ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 1036, 1037, 1054, 1065, and 1074

[EPA–HQ–OAR–2022–0985; FRL–8952–01–OAR]

RIN 2060–AV50

Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles—Phase 3

AGENCY: Environmental Protection Agency (EPA).

ACTION: Notice of proposed rulemaking.

SUMMARY: The Environmental Protection Agency (EPA) is proposing to promulgate new GHG standards for heavy-duty highway vehicles starting in model year (MY) 2028 through MY 2032 and to revise certain GHG standards for MY 2027 that were established previously under EPA's Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2 rule (''HD GHG Phase 2''). This document proposes updates to discrete elements of the Averaging Banking and Trading program, including a proposal to eliminate the last MY year of the HD GHG Phase 2 advanced technology incentive program for certain types of electric highway heavy-duty vehicles. EPA is proposing to add warranty requirements for batteries and other components of zero-emission vehicles and to require customer-facing battery state-of-health monitors for plug-in hybrid and battery electric vehicles. In this document, we are also proposing additional revisions and clarifying and editorial amendments to certain highway heavy-duty vehicle provisions and certain test procedures for heavy-duty engines. Finally, as part of this action, EPA is proposing to revise its regulations addressing preemption of state regulation of new locomotives and new engines used in locomotives.

DATES: Comments must be received on or before June 16, 2023. Comments on the information collection provisions submitted to the Office of Management and Budget (OMB) under the Paperwork Reduction Act (PRA) are best assured of consideration by OMB if OMB receives a copy of your comments on or before May 30, 2023. *Public hearing:* EPA will announce information regarding the public hearing for this proposal in a supplemental **Federal Register** document. Please refer to the **SUPPLEMENTARY INFORMATION** section for additional information on the public hearing.

ADDRESSES: You may send comments, identified by Docket ID No. EPA–HQ–OAR–2022–0985, by any of the following methods:

- *Federal eRulemaking Portal: https://www.regulations.gov/* (our preferred method). Follow the online instructions for submitting comments.
- *Email: a-and-r-Docket@epa.gov.* Include Docket ID No. EPA–HQ–OAR–2022–0985 in the subject line of the message.
- *Mail:* U.S. Environmental Protection Agency, EPA Docket Center, OAR Docket, Mail Code 28221T, 1200 Pennsylvania Avenue NW, Washington, DC 20460.
- *Hand Delivery or Courier:* EPA Docket Center, WJC West Building, Room 3334, 1301 Constitution Avenue NW, Washington, DC 20004. The Docket Center's hours of operations are 8:30 a.m.–4:30 p.m., Monday–Friday (except Federal Holidays).

Instructions: All submissions received must include the Docket ID No. for this rulemaking. Comments received may be posted without change to *https://www.regulations.gov/*, including any personal information provided. For detailed instructions on sending comments and additional information on the rulemaking process, see the ''Public Participation'' heading of the **SUPPLEMENTARY INFORMATION** section of this document.

FOR FURTHER INFORMATION CONTACT: Brian Nelson, Assessment and Standards Division, Office of Transportation and Air Quality, Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; telephone number: (734) 214–4278; email address: *nelson.brian@epa.gov.*

SUPPLEMENTARY INFORMATION:

Public Participation

Written Comments

Submit your comments, identified by Docket ID No. EPA–HQ–OAR–2022–0985, at *https://www.regulations.gov* (our preferred method), or the other methods identified in the **ADDRESSES** section. Once submitted, comments cannot be edited or removed from the docket. The EPA may publish any comment received to its public docket. Do not submit to EPA's docket at *https://www.regulations.gov* any information you consider to be Confidential Business Information (CBI), Proprietary Business Information (PBI), or other information whose disclosure is restricted by statute. If you choose to submit CBI or PBI as a comment to EPA's docket, please send those materials to the person listed in the **FOR FURTHER INFORMATION CONTACT** section. Multimedia submissions (audio, video, etc.) must be accompanied by a written comment. The written comment is considered the official comment and should include discussion of all points you wish to make. The EPA will generally not consider comments or comment contents located outside of the primary submission (*i.e.,* on the web, cloud, or other file sharing system). Commenters who would like EPA to further consider in this rulemaking any relevant comments that they provided on the HD2027 NPRM regarding proposed HD vehicle GHG standards for the MYs at issue in this proposal must resubmit those comments to EPA during this proposal's comment period. Please visit *https://www.epa.gov/dockets/commenting-epa-dockets* for additional submission methods; the full EPA public comment policy; information about CBI, PBI, or multimedia submissions; and general guidance on making effective comments.

