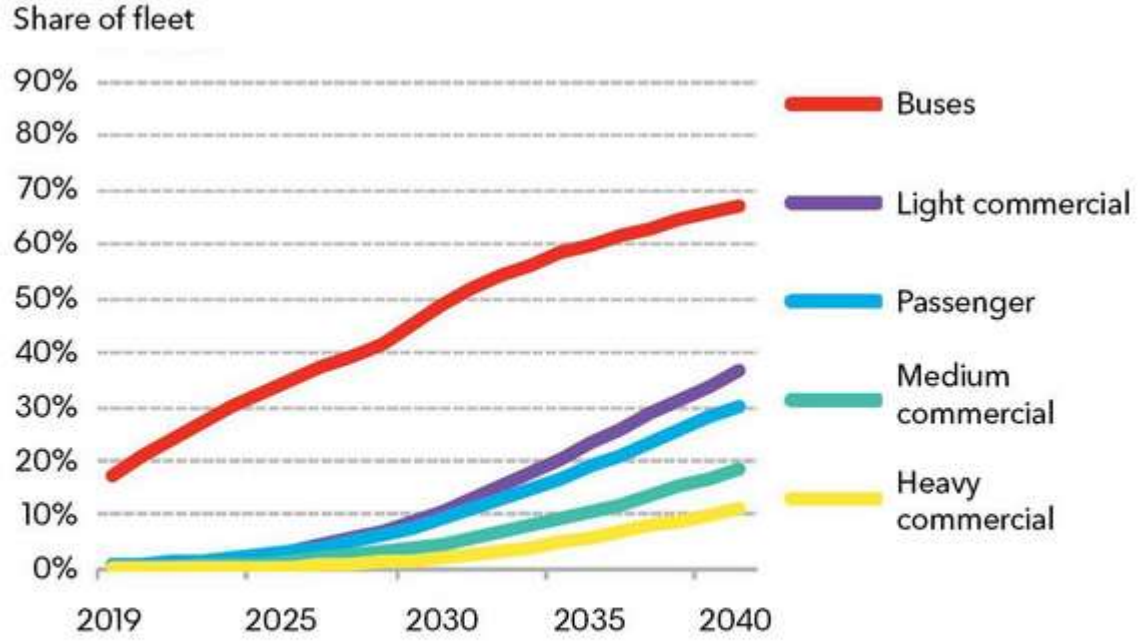
As part of the Advanced Clean Trucks rulemaking, CARB prepared and released the "CARB ACT Market Segment Analysis" (CARB, 2019d).[99] Based on data from EMA, this analysis broke the Class 2b-8 truck market into 87 discrete categories. Each category was graded based on four main factors – weight considerations, typical operating range, potential access to infrastructure, and packaging space for batteries – and given an overall suitability score based on these factors. Through this analysis, staff and manufacturers were able to identify which market sectors are best suited for electrification. This initial assessment found that based on today's technology, roughly 70% of Class 4-7 vehicles and roughly 35% of Class 8 vehicles have a duty cycle well-suited for electrification.

Bloomberg New Energy Finance

Bloomberg New Energy Finance (BNEF) found in their "Electric Vehicle Outlook 2019" analysis that due to decreasing battery costs, electrification will spread to other transportation sectors beyond the light-duty market (BNEF, 2019b).[100] For medium and heavy commercial vehicles, BNEF forecasted that roughly 10 percent of the heavy commercial in-use fleet and 20 percent of the medium commercial in-use fleet will be electric by 2040 in Europe, China, and the United States.

[99] (CARB, 2019d) "Zero Emission Truck Market Assessment," California Air Resources Board, last accessed February 11, 2020. https://ww3.arb.ca.gov/regact/2019/act2019/appe.pdf
[100] (BNEF, 2019b) "Electric Vehicle Outlook 2019," Bloomberg New Energy Finance, last accessed February 11, 2020. https://about.bnef.com/electric-vehicle-outlook/

Figure X: BNEF Electric Vehicle Outlook 2019 – Projected ZEV percentage of fleets in Europe, China, and the United States



Source: BloombergNEF. Note: Commercial vehicle adoption figures include the main markets of China, Europe, and the U.S.

ACT Research

In 2018, ACT Research released its "Commercial Vehicle Electrification: To Charge, or Not to Charge" study based on six months of analysis and fleet discussions (ACT Research, 2018).[101] This study found that although electric vehicles have a small beachhead in the heavy-duty market currently, they will steadily gain market share and become a major competitor to internal combustion engine powered vehicles. This prediction is based on advances in battery technology, environmental considerations and government policy, and the potential for significant operational cost savings. Based on their findings, ACT Research's study projected that the nationwide ZEV adoption will reach 7 to 21 percent by 2030 and 10 to 22 percent by 2035 as shown in the table below.

[101] (ACT Research, 2018) "Commercial Vehicle Electrification: To Charge or Not To Charge," ACT Research, August 2018. https://www.actresearch.net/cv-electrification-study/

Table: ACT Research Projected CEV Adoption Rates

CEV Adoption Rates By Truck Type

	2022	2023	2024	2025	2030	2035
Class 4-5 Total	10%	9%	9%	8%	16%	19%
Class 6-7 Total	14%	14%	14%	13%	21%	22%
Class 8 Total	2%	2%	3%	3%	7%	10%

North American Council on Fuel Efficiency

NACFE has released four guidance reports on zero-emission trucks over the past two years. Their first report, "Electric Trucks – Where They Make Sense", performed an initial assessment of electric trucks versus their diesel counterpart (NACFE, 2018a).[87] The report evaluated ten common arguments for and against electric trucks. The report found that while BEVs may not be a solution for every market or application, commercial BEVs will have an increasing role in freight transportation in Classes 3 through 8. NACFE foresees mixed fleets including a variety of fuel types optimized for their use case and duty cycle as being the norm out to 2050. In addition to their report, NACFE produced the following two graphics to illustrate their projections for when BEVs will reach parity with an equivalent diesel truck. The first figure is for Class 3 to 6 trucks, and the second is for Class 7 and 8 trucks.

Figure: NACFE - Class 3 Through 6 Commercial BEV Parity versus Diesel Class

CLASS 3 THROUGH 6 CBEV PARITY VS. DIESEL SYSTEM (NACFE)

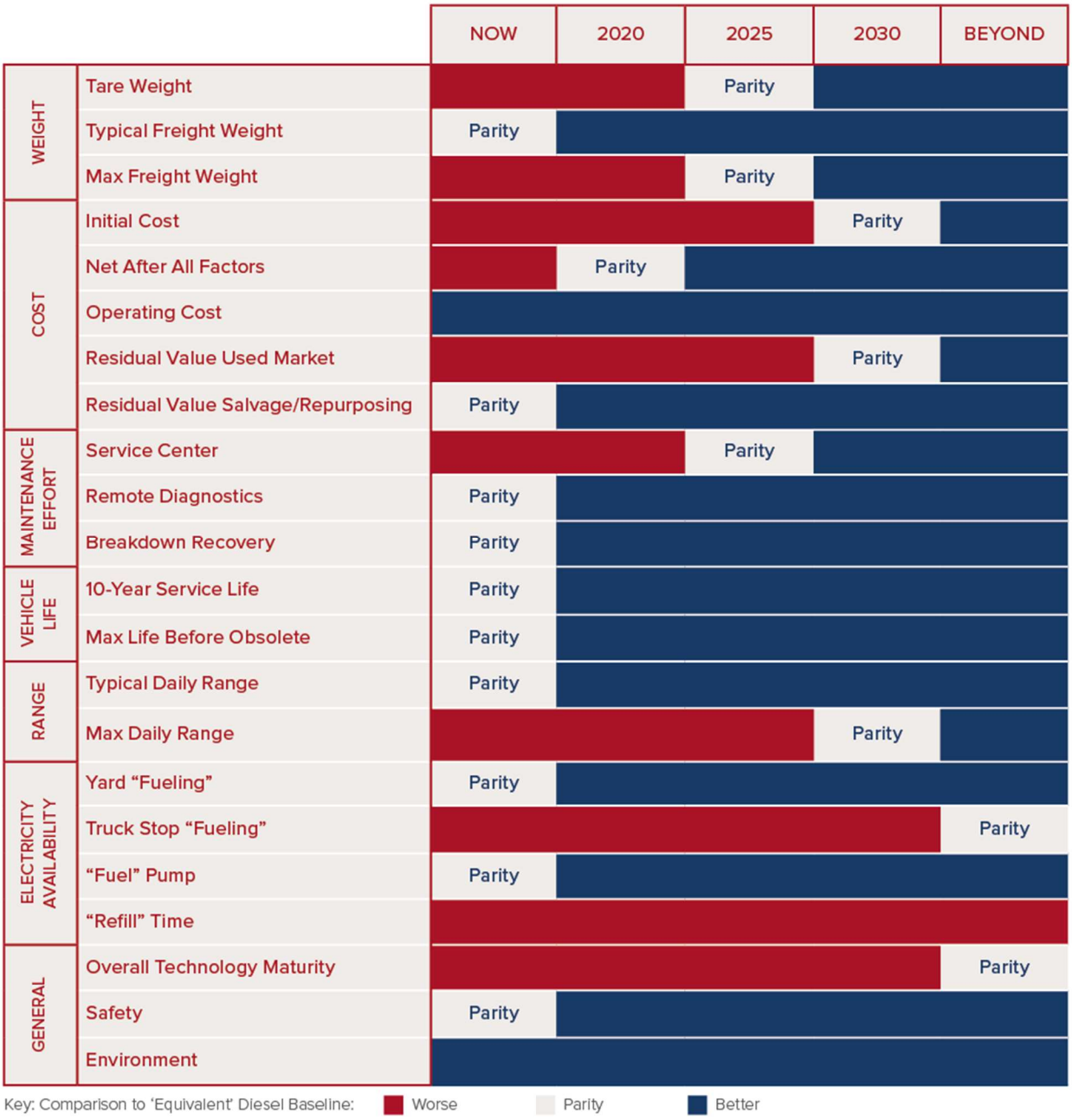
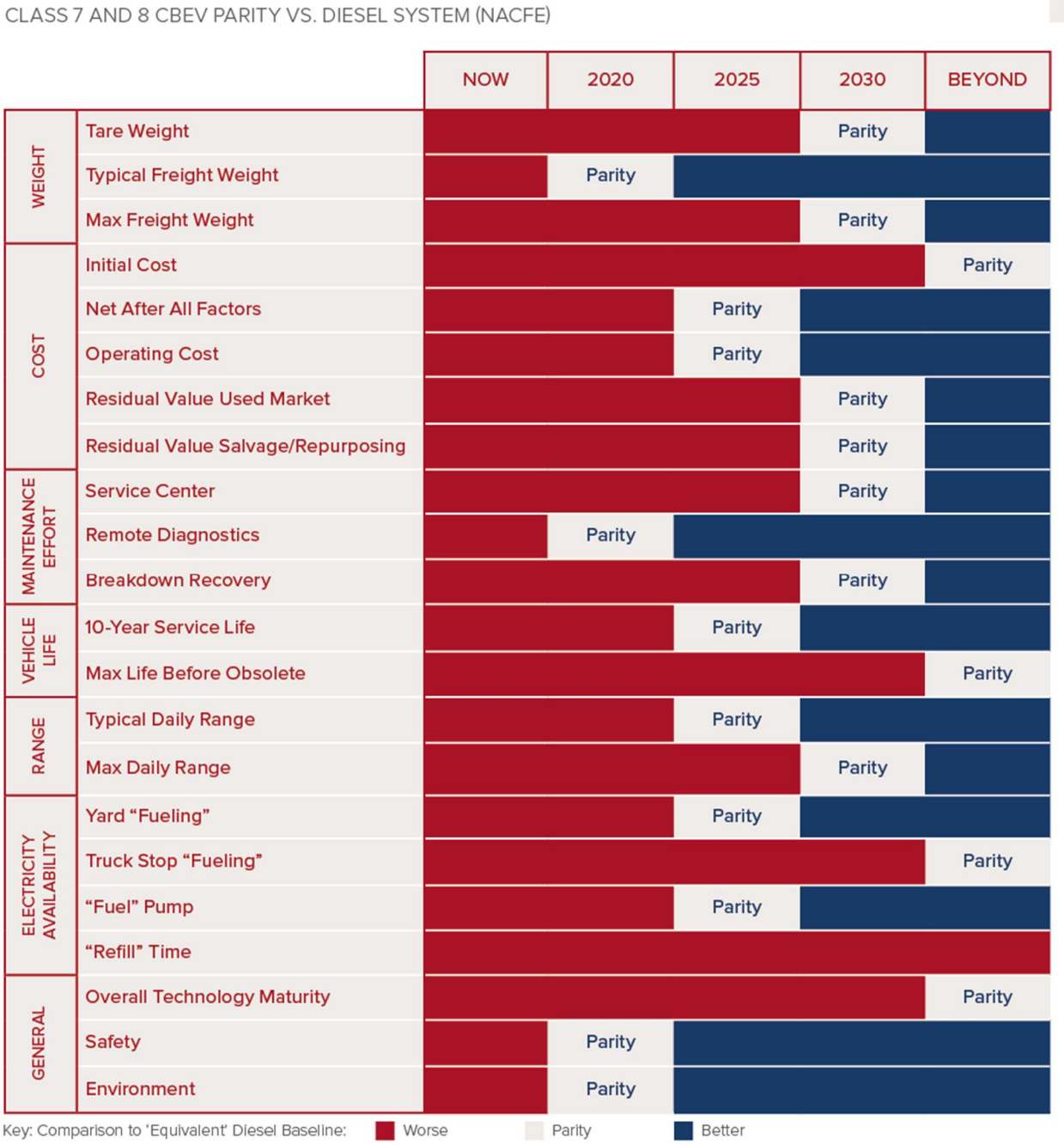