Participation in Virtual Public Hearing

EPA will announce information regarding the public hearing for this proposal in a supplemental **Federal Register** document. The hearing notice, registration information, and any updates to the hearing schedule will also be available at *https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-greenhouse-gas-emissions-standards-heavy.* Please refer to this website for any updates regarding the hearings. EPA does not intend to publish additional documents in the **Federal Register** announcing updates to the hearing schedule.

Docket: All documents in the docket are listed on the *www.regulations.gov* website. Although listed in the index, some information is not publicly available, *e.g.,* CBI or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, is not placed on the internet and will be publicly available only in hard copy form through the EPA Docket Center at the location listed in the **ADDRESSES** section of this document.

General Information

Does this action apply to me?

This action relates to companies that manufacture, sell, or import into the United States new heavy-duty highway vehicles and engines. This action also relates to state and local governments. Potentially affected categories and entities include the following:

Category	NAICS codes [a]	NAICS title
Industry	336110	Automobile and Light Duty Motor Vehicle Manufacturing.
Industry	336120	Heavy Duty Truck Manufacturing.
Industry	336211	Motor Vehicle Body Manufacturing.
Industry	336213	Motor Home Manufacturing.
Industry	333618	Other Engine Equipment Manufacturing.
Industry	811198	All Other Automotive Repair and Maintenance.
Government		State and local governments.[b]

[a] NAICS Association. NAICS & SIC Identification Tools. Available online: *https://www.naics.com/search.*

[b] It should be noted that the proposed revisions do not impose any requirements that state and local governments must meet, but rather implement the Clean Air Act preemption provisions for locomotives.

This table is not intended to be exhaustive, but rather provides a guide for readers regarding entities potentially affected by this action. This table lists the types of entities that EPA is now aware could potentially be affected by this action. Other types of entities not listed in the table could also be affected. To determine whether your entity is regulated by this action, you should carefully examine the applicability criteria found in 40 CFR parts 1036, 1037, 1054, 1065, and 1074.[1] If you have questions regarding the applicability of this action to a particular entity, consult the person listed in the **FOR FURTHER INFORMATION CONTACT** section.

What action is the Agency taking?

The Environmental Protection Agency (EPA) is proposing to promulgate new GHG standards for heavy-duty highway vehicles starting in model year (MY) 2028 through MY 2032 and to revise certain GHG standards for MY 2027 that were established previously under EPA's Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2 rule (''HD GHG Phase 2'') that we believe are appropriate and feasible considering lead time, costs, and other factors. EPA also proposes that it is appropriate to eliminate the last model year (MY 2027) of advanced technology incentives for certain electric highway heavy-duty vehicles, initially established under the HD GHG Phase 2 rule. EPA is proposing to add warranty requirements for batteries and other components of zero-emission vehicles and to require customer-facing battery state-of-health monitors for plug-in hybrid and battery electric vehicles. We are also proposing revisions and clarifying and editorial amendments to certain highway heavy-duty vehicle provisions of 40 CFR part 1037 and certain test procedures for heavy-duty engines in 40 CFR parts 1036 and 1065. In addition, in this action EPA is proposing to revise its regulations addressing preemption of state regulation of new locomotives and new engines used in locomotives, to more closely align with language in the Clean Air Act.

What is the Agency's authority for taking this action?

Clean Air Act section 202(a), 42 U.S.C. 7521(a), requires that EPA establish emission standards for air pollutants from new motor vehicles or new motor vehicle engines, which, in the Administrator's judgment, cause or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare. The Administrator has found that GHG emissions from highway heavy-duty vehicles and engines cause or contribute to air pollution that may endanger public health or welfare. Therefore, the Administrator is exercising his authority under CAA section 202(a)(1)–(2) to establish standards for GHG emissions from highway heavy-duty vehicles. In addition, section 209(e)(2)(B) of the CAA, 42 U.S.C. 7543(e)(2)(B), requires EPA to promulgate regulations implementing subsection 209(e) of the Act, which addresses the prohibition of state standards regarding certain classes of new nonroad engines or new nonroad vehicles including new locomotives and new engines used in locomotives, as well as EPA's authorization criteria for certain California standards for other nonroad engines or nonroad vehicles. See Section I.D of this preamble for more information on the agency's authority for this action.

Did EPA conduct a peer review before issuing this action?

This proposed regulatory action is supported by influential scientific information. EPA, therefore, is conducting peer review in accordance with OMB's Final Information Quality Bulletin for Peer Review. Specifically, we conducted the peer review process on two analyses: (1) Emission Adjustments for Onroad Vehicles in MOVES3.R1, and (2) Greenhouse Gas and Energy Consumption Rates for Onroad Vehicles in MOVES3.R1. In addition, we plan to conduct a peer review of inputs to the Heavy-Duty Technology Resource Use Case Scenario (HD TRUCS) tool used to analyze HD vehicle energy usage and associated component costs. All peer review were or will be in the form of letter reviews conducted by a contractor. The peer review reports for each analysis will be posted in the docket for this action and will be posted at EPA's Science Inventory (*https://cfpub.epa.gov/si/*).

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[1] See 40 CFR 1036.1 through 1036.15 and 40 CFR 1037.1 through 1037.15.

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Executive Summary

A. Need for Regulatory Action

The Environmental Protection Agency (EPA) is proposing this action to further reduce GHG air pollution from highway heavy-duty (hereafter referred to as ''heavy-duty'' or HD) engines and vehicles across the United States. Despite the significant emissions reductions achieved by previous rulemakings, GHG emissions from HD vehicles continue to impact public health, welfare, and the environment. The transportation sector is the largest U.S. source of GHG emissions, representing 27 percent of total GHG emissions.[2] Within the transportation sector, heavy-duty vehicles are the second largest contributor to GHG emissions and are responsible for 25 percent of GHG emissions in the sector.[3] GHG emissions have significant impacts on public health and welfare as evidenced by the well-documented scientific record and as set forth in EPA's Endangerment and Cause or Contribute Findings under Section 202(a) of the CAA.[4] Additionally, major scientific assessments continue to be released that further advance our understanding of the climate system and the impacts that GHGs have on public health and welfare both for current and future generations, as discussed in Section II.A.

The potential for the application of zero-emission vehicle (ZEV) technologies in the heavy-duty sector presents an opportunity for significant reductions in heavy-duty GHG emissions over the long term.[5] Major trucking fleets, HD vehicle and engine manufacturers, and U.S. states have announced plans to increase the use of heavy-duty zero-emissions technologies in the coming years. The 2021 Infrastructure Investment and Jobs Act (commonly referred to as the ''Bipartisan Infrastructure Law'' or BIL) and the Inflation Reduction Act of 2022 (''Inflation Reduction Act'' or IRA) together include many incentives for the development, production, and sale of ZEVs, electric charging infrastructure, and hydrogen, which are expected to spur significant innovation in the heavy-duty sector.[6] In addition, supporting assessments provided by some commenters during the comment period for the EPA's March 2022 Notice of Proposed Rulemaking ''Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards'' (hereafter referred to as ''HD2027 NPRM''), which proposed strengthening existing MY 2027 GHG standards for heavy-duty vehicles, suggested that significant ZEV adoption rates can be achieved over the next decade.[7] [8] We discuss these developments in more detail in Section I. EPA also projects that improvements in internal combustion engines, powertrains, and vehicle technologies such as those EPA projected would be used to achieve the HD GHG Phase 2 standards will also be needed to continue to reduce GHG emissions from the HD sector, and as described in Section II.D.1, these technology improvements continue to be feasible. With respect to the need for GHG reductions and these heavy-duty sector developments, EPA is proposing in this document more stringent MY 2027 HD vehicle CO_2 emission standards (*i.e.,* beyond what was finalized in HD GHG Phase 2) and new HD vehicle CO2 emission standards starting in MYs 2028 through 2032 that we believe are appropriate and feasible considering cost, lead time, and other factors, as described throughout this preamble and supporting materials in the docket for this proposed rulemaking.