Figure: NACFE - Class 7 and 8 Commercial BEV Parity versus Diesel



NACFE's report, "Medium-Duty Trucks – Cost of Ownership" evaluates the total cost of ownership of commercial battery-electric vehicles (NACFE, 2018b).[88] NACFE's main recommendation is, "[Commercial battery electric vehicles] (CBEVs) are no longer speculation. They are clearly entering the North American marketplace with every major existing OEM, and a number of new OEMs, introducing products. Electric trucks will

succeed or fail under the intense spotlight of the marketplace. Fleets choosing electric trucks today will get on the learning curve ahead of those that wait. Early adopters will expose flaws and omissions that OEMs will correct. They will validate or dismiss CBEV claims. They will also learn how to optimize their operations to make the most of electric vehicles for improving their company's bottom line financials. As CBEVs improve, these early adopters will be better positioned to rapidly take advantage of the improvements."

NACFE's report, "Viable Class 7/8 Electric, Hybrid, and Alternative Fuel Tractors", evaluates the future of alternatively fueled Class 7 and 8 vehicles with a focus on tractor trailers. The report's main conclusions are:

- North American freight movement is becoming more predictable, with dedicated routes enabled by e-commerce and other technologies, offering better duty cycles for alternative powertrains.
- Each alternative fuel powertrain offers benefits in the short term compared to current diesel and may have enough duty cycle scale to offer total cost of ownership (TCO) and emission savings.
- CBEVs and fuel cell trucks will be capable of lower TCO in the 2030 time frame.
- Vehicle specifications will be more optimized for the duty cycle and technology of the first user, limiting the applicability of the equipment for second or third users.
- A "messy middle" will exist until CBEVs and FCEVs alone power these trucks because alternatives offer significant improvements over the diesel and gasoline baselines.
- A future zero-emission freight world will only have electric vehicles (CBEV, FCEV, or catenary electric) that are powered well-to-wheel from truly renewable sources, such as hydro, solar, and wind.

In addition, NACFE prepared the figure below as a "Decision-Making Tool" to assist in comparing alternative fuels:

Figure: NACFE – Alternative Fuel Powertrain Parity (2030)

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

		Production Class 7/8 North American Tractor — 2030							
		Renewable Diesel	FCEV	CBEV	CNG/RNG	LNG	Propane	Diesal Hybrid	Other Hybrids
WEIGHT	Tare Weight	Parity	Parity	Parity			Parity	Parity	
	Typical Freight Weight	Parity	Parity		Parity	Parity	Parity	Parity	Parity
	Max Freight Weight	Parity	Parity	Parity				Parity	
COST	Initial Cost	Parity							
	Net After All Factors	Parity	Parity		Parity	Parity		Parity	
	Operating Cost				Parity	Parity	Parity		Parity
	Residual Value Used Market	Parity		Parity			Parity	Parity	
	Residual Value Salvage/ Repurposing	Parity	Parity	Parity	Parity	Parity	Parity	Parity	
MAINTENANCE EFFORT	Service Center	Parity		Parity				Parity	
	Remote Diagnostics	Parity	Parity	Parity	Parity	Parity	Parity	Parity	Parity
	Breakdown Recovery	Parity		Parity	Parity	Parity	Parity	Parity	Parity
VEHICLE LIFE	10-Year Service Life	Parity		Parity	Parity	Parity	Parity	Parity	Parity
	Max Life Before Obsolete	Parity			Parity	Parity	Parity		
RANGE	Typical Daily Range	Parity	Parity	Parity	Parity	Parity	Parity	Parity	Parity
	Max Daily Range	Parity	Parity	Parity				Parity	
"FUEL" AVAILABILITY	Yard "Fueling"	Parity	Parity	Parity	Parity	Parity	Parity	Parity	Parity
	Truck Stop "Fueling"	Parity					Parity	Parity	Parity
	"Fuel" Pump	Parity	Parity	Parity	Parity	Parity	Parity	Parity	Parity
	"Refill" Time	Parity	Parity					Parity	Parity
GENERAL	Overall Technology Maturity	Parity			Parity	Parity	Parity	Parity	Parity
	Safety	Parity		Parity	Parity	Parity	Parity	Parity	Parity
	Environment GHG & Particulates	Parity							

Key: Comparison to 'Equivalent' Diesel Baseline: Worse Parity Better

"We request comment on any barriers or incentives that EPA could consider in order to better encourage emission reductions from these advanced powertrain technologies. Commenters are encouraged to provide information on the potential impacts of regulatory barriers or incentives for all the advanced powertrain technologies discussed here (hybrids, battery-electric, fuel cell), including the extent to which these technologies may lower NOx and other criteria pollutant emissions."

CARB Comment: CARB recommends that U.S. EPA introduce a mechanism to give NOx credits to heavy-duty ZEVs. One approach U.S. EPA could consider is creating a Heavy-Duty Zero-Emission Averaging Set as described below:

> Certified Class 4 through 8 ZEV families could be eligible to generate NOx credits in U.S. EPA's Averaging Banking and Trading (ABT) program. The amount of NOx credits in this averaging set could be calculated using the following equation:
>
> Zero-emission NOx credits = Multiplier x Std *x* ECF *x* UL *x* Sales *x* 10^(-6)
>
> where:
> Heavy-Duty Zero-emission NOx credits could be calculated for each certified ZEV model within the vehicle family in Megagrams (Mg),
>
> Multiplier = compliance credit multiplier, which could range from 1 to 2.5 and which could be used to provide additional incentive for manufacturers to produce heavy-duty (HD) ZEVs,
>
> Std = the applicable FTP duty cycle NOx emission standard in g/bhp-hr for the corresponding model year as specified in 40 CFR §86.007-11.
>
> ECF = the transient cycle conversion factor (in bhp-hr/mile) is the total (integrated) cycle brake horsepower-hour for the applicable ZEV family model during the vehicle-FTP cycle (as defined in 40 CFR Appendix II to part §1036 subparagraph (c)) divided by 6.5 miles,
>
> UL = applicable useful life for the vehicle family in miles as defined in 40 CFR §1037.105 and 40 CFR §1037.106 last amended on October 25, 2016,
>
> Sales = sales volume for the class 4 through 8 ZEV models sold within the given vehicle family during the model year. Projected model year sales could be used for initial certification. Actual sales numbers could be used for end-of-year compliance determination.

Under this approach, heavy-duty zero-emission credits could be transferred into any other averaging set for ABT calculations, which would enable a manufacturer to make more heavy-duty ZEVs in lieu of cleaning up some of its other engines.
CARB staff is planning to propose the approach above to give credit for heavy-duty ZEVs in the CARB HD Omnibus Regulation, but – because California is adopting manufacturer sales mandates for heavy-duty ZEVs – CARB staff will likely not propose the use of multipliers (i.e., CARB staff will likely propose that the multiplier in the equation above be 1.0).

5. Alternative Fuels

"We do not expect a shift in the market between diesel and gasoline as a result of the CTI and we are requesting comment on the extent to which CTI could have such effects. "

"We request comment on how natural gas should be treated in the CTI, including the possible provision of incentives."

"We request comment on the extent to which the CTI should consider DME."

"We request comment on how LPG should be treated in the CTI, particularly for vocational heavy-duty engines and vehicles."

CARB Comment: CARB staff agrees with U.S. EPA that a shift in the market between diesel and gasoline is not expected as a result of the CTI or CARB's HD Omnibus Regulation. Both gasoline and diesel have their own pros and cons in terms of initial cost, operating cost, performance and towing capacity, miles driven, and durability. Customers' choice ultimately comes down to the application or the vehicle that gets the job done.

Recommendations: CARB staff recommends that the CTI establish performance-based standards for all heavy-duty engines irrespective of the fuel used to propel the vehicle. Furthermore, CARB staff supports incentives based on emissions performance, that is, incentivize engines that are certified to significantly lower NOx emissions (50% or lower) than the proposed standards. CARB currently has a program that encourages the development of low NOx engines and incentivizes their purchase by funding the incremental cost for the purchase of the low NOx engine[102]. CARB staff

[102] (CARB, 2020) Optional Reduced NOx Emission Standards for On-Road Heavy-duty Engines, California Air Resources Board, Accessed February 19, 2020. https://ww3.arb.ca.gov/msprog/onroad/optionnox/optionnox.htm

also plans to propose a new generation of voluntary optional low NOx standards that are 60% and 50% lower than the proposed HD Omnibus Regulation 2024 and 2027 model year engine standards, respectively. U.S. EPA could also design a similar incentive program utilizing voluntary optional standards. To accomplish this, CARB staff recommends that the CTI establish voluntary optional low NOx standards that are similar to CARB's proposed optional low NOx standards for 2027 and subsequent model year engines.

B. Standards and Test Cycles

1. Emission Standards for RMC and FTP Cycles

"Given the importance of this [FTP] weighting factor, we request comment on the appropriateness of the current weighting factors across the engine categories. We are also interested in comment on how to address any challenges manufacturers may encounter to implement changes to the weighting factors."

"Since we believe these new [RMC] weighting factors better reflect in-use operation of current and future heavy-duty engines, we request comment on applying these new weighting factors for NOx and other criteria pollutants as well."

CARB Comment: CARB staff generally supports data driven modifications to existing weighting factors in certification cycles to reflect real-world in-use operations. However, the current test programs and data supporting CARB staff's planned changes to the emission standards are based on current FTP and RMC weighting factors. The establishment of emission standard stringency is connected to these testing weighting factors and needs to be considered. Thus, unless it is found that the substantial changes to weighting factors are needed, CARB staff recommends keeping the current weighting factors.

U.S. EPA made that determination for the RMC test cycle and modified the weighting factors in the Phase 2 GHG program for evaluating GHG emissions. CARB adopted identical weighting factors in its Phase 2 GHG rulemaking. We support U.S. EPA consideration of applying the RMC weighting factors already incorporated in the Phase 2 GHG standards to NOx and other criteria pollutant emissions. If U.S. EPA modifies the RMC weighting factors, CARB staff would consider proposing aligning with that change in a future rulemaking to maintain consistent test procedures.

"We request information that would help us determine the appropriate levels of any new emission standards for the FTP and RMC cycles."

CARB Comment: As discussed above, CARB staff is contemplating proposing a NOx standard of 0.05 g/bhp-hr for 2024 to 2026 model year engines and a NOx standard of

0.02 g/bhp-hr for 2027 and newer model year engines.[103] As discussed below, several sources of data supporting these proposed standards exist.

As demonstrated through MECA's modeling[104], 0.02 to 0.04 g/bhp-hr NOx levels on the FTP/RMC are feasible with engine calibration strategies that raise exhaust gas temperatures along with relatively minor improvements to current aftertreatment systems such as increasing SCR volume or improved catalyst formulations. These results would provide sufficient compliance margins for the proposed 2024 model year engine NOx standard of 0.05 g/bhp-hr on the FTP. MECA's modeling[105] also showed that 0.014 to 0.016 g/bhp-hr NOx levels on the FTP are feasible with engine calibration and hardware changes such as cylinder deactivation and advanced aftertreatment systems such as split SCR systems with a close-coupled light off catalyst and dual dosing, and exhaust system insulation. These results would also allow a compliance margin of about 25 percent relative to a 0.02 g/bhp-hr FTP NOx standard.

SwRI Stages 1/1b also demonstrated a 0.023 g/bhp-hr NOx level on the FTP, and 0.032 g/bhp-hr on the RMC utilizing engine calibration changes, a PNA, an SCRF, and a fuel burner on a 13-liter turbocompound Volvo engine. Furthermore, SwRI Stage 3/3b[106] testing showed a 0.019 g/bhp-hr NOx level on the FTP with cylinder deactivation and a thermally aged split SCR system with close-coupled SCR and dual dosing. The SwRI Stage 3/3b results were achieved while improving GHG emission and fuel economy by approximately 1 percent on the composite FTP. These results indicate that it is technically feasible to achieve significantly lower NOx emissions standards of approximately 0.02 g/bhp-hr NOx on the FTP/RMC without fuel economy and GHG penalties.

CARB recommendation: CARB staff recommends that the CTI establish maximum technically feasible NOx emissions standards of about 0.02 g/bhp-hr or less on the FTP/RMC for 2027 model year engines. CARB staff believes that there is enough lead

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[103] (CARB, 2020) "Workshop Presentation - Proposed Heavy-Duty Engine Standards," California Air Resources Board, September 26, 2019. https://www.arb.ca.gov/msprog/hdlownox/files/workgroup_20190926/staff/01_hde_standards.pdf

[104] (MECA, 2019) "Technology Feasibility for Model Year 2024 Heavy-Duty Diesel Vehicles in Meeting Lower NOx Standards," Manufacturers of Emission Controls Association, June 2019. http://www.meca.org/resources/MECA_MY_2024_HD_Low_NOx_Report_061019.pdf

[105] (MECA, 2020) "Technology Feasibility for Model Year 2027 Heavy-Duty Diesel Vehicles in Meeting Lower NOx Standards," Manufacturers of Emission Controls Association, February 2020. http://www.meca.org/resources/MECA_2027_Low_NOx_White_Paper_FINAL.pdf

[106] (Sharp, 2019) "Heavy-Duty Low NOX Demonstration Programs at SwRI - CARB Workshop Presentation," Christopher Sharp, Southwest Research Institute, September 26, 2019. https://www.arb.ca.gov/msprog/hdlownox/files/workgroup_20190926/guest/swri_hd_low_nox_demo_programs.pdf

time between now and the 2027 model year to refine technologies and strategies to meet this emission standard while also improving GHG emissions and fuel economy.

> "Given the importance of this [FTP] weighting factor, we request comment on the appropriateness of the current weighting factors across the engine categories. We are also interested in comment on how to address any challenges manufacturers may encounter to implement changes to the weighting factors."
>
> "Since we believe these new [RMC] weighting factors better reflect in-use operation of current and future heavy-duty engines, we request comment on applying these new weighting factors for NOx and other criteria pollutants as well."

CARB Comment: CARB staff in general supports data driven modifications to existing weighting factors in certification cycles to reflect real-world in-use operations. We support U.S. EPA consideration of applying the RMC weighting factors already incorporated in the Phase 2 GHG standards to NOx and other criteria pollutant emissions.

2. New Emission Test Cycles and Standards

> "EPA requests comment on the addition of a low-load cycle, the appropriateness of CARB's Candidate #7 low-load cycle, or other engine operation a low-load cycle should encompass, if adopted."
>
> "We request comment on the need or appropriateness of setting a federal idle standard for diesel engines... We request comment on including additional test cycles that may encourage manufacturers to improve the emissions performance of their heavy-duty gasoline engines in operating conditions not covered by the FTP cycle."
>
> "We request comment on the need for a low-load or idle cycle in general, and suitability of CARB's diesel-targeted low-load and clean idle cycles for evaluating the emissions performance of heavy-duty gasoline engines as well."

CARB Comment: One of the project objectives of the SwRI Stage 2 program was to develop a low load cycle that could be used as a certification cycle to verify that emissions are controlled under sustained low load and transient operations. SwRI, with NREL as a subcontractor, developed a number of low load cycle profiles that represent urban tractor and vocational vehicle operations characterized by low loads using real-world activity data from NREL's Fleet DNA database and CARB collected heavy-duty

vehicle activity.[107] CARB staff evaluated several candidate LLC profiles. After considering feedback from affected industry and other knowledgeable stakeholders, CARB staff selected candidate LLC#7[108] because it contains in ideal composition of sustained low load and engine transient operations (low load to high and high to low load transients) that challenge SCR functionality.

There are significant emissions reductions to be gained from controlling non-essential engine idling. CARB has idle restrictions in place that require the vehicle driver to shut off the engine after 5 minutes of continuous idling and a new engine certification requirement that requires new engines be equipped with a 5-minute non-programmable automatic engine shutdown system or optionally certify to a clean idle NOx standard of 30 grams per hour. To certify engines to the clean idle standards, manufacturers have to demonstrate that idling emissions do not exceed the clean idle standard under curb idle and elevated idle with accessory and hoteling loads. This program has been in effect since 2008.

As part of the HD Omnibus Regulation, CARB staff is planning to propose lower idling emissions standards for the 2024 and 2027 model year engines.[109]

Recommendations: CARB staff recommends that the CTI add new test procedures consistent with CARB staff's proposed LLC#7 and idling test procedures to its certification requirements to control emissions at light load, transient, and idle operations. Appendix C to this Attachment provides results of recent NOx emission measurements during idling that underscore the need for a federal idling standard.

C. In-Use Emission Standards

"We request comment on all aspects of a moving average window analysis approach. Commenters are encouraged to share the benefits and limitations of the window sizes, binning criteria, and performance calculations introduced here, as well as other strategies EPA should consider. We also request data providing time and cost estimates for

[107] (CARB, 2019) "CARB Workshop Presentation - Heavy-Duty Low NOx Program Low Load Cycle Development," California Air Resources Board, January 23, 2019. https://ww3.arb.ca.gov/msprog/hdlownox/files/workgroup_20190123/02-llc_ws01232019-1.pdf
[108] (CARB, 2019) "CARB Workshop Presentation - Heavy-Duty Low NOx Program Low Load Cycle," California Air Resources Board, September 26, 2019. https://www.arb.ca.gov/msprog/hdlownox/files/workgroup_20190926/staff/03_llc.pdf
[109] (CARB, 2019) "CARB Workshop Presentation - Proposed Heavy-Duty Engine Standards," California Air Resources Board, September 26, 2019. https://www.arb.ca.gov/msprog/hdlownox/files/workgroup_20190926/staff/01_hde_standards.pdf

implementing a MAW-based in-use program and what aspects of this approach could be phased in to reduce some of the upfront burden."

"We request comment on appropriate scaling factors or other approaches to setting MAW-based standards. Finally, we request comment on whether there is a continued need for measurement allowances in an in-use program such as described above."

CARB Comment: CARB staff analysis of the manufacturer submitted heavy-duty in-use testing (HDIUT) data set for 2010 to 2014 model year engines equipped with SCR showed that the Not-to-Exceed (NTE) method and exclusions reduce valid data to a small fraction of total operation. In some cases, manufacturers completed HDIUT testing without any valid data, which clearly subverts the purpose of the program. Of the HDIUT tests analyzed, 24 percent reported zero valid NTE events, and as a result passed HDIUT testing by default. The average percent of data and percent of NOx emissions represented in NTE events was less than six percent in the HDIUT data set. Overall, the NTE method does not capture the operation of the heavy-duty fleets in terms of test time or NOx emissions (Bartolome et al., 2018).[110]

In Europe under the Euro VI Regulation (OJ, 2011),[111] similar in-use testing is required for their program utilizing a Moving Average Window (MAW) approach. Because the MAW method utilizes fewer exclusions to invalidate windows, the Europeans are able to evaluate a broader range of engine operations than in the U.S. In an evaluation of U.S. and European heavy-duty diesel engine products, the ICCT concluded the European-certified heavy-duty diesel engines have lower emissions over the full range of engine operation, despite having a NOx emission standard that is 72 percent higher (i.e., less stringent) than the U.S. EPA standards (Posada et al., 2019).[112] The lower emissions are attributed to their Euro VI in-use testing program that assesses a broader range of operation and requires engine manufacturers to design towards the NOx emission standard over a greater portion of engine operation.