EPA sets highway heavy-duty vehicle and engine standards for GHG emissions

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[2] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2020 (EPA–430–R–22–003, published April 2022).

[3] *Ibid.*

[4] 74 FR 66496, December 15, 2009; see also 81 FR 54422, August 15, 2016 (making a similar endangerment and cause or contribute findings for GHGs from aircraft under section 231(a)(2)(A)). Recently, in April 2022, EPA denied administrative petitions relating to the 2009 finding, determining that ''[t]he science supporting the Administrator's [2009] finding that elevated concentrations of greenhouse gases in the atmosphere may reasonably be anticipated to endanger the public health and welfare of current and future U.S. generations is robust, voluminous, and compelling, and has been strongly affirmed by recent scientific assessments. . . .'' EPA's Denial of Petitions Relating to the Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act 1, available at *https://www.epa.gov/system/files/documents/2022-04/decision_document.pdf.*

[5] Throughout the preamble, we use the term ZEV technologies to refer to technologies that result in zero tailpipe emissions. Example ZEV technologies include battery electric vehicles and fuel cell vehicles.

[6] Infrastructure Investment and Jobs Act, Public Law 117–58, 135 Stat. 429 (2021) (''Bipartisan Infrastructure Law'' or ''BIL''), available at *https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf*; Inflation Reduction Act of 2022, Public Law 117–169, 136 Stat. 1818 (2022) (''Inflation Reduction Act'' or ''IRA''), available at *https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf.*

[7] Notice of Proposed Rulemaking for Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards. 87 FR 17414 (March 28, 2022).

[8] U.S. EPA, ''Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards—Response to Comments.'' Section 28. Docket EPA–HQ–OAR–2019–0055.

under its authority in CAA section 202(a). Section 202(a)(1) states that ''the Administrator shall by regulation prescribe (and from time to time revise) . . . standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles or new motor vehicle engines, . . . which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.'' Section 202(a)(2) provides that standards under section 202(a) apply to such vehicles and engines ''after such period as the Administrator finds necessary to permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period.'' Pursuant to section 202(a)(1), such standards apply to vehicles and engines ''for their useful life.'' EPA also may consider other factors such as the impacts of potential GHG standards on the industry, fuel savings, oil conservation, energy security, and other relevant considerations. Congress authorized the Administrator to determine the levels of emission reductions achievable for such air pollutants through the application of technologies taking into account cost, lead time, and other factors.

Pursuant to our 202(a) authority, EPA first established standards for the heavy-duty sector in the 1970s. Since then, the Agency has revised the standards multiple times based upon updated data and information, the continued need to mitigate air pollution, and Congressional enactments directing EPA to regulate emissions from the heavy-duty sector more stringently. Since 1985, HD engine and vehicle manufacturers could comply with criteria-pollutant standards using averaging,[9] EPA also introduced banking and trading compliance flexibilities in the HD program in 1990,[10] and EPA's HD GHG standards and regulations have consistently included an averaging, banking, and trading (ABT) program from the start.[11] Since the first standards, subsequent standards have extended to additional pollutants (including GHGs), increased in stringency, and spurred the development and deployment of numerous new vehicle and engine technologies. For example, the most recent GHG standards for HD vehicles will reduce CO_2 emissions by approximately 1.1 billion metric tons over the lifetime of the new vehicles sold under the program (HD GHG Phase 2, 81 FR 73478, October 25, 2016) and the most recent criteria-pollutant standards are projected to reduce NO_X emissions from the in-use HD fleet by almost 50 percent in 2045 (''Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards'' (hereafter referred to as ''HD2027 FRM''), 88 FR 4296, January 24, 2023). This proposal builds upon this multi-decadal tradition of regulating heavy-duty vehicles and engines, by applying the Agency's clear and longstanding statutory authority considering new real-world data and information, including recent Congressional action in the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA).