CARB staff has been evaluating the United States and European in use testing programs to develop a significantly more effective in-use test procedure that evaluates

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[110] (Bartolome et al., 2018) "Toward Full Duty Cycle Control: In-Use Emissions Tools For Going Beyond The NTE," Christian Bartolome, Lee Wang, Henry Cheung, Stephan Lemieux, Kim Heroy-Rogalski, William Robertson, California Air Resources Board, 28th CRC Real-World Emissions Workshop, March 2018.

[111] (OJ, 2011) Commission Regulation (EU) No 582/2011, Official Journal of the European Union, L 167/1-168, May 25, 2011. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:167:0001:0168:EN:PDF

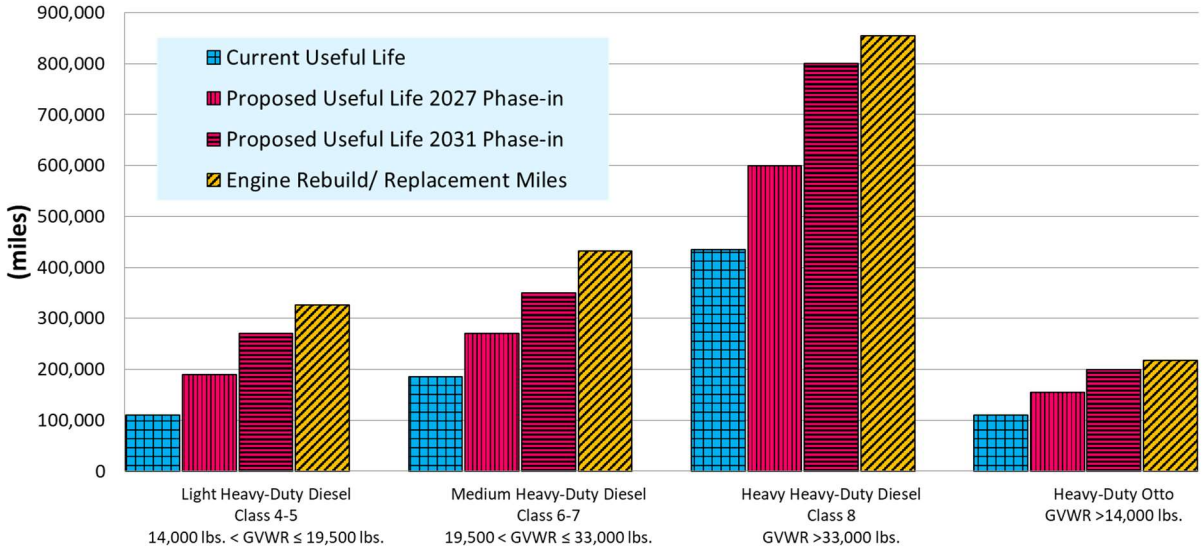
[112] (Posada et al., 2019) "Analysis of HDV in-use NOx emissions performance and compliance protocols," F. Posada, H. Badshah, A. Isenstadt, R. Muncrief, The International Council on Clean Transportation, CARB Low NOx Workshop, September 26, 2019.

all types of in-use operations to better control real-world emissions. CARB staff has been working with technical representatives of OEMs and U.S. EPA to develop a 3-bin MAW (3B-MAW) approach that evaluates almost all real-world operation and that distinguishes the modes of operation and categorizes them into three separate operational bins, based on the operational characteristics that best applies to the certification test cycle (idle, LLC or FTP/RMC). CARB staff's proposal would replace the NTE test procedures with the 3B-MAW procedures for the manufacturer-run HDIUT program and for CARB's Heavy-Duty In-Use Compliance (HDIUC) testing program beginning with 2024 and subsequent model year engines, with some modifications in 2027 and subsequent model year engines. CARB staff recommends that CARB staff and U.S. EPA staff continue to work together to develop a robust, consistent 3B-MAW procedure.

D. Extended Regulatory Useful Life

CARB Comment: Manufacturers are responsible for ensuring their engines meet emission standards for applicable regulatory useful life periods. The useful life period is meant to ensure adequate durability of the engine and the vehicle's emission control systems. However, as shown in the figure below, the current mileages for the useful life are significantly lower than the mileage at which modern heavy-duty engines get rebuilt or replaced. This highlights the need for longer useful life periods to reduce emissions by: (1) better representing the longer modern service lives of heavy-duty engines, and (2) encouraging manufacturers to make parts more durable in order to avoid non-compliance with in-use testing requirements and inconvenient, costly recalls.

Figure of Current and Proposed Heavy-Duty Useful Life Compared to Engine Rebuild/Replacement Mileages (MacKay, 2019)[113]



As part of the HD Omnibus Regulation rulemaking, CARB staff plans to propose amendments that would phase in increased useful life mileage periods beginning with the 2027 model year, with the final phase-in occurring with the 2031 model year. The table below shows the current useful life periods and the lengthened useful life periods CARB staff plans to propose for the different heavy-duty engine categories that are used in heavy-duty vehicles weighing greater than 14,000 pounds GVWR.

[113] (MacKay, 2019) "CARB Summary Report on the Analysis of the MacKay & Company Data on Heavy-Duty Engine Rebuilds and Replacements," California Air Resources Board / MacKay & Company, March 2019.

Table of Current and Proposed Heavy-Duty Useful Life Periods

Vehicle / Engine Category (GVWR)	Current Useful Life Periods (Miles)	Proposed Phase-in for Useful Life Effective MY 2027 (Miles)	Proposed Phase-in for Useful Life Effective MY 2031 (Miles)
Heavy Heavy-Duty Diesel Class 8 GVWR >33,000 lbs.	435,000 10 years 22,000 hours	600,000 11 years 30,000 hours	800,000 12 years 40,000 hours
Medium Heavy-Duty Diesel Class 6-7 19,500 < GVWR ≤ 33,000 lbs.	185,000 10 years	270,000 11 years	350,000 12 years
Light Heavy-Duty Diesel Class 4-5 14,000 lbs. < GVWR ≤ 19,500 lbs.	110,000 10 years	190,000 12 years	270,000 15 years
Heavy-Duty Otto GVWR >14,000 lbs.	110,000 10 years	155,000 12 years	200,000 15 years

The proposed useful life mileage periods were chosen to roughly correspond to the mileage when engines are either rebuilt or replaced. These proposed mileage values in the table were estimated using CARB staff's analysis of engine rebuild data, along with additional stakeholder input.

> "We welcome comment on the average number of times an engine core receives an overhaul before being scrapped. We are also requesting comment on the whether the 2013 EPA report continues to reflect modern engine rebuilding practices."

CARB Comment: CARB does not have specific data regarding the average number of times that an engine core receives an overhaul/rebuild, but it did obtain data from MacKay & Company (MacKay, 2019)[114] that gives the mileage at which these overhaul/rebuilds occur. CARB's analysis looked at the out-of-frame mileages for vehicle classes 4 through 8 using the MacKay survey data collected from 2012- 2018. In the table below, the comparison to the 2013 U.S. EPA report shows that the U.S. EPA mileages are greater than the CARB values. However, because the percentage differences in the rebuild mileages ranged from only 4 to 11 percent, CARB staff believes those percentages represent sufficiently low mileage variances, and so the U.S. EPA values remain reasonable estimates for reflecting modern engine rebuild practices.

[114] (MacKay, 2019) "CARB Summary Report on the Analysis of the MacKay & Company Data on Heavy-Duty Engine Rebuilds and Replacements," California Air Resources Board / MacKay & Company, March 2019.

Vehicle class	Out-of-frame overhaul/ rebuild (miles)		Percent Difference
	U.S. EPA (Miles)	CARB Analysis of MacKay & Co. Weighted Average Engine Rebuild/ Replacement from 2012-2018 (Miles)	
Class 3	256,000	n/a	n/a
Class 4	346,300	330,101	5%
Class 5	344,200	320,917	7%
Class 6	407,700	390,209	4%
Class 7	509,100	455,296	11%
Class 8	909,900	854,616	6%

"Beginning no later than model year 2021, *chassis-certified* heavy-duty gasoline vehicles are subject to a 150,000-mile useful life. We request comment on whether this would be the appropriate value for heavy-duty gasoline *engines,* or if a higher value would be more appropriate."

CARB Comment: CARB believes a higher mileage value for the heavy-duty gasoline engines is feasible because there is engine replacement data to support that belief. The MacKay data obtained by CARB also provided information on heavy-duty Otto-cycle (i.e., gasoline-fueled) engines replacement miles. Recall that this engine class is not typically designed to be rebuilt (i.e., the chassis and engine may wear out at the same time). From CARB's analysis, on average, these engines get replaced at 217,283 miles. This is comparable to recent product literature (Isuzu, 2019)[115] that advertises a 200,000 mile design life for the gasoline engine. Consequently, under CARB's 2020 useful life proposal, useful life periods would be phased-in at 155,000 miles in MY 2027, and 200,000 miles in MY 2031. These proposed values are shown in the table below.

Vehicle Class	CARB Analysis of MacKay & Co. Weighted Average Engine Replacement from 2012-2018 (miles)	CARB UL Proposal MY 2027 (miles)	CARB UL Proposal MY 2031 (miles)
HD Otto	217,283	155,000	200,000

E. Ensuring Long-Term In-Use Emissions Performance

1. Lengthened Emissions Warranty

CARB Comment: Longer warranty periods help both to encourage manufacturers to produce more durable emission control systems and components that improve the emissions performance of their engines and vehicles, and to give vehicle owners

[115] (Isuzu, 2019) "Your Vocation on an Isuzu Truck," Advertisement in Work Truck Magazine, April 2019.

greater incentive to fix non-performance-related malfunctions that otherwise might not get repaired if the owner had to bear the cost for the repair. Both of these developments result in emission control systems that operate cleaner for longer periods of their usage.

Evidence generated by CARB testing of in-use heavy-duty vehicles (CARB, 2017a)[116] and recent warranty claim data for heavy-duty vehicles (CARB, 2018)[117] together point to current shortcomings with heavy-duty engine and vehicle emission warranty requirements. CARB's test programs have identified numerous heavy-duty vehicles with mileages within their applicable regulatory useful life periods, but beyond their warranty periods, that had NOx emission levels significantly above the applicable certification standards. Also, CARB staff's review of manufacturer warranty claims showed high warranty claim rates for major heavy-duty diesel engine components. Statements at public meetings with fleet owners, retrofit installers, and equipment dealers confirmed these findings, and suggested that some fleets are experiencing significant vehicle downtime due to parts failures. A survey conducted in 2017 of California truck owners/operators by the Sacramento Institute for Social Research (ISR) found over half of respondents reported having experienced downtime because of repairs for their California heavy-duty vehicles manufactured between 2007 and 2017 (ISR, 2017).[118] Further, over 15 percent of these respondents experienced downtime events lasting over a month per vehicle (on average).

Longer warranty periods for heavy-duty vehicles and engines are needed for three main reasons: (1) to better represent their longer modern service lives and ensure that the emission control systems remain operational throughout a greater portion of a vehicle's service life, (2) to reduce incidences of tampering and mal-maintenance, and (3) to encourage manufacturers to make parts more durable. As an added benefit, the lengthened warranty periods would protect heavy-duty vehicle owners from having to pay to replace emissions-related components that are supposed to remain durable throughout the useful life of the engine.

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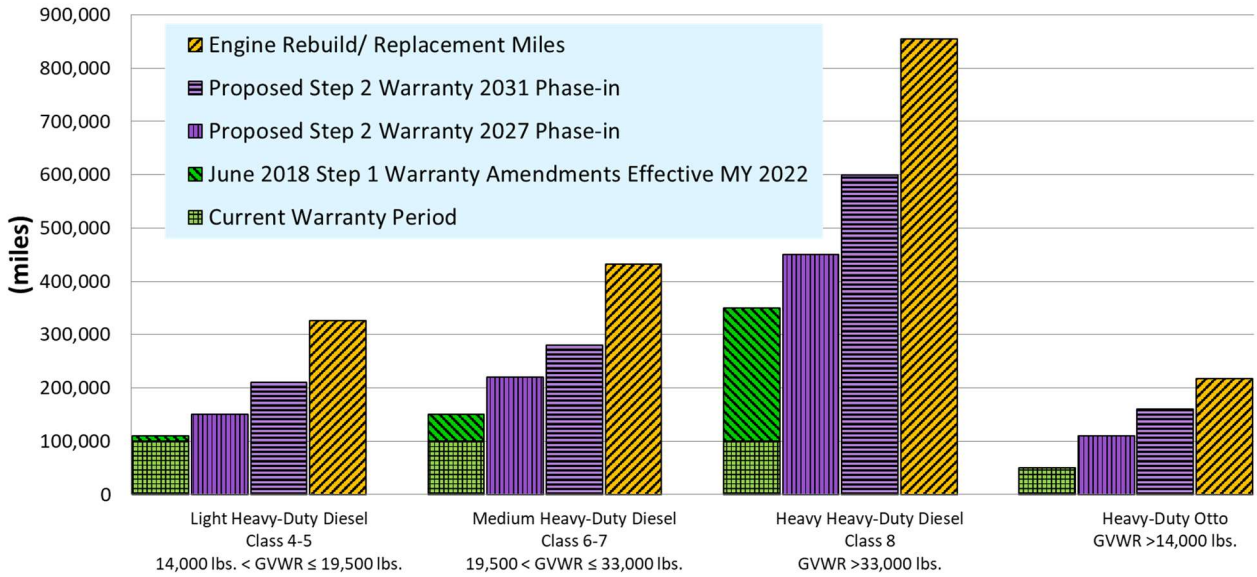
[116] (CARB, 2017a) "Evaluation of the Heavy-Duty In-Use Testing (HDIUT) Program: Not-to Exceed (NTE) vs. Work-Average Window (WAW) Concepts, In-Use Testing Workgroup Meeting," California Air Resources Board, February 22, 2017. https://www.arb.ca.gov/msprog/hdlownox/files/workgroup02222017/inuse_wg_presentation_02222017.pdf

[117] (CARB, 2018) "Staff Report: Initial Statement of Reasons for Proposed Rulemaking, "Public Hearing To Consider Proposed Amendments to California Emission Control System Warranty Regulations and Maintenance Provisions For 2022 and Subsequent Model Year On-Road Heavy-Duty Diesel Vehicles and Heavy-Duty Engines With Gross Vehicle Weight Ratings Greater Than 14,000 Pounds and Heavy-Duty Diesel Engines In Such Vehicles," (Step 1 Warranty), California Air Resources Board, May 8, 2018. https://www.arb.ca.gov/regact/2018/hdwarranty18/isor.pdf

[118] (ISR, 2017) Survey and Analysis of Heavy-Duty Vehicle Warranties in California | 15MSC009, Institute for Social Research, California State University, Sacramento, December 2017.

CARB staff's current thinking for proposed amendments to warranty periods are depicted in the figure below, along with the adopted Step 1 warranties in 2022 for the heavy-duty diesel vehicle classes 4-8, and the current warranty period for the heavy-duty Otto-cycle engine category (shown for completeness). For comparison, the engine rebuild/replacement miles are also shown. In particular, the discrepancy in the mileages of the current federal warranty of 100,000 miles and the rebuild/replacement mileages highlights the need for the lengthened phased-in warranty coverage.

Figure of Current, Step 1 and Proposed Step 2 Heavy-Duty Warranties Compared to Engine Rebuild/Replacement Mileages



1. "In conversations with rebuilding facilities, it appears that aftertreatment components typically remain with the vehicle when engines are rebuilt out of frame and are not part of the rebuild process. We request comment on the performance and longevity of the aftertreatment components when the engine has reached the point of requiring a rebuild. Currently, aftertreatment components are covered by the useful life of the engine overall. "While our current logic, explained above, would not support proposing useful life values for the entire engine that extend beyond the rebuild interval, it may not be appropriate for the durability requirements for the aftertreatment to be limited by the rebuild interval for the rest of the engine if current aftertreatment systems remain in service much longer. Thus, we are requesting comment on how to treat such components, including whether there is a need for separate provisions for aftertreatment components."

CARB Comment: CARB staff agrees that the rebuild data is more indicative of the service life of the engine overall, and may not necessarily be reflective of the durability of the emissions control and aftertreatment systems. As U.S. EPA stated in the ANPRM, these systems remain with the vehicle and are not typically part of the rebuild

process, therefore it could appear that their durability exceeds that of the engine. However, CARB staff is unaware of the existence of any data that would support this. As described below, an indirect approach that looks at the available extended warranty coverages can be used for such an assessment.

In gathering the indirect supporting information on the durability of the emissions control systems, CARB staff found that some manufacturers offer extended warranties beyond the regulatory-required warranties. Under these extended warranties, some OEMs cover emissions control and aftertreatment systems out to 500,000 miles (Paccar 2020,[119] Detroit Diesel, 2020[120]). Additionally, extended warranties that cover the emissions control and aftertreatment systems are also provided by independent third-party businesses with mileages being offered as high as 1,000,000 miles, provided that the vehicles satisfy certain initial inspection requirements and continued to be maintained in accordance with the OEMs' recommendations (Truck Master Plus, 2020,[121] and Premium 2000, 2020[122]).

However, published durability information from the parts suppliers proved difficult to obtain. In CARB staff's consultations with the suppliers regarding their DPFs and SCR systems, many verbally stated that these systems are typically designed for 1,000,000 miles of operation. Additionally, at least one supplier stated on their product webpage that their turbochargers should last as long as the engine, but in order to ensure that happens, the maintenance instructions must be strictly observed (BorgWarner, 2020[123]).

Continuing to do the OEMs' recommended maintenance is a common factor in the extended warranty coverage. The essence of these businesses' willingness to offer coverage out to these longer mileages lies in their accompanying requirement on vehicle owners to continue the recommended maintenance, otherwise the extended warranties would not be honored. Continuing to properly perform all of the maintenance helps to ensure that the engine and emission control system, as a whole, continue operating in a healthy state in which cascading upstream component problems are

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[119] (Paccar, 2020) "Extended Warranty Plans," Paccar Powertrain, January 29, 2020. https://paccarpowertrain.com/extended-warranty-plans.pdf

[120] (Detroit Diesel, 2020) "Powertrain Service Coverage for On-Highway Trucks," Detroit Diesel Corporation, January 29, 2020. https://detroitads.azureedge.net/Detroit%20Powertrain%20Serice%20Coverage%20for%20On-Highway%20Trucks.pdf

[121] (Truck Master Plus, 2020) Mileage Limitations and Eligibility, Truck Master Plus, January 29, 2020. http://truckmasterplus.com/mileage-guidelines/

[122] (Premium 2000, 2020) Benchmark Warranty- Premium 2000+ Used Truck Warranties, January 29, 2020. https://www.premium2000.com/programs/benchmark-warranty

[123] (BorgWarner, 2020) "Recommendations for Servicing and Care," BorgWarner, January 29, 2020. http://www.turbos.borgwarner.com/en/products/turbochargerRecommendations.aspx

avoided, and thus allowing the downstream components to operate for their designed useful lives.

Therefore, given that the available extended warranty periods, range from 500,000 to 1,000,000 miles (with continued proper maintenance), and the claim by some suppliers of a 1,000,000 mile design life, it is reasonable to conclude that the overall longevity of these emissions control systems could very well reach beyond the engine rebuild mileage. However, from the lack of directly supporting data to definitively obtain a numerical value, and because these systems need to last as long as the engine, CARB staff believes that it is still reasonable for their useful life to remain covered by the engine overall, and not under a separate provision.

2. "In 2018, CARB published an Initial Statement of Reasons document [Step 1 Warranty] regarding proposed amendments to heavy-duty maintenance and warranty requirements. This document includes analysis of warranty data indicating that emission components for heavy heavy-duty engines had failure rates ranging from 1-17 percent, while medium heavy-duty engines had emission component failure rates ranging from 0-37 percent. ARB did this analysis using data from MY2012 engines, as this was the only model year with a complete five-year history. That model year included the phase-in of advanced emission controls systems, which may have an impact on failure rates compared to other model years. EPA is seeking comment on whether these rates reflect component failures for other model year engines and information on representative failure rates for all model years."

CARB Comment: CARB staff updated this analysis using its MY 2013 Emission Warranty Information Report data because it was the latest complete five year set. The results are shown below.

2013 Model Year Warranty Claims Rates and Costs for the Heavy-Duty Vehicles

Component	HHDD Warranty Claims Rate[124]	MHDD Warranty Claims Rate	LHDD Warranty Claims Rate	HDO Warranty Claims Rate
CAT	0.0%	0.00%	0.00%	8.23%
DOC	8.1%	4.95%	0.18%	0.00%
DPF	1.1%	1.45%	3.38%	0.00%
ECU	5.9%	12.91%	0.26%	0.00%
SCR	1.3%	11.03%	0.00%	0.00%
DEF DOSER	9.2%	6.52%	0.86%	0.0%

[124] Note that the total claims values shown are for HHDD and urban buses. This was done in order to remain consistent with CARB's certification requirements that define an urban bus as a bus that is normally powered by a heavy heavy-duty engine and weighs greater than 33,000 pounds GVWR.