This Notice of Proposed Rulemaking is consistent with Executive Order 14037 on Strengthening American Leadership in Clean Cars and Trucks, which directs the Administrator to ''consider updating the existing greenhouse gas emissions standards for heavy-duty engines and vehicles beginning with model year 2027 and extending through and including at least model year 2029'' and directs EPA to ''consider beginning work on a rulemaking under the Clean Air Act to establish new greenhouse gas emissions standards for heavy-duty engines and vehicles to begin as soon as model year 2030.''[12] Consistent with this direction, in the HD2027 NPRM, we proposed building on and improving the existing emission control program for highway heavy-duty vehicles by further strengthening certain MY 2027 GHG standards finalized under the HD GHG Phase 2 rule. However, we did not take final action on the GHG portion of the HD2027 proposal in the final rule (HD2027 FRM). Since that time, EPA has continued its analysis of the heavy-duty vehicle sector including the recent passage of the IRA, which as we discuss further in this preamble provides significant incentives for GHG reductions in the heavy-duty vehicle sector. Based on this updated information and analysis, and consistent with EPA's authority under the Clean Air Act section 202(a), we are issuing this Notice of Proposed Rulemaking (''HD GHG Phase 3 NPRM'') to propose certain revised HD vehicle carbon dioxide (CO_2) standards for MY 2027 and certain new HD vehicle CO_2 standards for MYs 2028, 2029, 2030, 2031, and 2032 that would achieve significant GHG reductions for these and later model years (note the MY 2032 standards would remain in place for MY 2033 and later). We are requesting comment on an alternative set of CO_2 standards that would more gradually increase in stringency than the proposed standards for the same MYs. EPA also requests comment on setting GHG standards starting in MYs 2027 through 2032 that would reflect: values less stringent than the lower stringency alternative for certain market segments, values in between the proposed standards and the alternative standards, values in between the proposed standards and those that would reflect ZEV adoption levels (*i.e.,* percent of ZEVs in production volumes) used in California's ACT, values that would reflect the level of ZEV adoption in the ACT program, and values beyond those that would reflect ZEV adoption levels in ACT such as the 50- to 60-percent ZEV adoption range represented by the publicly stated goals of several major original equipment manufacturers (OEMs) for 2030.[13] [14] [15] [16] [17] We also request comment on promulgating additional new standards with increasing stringency in MYs 2033 through 2035. EPA anticipates that the appropriate choice of final standards within this range will reflect the Administrator's judgments about the uncertainties in EPA's analyses as well as consideration of public comment and updated information where available.

CAA section 202(a) directs EPA to regulate emissions of air pollutants from new motor vehicles and engines, which in the Administrator's judgment, cause or contribute to air pollution that may reasonably be anticipated to endanger

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[9] 50 FR 10606, Mar. 15, 1985; see also *NRDC* v. *Thomas*, 805 F.2d 410, 425 (D.C. Cir. 1986) (upholding emissions averaging in the 1985 HD final rule).

[10] 55 FR 30584, July 26, 1990.

[11] 76 FR 57128, September 15, 2011 (explaining ABT is a flexibility that provides an opportunity for manufacturers to make necessary technological improvements while reducing the overall cost of the program); 81 FR 73495, October 25, 2016 (explaining that ABT plays an important role in providing manufacturers flexibilities, including helping reduce costs).

[12] 86 FR 43583, August 5, 2021. Executive Order 14037. Strengthening American Leadership in Clean Cars and Trucks.