Component	HHDD Warranty Claims Rate[124]	MHDD Warranty Claims Rate	LHDD Warranty Claims Rate	HDO Warranty Claims Rate
DPF DOSER	7.1%	2.17%	2.99%	0.0%
EGR COOLER	9.6%	17.76%	0.72%	0.0%
EGR VALVE	3.2%	6.72%	5.09%	0.0%
FUEL INJECTOR	6.0%	5.32%	1.33%	0.0%
TURBOCHARGER	9.8%	12.06%	5.41%	0.0%
BLOWBY FILTER	0.0%	0.0%	1.9%	0.0%
BOOST CONTROL VALVE	0.1%	0.5%	0.3%	0.0%
CHARGE AIR COOLER	0.0%	0.2%	0.0%	0.1%
CHARGE AIR DUCT	0.3%	0.9%	0.4%	0.0%
CLAMP	0.1%	0.3%	0.3%	0.0%
CRANKCASE SEPARATOR	0.2%	0.0%	0.0%	0.0%
CYL HEAD	0.2%	0.0%	0.0%	0.0%
DEF PUMP	4.1%	0.0%	0.0%	0.0%
DEF TANK	0.2%	0.0%	3.9%	0.0%
ECU REPROGRAM	29.5%	0.6%	6.1%	0.0%
ELECTRICAL HARNESS	1.1%	1.3%	1.3%	0.0%
EXHAUST MANIFOLD	3.3%	2.6%	4.5%	0.0%
EXHAUST VALVE	0.7%	0.0%	0.0%	0.0%
FUEL LINE	0.1%	0.0%	0.1%	0.0%
FUEL PUMP	3.4%	1.4%	0.0%	0.1%
FUEL TANK	0.0%	0.0%	0.0%	0.0%
GASKET	1.0%	1.4%	0.3%	0.0%
IGNITION CONTROL MODULE	2.6%	0.8%	0.0%	0.0%
INTAKE MANIFOLD	0.0%	0.0%	0.0%	0.2%
NOx SENSOR	15.2%	7.9%	3.4%	0.0%
OIL PUMP	0.3%	0.0%	2.0%	0.0%
OIL RAIL	0.1%	1.1%	0.1%	0.0%
OIL SEPARATOR	8.0%	0.0%	1.6%	0.0%
OTHER SENSORS	29.1%	11.2%	41.9%	3.4%
PRESS CONTROL VALVE	0.4%	0.0%	0.0%	0.0%
RUBBER HOSE	0.2%	1.2%	0.9%	0.0%
THROTTLE VALVE	1.3%	0.7%	0.1%	0.0%
VACUUM PUMP	0.0%	0.0%	2.1%	0.0%
TOTAL	**162.7%**	**112.8%**	**91.4%**	**12.0%**

3. "We welcome comment on annual vehicle miles travelled for different classes and vocations."

CARB Comment: The average annual vehicle miles traveled (VMT) and population distribution were obtained from CARB's latest emission model (EMFAC 2017). These values are given in the following tables.

HHD Vehicle Subcategory	Population %	Annual VMT (miles)
Motor Coach	1.31%	33457
T7 CAIRP	13.15%	45458
T7 CAIRP construction	1.19%	45458
T7 other port	0.70%	41075
T7 POAK	2.57%	38794
T7 POLA	7.74%	42446
T7 Public	11.01%	7677
T7 Single	11.79%	20939
T7 single construction	8.29%	20939
T7 SWCV	7.18%	15437
T7 tractor	21.75%	41075
T7 tractor construction	5.54%	20939
T7 utility	0.27%	7677
UBUS	7.50%	32298
	weighted avg	**30,225**

MHD Vehicle Subcategory	Population %	Annual VMT (miles)
T6 CAIRP Heavy	1.16%	45458
T6 CAIRP Small	0.63%	14358
T6 Instate Construction Heavy	3.32%	20939
T6 Instate Construction Small	10.17%	14358
T6 Instate Heavy	14.31%	41075
T6 Instate Small	45.59%	14358
T6 Public	7.51%	5565
T6 Utility	1.55%	5565
All Other Buses	3.68%	16813
SBUS	5.87%	12406
UBUS	6.21%	28120
	weighted avg	**18,796**

LHD Vehicle Subcategory	Population %	Annual VMT (miles)
T6 CAIRP Heavy	1.38%	45458
T6 CAIRP Small	0.75%	14358
T6 Instate Construction Heavy	3.94%	20939

LHD Vehicle Subcategory	Population %	Annual VMT (miles)
T6 Instate Construction Small	12.08%	14358
T6 Instate Heavy	16.99%	41075
T6 Instate Small	54.12%	14358
T6 Public	8.91%	5565
T6 Utility	1.84%	5565
	weighted avg	**18,641**

HDO Vehicle Subcategory	Population %	Annual VMT (miles)
OBUS	16.18%	10046
SBUS	8.29%	12406
T6TS	68.15%	11420
T7IS	0.17%	23724
UBUS	7.22%	28120
	weighted avg	**12,506**

4. "We request comment on emission component durability, as well as maintenance or operational strategies that could substantially extend the life of emission components and any regulatory barriers to implementing these strategies."

CARB Comment: The required engine-dynamometer certified durability demonstrations establish technical feasibility of lower emission standards as long as necessary maintenance and replacements are conducted. CARB staff believes that longer useful life periods are clearly feasible because manufacturers can either design parts and systems that are durable and function for the full useful life periods, or specify appropriate maintenance intervals such that owners inspect, repair, and replace parts as needed during the full useful life period. In the latter case, the only restrictions on the manufacturer are that:

(1) The repair/replacement intervals must be at least as long as the regulatory minimum maintenance intervals, and
(2) The manufacturer must cover replacement cost for any parts deemed not replaceable (i.e., for the diesel particulate filter, catalytic converter bed, and under CARB's June 2018 Step 1 warranty amendments, the EGR system and turbocharger,).

Consider the example of a heavy heavy-duty diesel engine with a useful life period of 800,000 miles/12 years/40,000 hours. The manufacturer of this engine could choose to make the engine and aftertreatment durable to 800,000 miles/12 years/40,000 hours, if it finds it technically feasible to do so. If, on the other hand, the manufacturer determines it is not feasible or cost-effective to make the entire emission control system durable for this period, it could instead specify repair/replacement intervals at which

time the owner's manual would direct the owner to repair or replace certain components. Each OEM will need to determine its preferred mix of improving durability and specifying needed maintenance, but it is clearly technically feasible to do so.

5. "We request comment on an appropriate length of emissions warranty period for engine and aftertreatment components to incentivize improved durability with reasonable cost."

CARB Comment: The table below summarizes warranty periods that will likely be proposed in CARB's HD Omnibus Regulation, along with the current warranty periods, the Step 1 warranty periods due to take effect with the 2022 model year, and values derived from CARB's analysis of the MacKay data for engine rebuilds/ replacements. The current warranty periods are disproportionate to the actual service lives of modern on-road heavy-duty vehicles, and engines, as evidenced by the MacKay mileages. CARB staff considers the proposed phase-in values to be an appropriate length for the emissions warranty because they represent a more significant percentage of the engine rebuild/replacement mileage.

Vehicle / Engine Category Gross Vehicle Weight Rating (GVWR)	**Current Warranty (Miles)**	**June 2018 Step 1 Warranty Amendments** **Effective MY 2022 (Miles)**	**Proposed Phase-in for Step 2 Warranty** **Effective MY 2027 (Miles)**	**Proposed Phase-in for Step 2 Warranty** **Effective MY 2031 (Miles)**	**CARB Analysis of MacKay & Co. Weighted Average Engine Rebuild/ Replacement from 2012-2018 (Miles)**
Heavy Heavy-Duty Diesel Class 8 GVWR >33,000 lbs.	100,000 5 years 3,000 hours	350,000 5 years	450,000 7 years 22,000 hours	600,000 10 years 30,000 hours	854,616
Medium Heavy-Duty Diesel Class 6-7 19,500 < GVWR ≤ 33,000 lbs.	100,000 5 years 3,000 hours	150,000 5 years	220,000 7 years 11,000 hours	280,000 10 years 14,000 hours	432,652
Light Heavy-Duty Diesel Class 4-5 14,000 lbs. < GVWR ≤ 19,500 lbs.	100,000 5 years 3,000 hours	110,000 5 years	150,000 7 years 7,000 hours	210,000 10 years 10,000 hours	326,444
Heavy-Duty Otto GVWR >14,000 lbs.	50,000 5 years	n/a	110,000 7 years 6,000 hours	160,000 10 years 8,000 hours	217,283

Regarding the increased costs under the proposal, CARB staff expects that these lengthened warranty periods would increase the incremental cost, however they are

expected to be reasonable and cost-effective because, on an average basis, they would be recouped as a repair cost savings for any repairs done during the warranty period.

6. "Commenters are encouraged to address whether warranty should be tied to longer useful life, as well as whether the warranty period should vary by component and/or engine category."

CARB Comment: The regulatory useful life is the period of time or of engine operation during which manufacturers are liable for emissions compliance, whereas the emissions warranty is a requirement for the manufacturers to cover any emissions-related repairs. The useful life mileages are based on the engine rebuild mileages and so they represent the real-world usage of the vehicle before the engine is scrapped. The warranty period should be tied to the useful life, and it should be a significant portion of the useful life period, because doing so would help ensure that the vehicle would meet its applicable emission standards for the majority of its useful life period. Warranty coverage facilitates reducing emissions by (1) making it more likely that, since the cost of the repairs are covered by the manufacturer during the warranty period, any needed emissions-related repairs will be completed and vehicle owners are less likely to tamper with emission aftertreatment systems, and (2) helping ensure that manufacturers will design more durable emission control systems by being well-designed and properly built to function as intended during the warranty period.

Regarding the concept of varying the warranty period by engine category, CARB adopted different warranty periods for diesel engines in its June 2018 Step 1 warranty amendments. More specifically, CARB adopted provisions in which the scope of the warranty was based on the vehicle, while the duration of the warranty period was based on the primary intended service class of the engine. This meant that any heavy-duty engine could now be used in any class of heavy-duty vehicle, but held only to the warranty period of the engine. Previously such an allowance was not a source of any issues because all of the warranty periods were the same for each vehicle class (i.e., 5 years or 100,000 miles). Since adopting this amendment, some issues involving the overall suitability of some possible combinations of engine classes and vehicle classes have come to light, which CARB staff plans to rectify in its HD Omnibus Regulation. Further, CARB staff plans to propose to amend the warranty periods for heavy-duty Otto-cycle engines, which would be applicable to all of these engines used in heavy-duty vehicles greater than 14,000 lbs. GVWR. Because heavy-duty Otto-cycle engines are not grouped by primary intended service classes, it is not currently possible to propose discrete warranty periods for them. CARB staff believes establishing some finer classification method for such engines may have future merit, although at this time cannot provide any specific criteria or guidance for doing so.

Regarding the concept of varying the warranty period on the basis of components, CARB staff sees potential advantages and disadvantages to such an approach but does not currently plan to propose such an approach. On one hand, CARB staff believes that the warranty period should remain applicable to the entire engine and its emissions control systems, and not vary by component. Specifically, if the warranty period were to

vary by component, or be configured to vary over time, then CARB staff feels that more complexities would be introduced in to a process that many stakeholders already believe is complicated enough. In particular, such a change could further confuse vehicle owners about their own warranty coverage, confuse and contribute to complications with repair facilities in carrying out the warrantied repairs, as well as create challenges for the OEMs when dealing with California's Emissions Warranty Information Reporting requirements. However, on the other hand, California already has a varied warranty period for emission control system parts for light-duty vehicles (i.e., the 7 year/70,000 mile high-price parts list), which, while more burdensome administratively for manufacturers and CARB than non-varied warranty period requirements, has been fully implemented and functioning for many years. Ultimately, for simplicity, CARB staff does not currently plan to propose to vary the warranty period by component for heavy-duty emission-related components.

2. Tamper-Resistant Electronic Controls

"Finally, we are following ongoing work at SAE International that focuses on preventing cyber security hacking activity. The efforts to combat such safety- and security-related concerns may provide a pathway to apply similar solutions for emission control software and modules. We anticipate such a long-term approach would require effort beyond the CTI rulemaking timeframe. EPA requests comment on these or other actions we could take to help prevent ECM tampering."

CARB Comment: We agree cyber security and anti- tampering measures are important for vehicle safety and the integrity of CARB and U.S. EPA emissions control programs. CARB staff is similarly following the work at SAE International and has also had dialogue with the National Highway Traffic Safety Administration (NHTSA) on such issues. Since these concerns arise from manufacturer-specific vehicle communication networks, and not the OBD system or regulations, the solutions to security must involve the vehicle manufacturers themselves. CARB OBD regulations do not require any intrusive vehicle or network messages such that the messages could be used to put the vehicle or operator at a security risk.

3. Serviceability Improvements

"EPA requests comment on the following serviceability topics:
• Usefulness of currently available emission diagnostic information and equipment
• The adequacy of emission-related training for diagnosis and repair of these systems
• The readiness and capabilities of repair facilities in making repairs
• The reasonableness of the cost of purchasing this information and the equipment

• The prevalence of using of this equipment outside of large repair facilities
• If there are any existing barriers to enabling owners to quickly diagnose emission control system problems"

"Therefore, we request comment on which signals we should require to be made available publicly to ensure adequate access to critical emissions diagnostic information."

"We broadly request comment on actions EPA should take, if any, to improve maintenance practices and the repair experience for owners. We welcome comment on the adequacy of existing emission control system maintenance instructions provided by OEMs."

CARB Comment: CARB staff is supportive of adding data or features to the OBD requirements to facilitate maintenance and repairs.

"In addition, we request comment on whether other stakeholders (such as state and local agencies) may find it difficult in the field to detect tampering due to limitations of available scan tools and limited publicly available broadcast OBD parameters. We request comment on signals that are not currently broadcast publicly that would enable agencies to ensure vehicles are compliant during inspections."

CARB Comment: Many state and local agencies have considerable experience in detecting fraudulent inspections and tampered vehicles using available data. The vehicle's existing parameters set creates a "fingerprint" for each year/make/model, and this information may be used to help identify fraudulent inspections. CARB staff is supportive of adding data or features to the OBD system to facilitate identifying tampered vehicles.

4. Emission Controls Education and Incentives

"We seek comment on the potential benefits of educational and/or voluntary, incentive-based programs such as EPA's SmartWay program"

CARB Comment: CARB staff and project partners conduct public outreach and education through several mechanisms: press events, public meetings, an annual showcase, seminars, press releases, and written collateral. CARB staff is supportive of U.S. EPA conducting similar activities.

5. Improving Engine Rebuilding Practices

"We solicit comment on whether we could appropriately ensure compliance without creating unnecessary market disruption by requiring

owners to attest that any problems shown in their engine's report will be repaired within a certain timeframe."

"We request comment on the feasibility and challenges of such an approach, including suggestions of relevant OBD parameters, report format, and how to collect the information (e.g., could manufacturers build into new vehicles the ability for such a status report to be run using a generic scan tool and be output in a text file)."

CARB Comment: CARB is currently developing a HD I/M program, as discussed further at https://ww2.arb.ca.gov/our-work/programs/heavy-duty-inspection-and-maintenance-program. The implementation of a robust nationwide HD I/M program on heavy-duty vehicles would significantly address concerns regarding emission-related failures being properly repaired. Whether the engine has been recently rebuilt or not, a HD I/M program should verify the proper operation of the emission control system through the interrogation of the OBD system and/or physical inspection. The frequency of the inspection should be sufficient such that any emission-related repairs, if needed, would be made shortly after an engine rebuild so as to minimize any potential emission increases. It may be the that the efforts to verify a vehicle's emissions performance and/or status before an engine rebuild may not add significant benefit over simply verifying performance through an I/M or similar program after the rebuild. CARB staff is supportive of adding data or features to the OBD requirements to be used to ensure rebuilds and repairs are properly performed.

F. Certification and Compliance Streamlining

1. "Our regulations currently require engine families to undergo a thorough certification process each year. This includes ''carry-over'' engines with no year-to-year calibration or hardware changes. Although we have already adopted certain simplifications, we intend to consider additional improvements to this this process under the CTI to reduce the burden of certification for carry-over engines. We request comment on specific revisions that could apply for certifying carryover engines."

CARB Comment: CARB staff examined the possibility of streamlining the certification of carryover engines for both on-road and off-road engines back in 2014. After a year-long analysis of the various aspects of certification, CARB published guidelines for "Streamlined certification process for carryover and partial carryover certification applications[125]" on June 23, 2015. The intent of the streamlining was to expedite the annual certification process for products that do not undergo any changes from year-to-year.

[125] Mail-Out # ECARS 2015-7. https://ww3.arb.ca.gov/msprog/mailouts/ecars1507/ecars1507.pdf

Since the implementation of the streamlined certification process, CARB certification staff has observed that while many off-road spark-ignition and compression-ignition manufacturers take advantage of this process, no on-road heavy-duty diesel or Otto-cycle manufacturer has utilized this process.

Analysis of the past certification data indicates that there are two main reasons that complicates the streamlining of certification process to on-road heavy-duty engine manufacturers. These are described briefly below.

OBD Approval Process

A brief overview of the certification process for on-road heavy-duty engine families are shown below in Figure 1. As shown, manufacturers must first obtain the OBD approval letter before receiving the actual Executive Order (EO) for each engine family. OBD approvals are done on an annual basis for each manufacturer.

Since the two processes (OBD approval and certification approval) are intertwined, the certification timelines can only be tied to the end of the OBD approval process. CARB staff was cognizant of this issue at the time, and therefore established strict deadlines for issuing EOs for carryover and partial carryover engine families based on the receipt of the OBD approval letter.

Because of the relationship between OBD approval and the certification process, no on-road heavy-duty manufacturer has used the streamlined certification process for carryover and partial carryover engines. A survey of the 2019 model year on-road heavy-duty diesel EOs indicate that may manufacturers have a number of OBD deficiencies in their applications, and therefore submit frequent OBD running changes to CARB throughout the model year, in addition to OBD calibration changes with each new OBD application. Since manufacturers are trying to minimize the number of OBD deficiencies, it is unlikely to see true carryover applications with no calibration changes as indicated in the ANPRM.

Running changes

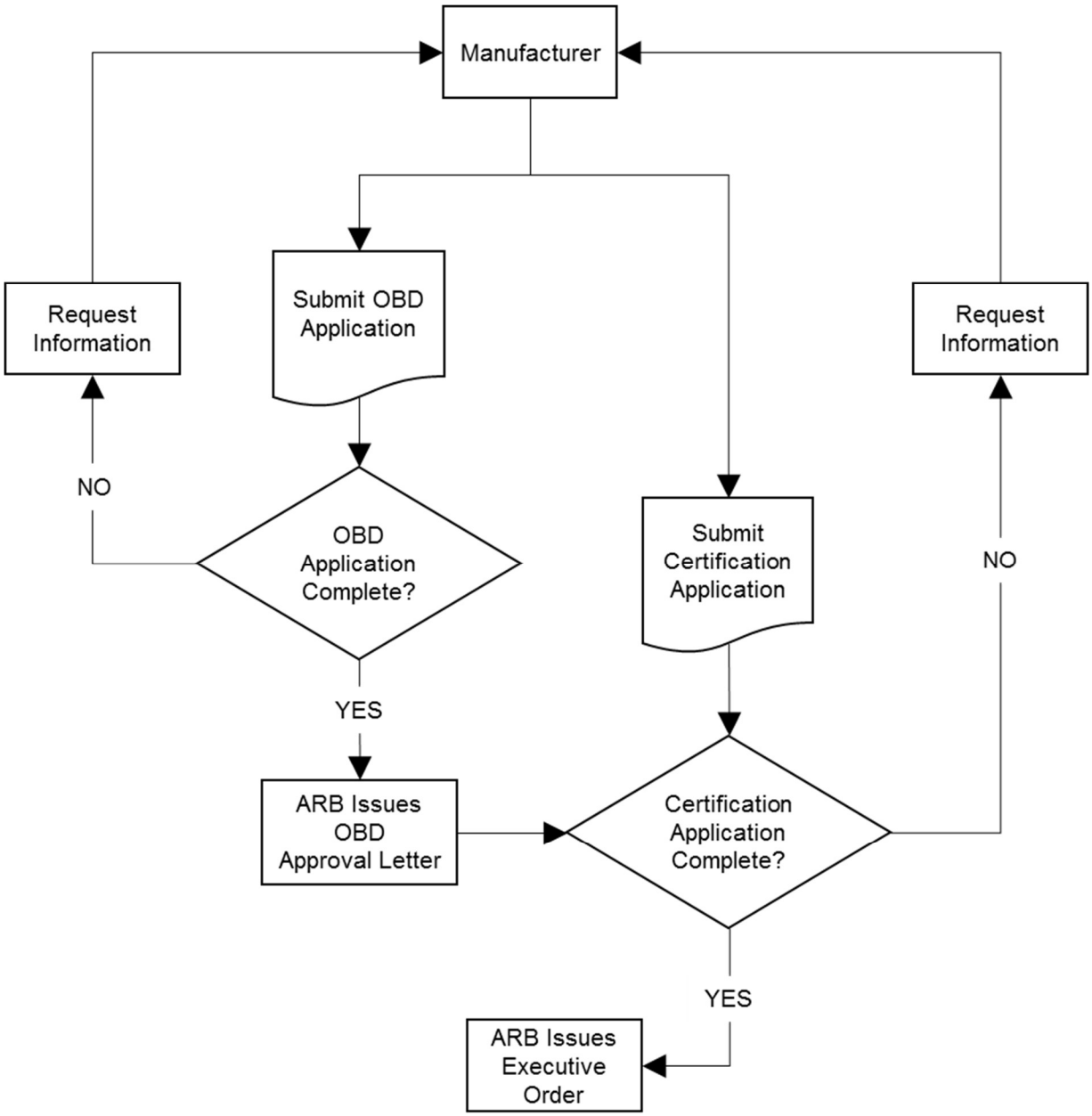
CARB staff reviewed the certification applications for the 2019 model year on-road heavy-duty diesel engines and discovered that many manufacturers submit a number of running changes throughout the model year, sometimes near the end of model year. Running changes include: calibration changes, addition of new models, and introduction of new components. While many of these running changes do not impact the worst-case emissions characteristics of the engine family, nevertheless, certification staff still need to analyze the impacts of the running change before making that determination.

The same issue also arises with each new model year certification application, that is, in many cases, the new model year application does include some form of running change compared to last year's application. In those cases, the application cannot be

considered as a true carryover, and becomes more of a partial carryover scenario, requiring a more extensive application review process.

Given the complexities with regards to carryover applications, CARB recommends that U.S. EPA harmonize with CARB in terms of expediting the application review process using the CARB Mail-out ECARS 2015-7.

Figure 1. On-Road Heavy-Duty Certification and OBD Review Processes



2. Modernizing of Heavy-Duty Engine Regulations

"We request comment on the benefits and concerns with USEPA migrating requirements to part 1036."

CARB Comment: CARB staff is supportive of U.S. EPA's intent to consolidate criteria pollutant emission requirements in 40 CFR part 86 with the GHG emissions requirements in part 1036. This would benefit regulators as well as the regulated community in understanding clearly the requirements and facilitates implementation and compliance with the regulations. If U.S. EPA does consolidate requirements in part 1036, CARB staff anticipates that we will likely, for consistency, propose amendments to CARB regulations in a future rulemaking.

3. Heavy-Duty In-Use Testing Program

"We welcome comment on possible strategies and challenges to incorporating onboard NOx sensor data in EPA's engine family test order process."

"We request comment on the potential use of telematics and communication technology in ensuring in-use emissions compliance."

CARB Comment: Application of sensors capable of measuring engine and tailpipe emissions is continuously increasing in vehicles. Telematics facilitates accessing data measured by these sensors in real-time. Manufacturers can use these data to monitor the performance of a vehicle's engine and aftertreatment system and take actions to fix problems as they arise. Regulatory programs could also leverage these data to verify in-use emissions compliance, as it provides quick, real-world screening tool for flagging potential emissions issues. However, if such technology is incorporated into in-use compliance efforts, it will be critical to ensure a system of checks and balances to ensure the emissions readings recorded are indeed accurate. CARB staff does express concerns with relying solely on sensor data without additional validation and verification testing, especially considering the recent efforts by multiple OEMs to circumvent and cheat diesel vehicle compliance standards.

"we request comment on the need to measure PM emissions during in-use testing of DPF-equipped engines – whether under the current regulations or under some future program. PEMS measurement is more complicated and time-consuming for PM measurements than for gaseous pollutants such as NOx and eliminating it for some or all in-use testing would provide significant cost savings. Commenters are encouraged to address whether there are less expensive alternatives for ensuring that engines meet the PM standards in use."

CARB Comment: CARB staff supports exploring opportunities for streamlining PEMS base PM emissions measurements for in-use testing programs. However, CARB staff does not support the complete elimination of PEMS-based PM measurement requirements for in-use testing at this time.

4. Durability Testing

"We request comment on the need, usefulness and appropriateness for a diesel aftertreatment rapid-aging protocol, and we request comment on the test program EPA has initiated to inform the accelerated durability demonstration method outlined here"

"We request comment on the suitability of onboard data to supplement our current or future deterioration factor demonstrations, as well as opportunities to reduce testing burden by reporting in-use data"

CARB Comment: In order to evaluate the efficacy of current durability demonstration program (DDP) practices, CARB staff reviewed the information from the 2014 through 2017 vehicle and engine compliance activities report (U.S. EPA, 2019),[126] which was recently published by U.S. EPA. The report provides detailed information regarding the recall activities and defects reporting for the heavy-duty sector. Analysis of this information is essential because it examines the overall status of emissions-related component durability for the industry as a whole during several calendar years. Staff also examined the information from the recent recall of Cummins engines (CARB, 2018c).[127]

It should be noted that one of the key objectives of the DDP is to verify emissions-related component durability. Without durable emissions-related components, the engine and aftertreatment system (EAS) cannot achieve emissions compliance at the end of its useful life. A robust DDP would include modes of operation that would expose the EAS components to the types of vibration, temperature, pressure, and transient operations that are representative of real-life, in use operations. Therefore, the presence of any defective components in the durability engine should be detected through the DDP process.

[126] (U.S. EPA, 2019) "2014-2017 Progress Report, Vehicle and Engine Compliance Activities," EPA-420-R-19-003, U.S. Environmental Protection Agency, April 2019. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100WKFC.pdf

[127] (CARB, 2018c) "CARB investigation leads to nationwide recall of 500,000+ Cummins heavy-duty trucks," California Air Resources Board, July 31, 2018. https://ww2.arb.ca.gov/news/carb-investigation-leads-nationwide-recall-500000-cummins-heavy-duty-trucks

CARB staff compared the data from the 2014 through 2019 model year durability reports for the California-certified on-road heavy-duty manufacturers with the information from the U.S. EPA compliance activities report, and the data from the Cummins recall program. Comparison of the data revealed that none of the problems identified in the field (either component defects or recalls) were observed through the existing DDP process. The lack of any correlation between the results from the laboratory aging process versus real-life in-use operations strongly suggests that the current DDP program is not adequately representing real-world deterioration, nor achieving its intended purpose.

Analysis of data from U.S. EPA's "2014-2017 Progress Report, Vehicle and Engine Compliance Activities," CARB's investigation of excess emissions that led to a nationwide recall of more than 500,000 heavy-duty trucks, and recent comments by engine manufacturers clearly indicate that the current laboratory aging process does not yield valid results for estimating full useful life DFs. There are many factors that contribute to this discrepancy including:

- Some manufacturers are not using proper dynamometer hardware to age the EAS in the laboratory as part of the DDP. Recent communication from EMA (EMA, 2019) indicates that some manufacturers are using "less expensive engine dynamometers" that are not capable of simulating motoring conditions as part of the aging cycle.[128] Motoring conditions are essential in simulating transient operations (over 14 percent of the FTP cycle is motoring), and the absence of motoring conditions during the aging process means that meaningful transient operations were not properly simulated in the laboratory. Staff believes that inclusion of transient conditions are essential in validation of EAS durability.

- No standardized aging cycles are currently being used by engine manufacturers. A more robust approach would require the manufacturers to use standardized aging cycles/processes so that results from different laboratory aging programs could be compared.

- The current equivalent fuel-burned approach used by all manufacturers, which correlates the amount of fuel burned to VMT, does not rely on a systematic and scientific approach. U.S. EPA has developed a new tool, Greenhouse Gas Emissions Model (GEM model) (U.S. EPA, 2016), which uses specific vehicle

[128] (EMA, 2019) Letter to CARB regarding "A Representative Nationwide Alternative to CARB's Proposed Omnibus Low-NOx Rulemaking," Truck and Engine Manufacturers Association, July 11, 2019.

and engine parameters to establish a relationship between VMT and hours of engine operation over standardized heavy-duty chassis cycles.[129]

- Acceleration factors are being used by manufacturers as a tool to decrease the amount of laboratory aging time. No standardized or scientific methodology has been proposed by the industry to verify the validity of the acceleration factors in estimating DFs.

- Emissions-related component deterioration and failure mechanisms are not fully captured by the current aging process. This was discussed earlier as part of U.S. EPA's 2014-2017 vehicle and engine compliance activities review. The discrepancy between component failure rates in the laboratory and in the field means that the current aging process is not representative of real-life operations.

There is a strong need to find a new enhanced process which is more representative of the real-life aging of on-road heavy-duty diesel engines. CARB staff emphasizes that focusing on the "diesel aftertreatment rapid-aging protocol" will not provide any useful data that can be correlated with the type of EAS component failures and recalls that have been observed through U.S. EPA compliance activities (U.S. EPA, 2019).[126] As such, CARB staff recommends that U.S. EPA harmonize with the CARB's proposed DDP amendments as described in the recent CARB workshop (CARB, 2019e).[130]

CARB staff is also supportive of the introduction of in-use NOx emission monitoring strategies for verifying the results from the DDP program. CARB staff recommends that in-use NOx emissions reporting adhere to the following guidelines:

(a) In-use NOx emission reports for each vehicle/engine should at least contain the following information:

(1) Engine family name
(2) Vehicle family name
(3) California sales volume of vehicles for each family
(4) Engine model name

[129] (U.S. EPA, 2016) "Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2 Final Rule," U.S. Environmental Protection Agency and U.S. Department of Transportation National Highway Traffic Safety Administration (EPA–HQ–OAR–2014–0827; NHTSA–2014– 0132), October 25, 2016. https://www.gpo.gov/fdsys/pkg/FR-2016-10-25/pdf/2016-21203.pdf

[130] (CARB, 2019e) "Heavy-Duty Low NOx Program Proposed Durability Demonstration Program for On-Road Heavy-Duty Diesel Engines," California Air Resources Board, September 26, 2019. https://ww3.arb.ca.gov/msprog/hdlownox/files/workgroup_20190926/staff/06_obd_ddp_abt.pdf?_ga=2.228568158.23008513.1581801318-1180861964.1577464384

(5) Rated engine model power (hp)
(6) Vehicle identification number (VIN)
(7) Engine serial number
(8) Odometer reading (miles)
(9) Engine run time/hour-meter reading (hours)
(10) Date when all data was recorded
(11) All parameters identified in NOx emission tracking requirements (as identified in title 13, CCR, sections 1971.1(h)(5.3) through (h)(5.7))
(12) In lieu of NOx emission tracking requirement parameters above, manufacturers could submit another set of parameters that identify the in-use NOx emissions characteristics of each vehicle. The format and content of these parameters must be determined based on good engineering judgment and is subject to U.S. EPA/CARB approval.

(b) Staff recognizes that it may not be feasible to collect data from all vehicles/engines that have been originally sold in the U.S. market. As such, for each engine family, manufacturers must submit all in-use vehicle NOx emissions data collected by the manufacturer in that reporting year, and at a minimum collect data on 20 percent of vehicles that were originally sold in the U.S. market.

(c) Manufacturers who collect data on more than 50 percent of their U.S. sales for three consecutive model years in 2024 through 2030 model years, will be eligible for a longer accelerated aftertreatment aging period. For 2031 and subsequent model years, manufacturers must collect data on more than 50 percent of their U.S. sales for five consecutive model years, in order to be eligible for longer accelerated aftertreatment aging periods.

(d) In-use NOx emissions data is not required for engines that have passed their applicable useful life.

(e) In-use NOx emission reports must include data from vocational, and if applicable, tractor vehicles as defined in 40 CFR §1037.801, last amended October 25, 2016.

CARB has already adopted the REAL (Real Emissions Assessment Logging) program elements that will use various sensors information and other collected variables to assess if actual on-road performance over the useful life mimics what is represented in the laboratory certification tests. We recommend U.S. EPA include provisions in the CTI equivalent to California's REAL program, which CARB adopted last year. REAL, which is voluntary starting in model year 2022 and mandatory starting in model year

2024, uses OBD sensors but collects data that gets stored on the vehicles to assess over the road real world emissions performance.

G. Incentives for Early Emission Reductions

"Thus, we are requesting comments on potential provisions that would provide a regulatory incentive for reducing emissions earlier than required, including but not limited to incentives for low-emission, advanced powertrain technologies."

"we request comment on alternative approaches to incentivize early emission reductions. In particular, we would be interested in the early adoption of technology that reduces low-load emissions. One approach we are considering would be for manufacturers to certify engines with new technology to the existing requirements (i.e., FTP and RMC test cycles and durability demonstration), but then track the engines in-use using improved in-use provisions. ... We request comment on options to potentially generate numerical off-cycle credit under this approach, or other interim benefits, such as delayed compliance for some other engine family, that could incentivize early emissions reductions."

CARB Comment: CARB staff is supportive of incentive programs for early introduction of advanced technologies. As such, CARB recommends that U.S. EPA consider the following incentive programs:

- Introduce a mechanism to give NOx credits to HD ZEVs;
- Provide early compliance credit multipliers to heavy-duty engines and hybrid powertrains that meet future model year emissions standards.

Please see also the first CARB comment above under III. Potential Solutions and Program Elements for further discussion of CARB's incentive programs.