[13] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

[14] Scania, 'Scania's Electrification Roadmap,' Scania Group, November 24, 2021, *https://www.scania.com/group/en/home/newsroom/news/2021/Scanias-electrification-roadmap.html.*

[15] AB Volvo, 'Volvo Trucks Launches Electric Truck with Longer Range,' Volvo Group, January 14, 2022, *https://www.volvogroup.com/en/news-and-media/news/2022/jan/news-4158927.html.*

[16] Deborah Lockridge, 'What Does Daimler Truck Spin-off Mean for North America?,' Trucking Info (November 11, 2021). *https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america.*

[17] Navistar presentation at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 9–11, 2022).

public health or welfare. While standards promulgated pursuant to CAA section 202(a) are based on application of technology, the statute does not specify a particular technology or technologies that must be used to set such standards; rather, Congress has authorized and directed EPA to adapt its standards to emerging technologies. In 2009, the Administrator issued an Endangerment Finding under CAA section 202(a), concluding that GHG emissions from new motor vehicles and engines, including heavy-duty vehicles and engines, cause or contribute to air pollution that may endanger public health or welfare.[18] Pursuant to the 2009 Endangerment and Cause or Contribute Finding, EPA promulgated GHG regulations for heavy-duty vehicles and engines in 2011 and 2016, referred to as the HD GHG Phase 1 and HD GHG Phase 2 programs, respectively.[19] In the HD GHG Phase 1 and Phase 2 programs, EPA set emission standards that the Agency found appropriate and feasible, considering cost, lead time, and other factors.

Over time, manufacturers have not only continued to find ways to further reduce emissions from motor vehicles, including HD vehicles, they have found ways to eliminate tailpipe emissions entirely through the use of zero-emission vehicle technologies. Since the 2009 Endangerment and Cause or Contribute Finding and issuance of the HD GHG Phase 1 and Phase 2 program regulations, there has continued to be significant technological advancement in the vehicle and engine manufacturing sectors, including for such zero-emission vehicle technologies. The HD Phase 3 regulations that we are proposing take into account the ongoing technological innovation in the HD vehicle space and reflect CO_2 emission standards that we consider appropriate and feasible considering cost, lead time, and other factors.

B. The Opportunity for Clean Air Provided by Zero-Emission Vehicle Technologies

When the HD GHG Phase 2 rule was promulgated in 2016, we established CO_2 standards on the premise that ZEV technologies, such as battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs), would become more widely available in the heavy-duty market over time, but not in significant volume in the timeframe of the Phase 2 program. We finalized BEV, plug-in hybrid electric vehicle (PHEV), and FCEV advanced technology credit multipliers to encourage the development and sales of these advanced technologies.

Several significant developments have occurred since 2016 that point to ZEV technologies becoming more readily available much sooner than we had previously projected for the HD sector. These developments support the feasibility of ZEV technologies and render adoption of ZEV technologies to reduce GHG emissions more cost-competitive than ever before. First, the HD market has evolved such that early ZEV models are in use today for some applications and are expected to expand to many more applications; costs of ZEV technologies have gone down and are projected to continue to fall; and manufacturers have announced plans to rapidly increase their investments in ZEV technologies over the next decade. In 2022, there were a number of manufacturers producing fully electric HD vehicles for use in a number of applications, and these small volumes are expected to rise (see Section I.C and Draft Regulatory Impact Analysis (DRIA) Chapter 1). The cost to manufacture lithium-ion batteries (the single most expensive component of a BEV) has dropped significantly in the past eight years, and that cost is projected to continue to fall during this decade, all while the performance of the batteries (in terms of energy density) improves.[20] [21] Many of the manufacturers that produce HD vehicles and major firms that purchase HD vehicles have announced billions of dollars' worth of investments in ZEV technologies and significant plans to transition to a zero-carbon fleet over the next ten to fifteen years.[22]

Second, the 2021 BIL and the 2022 IRA laws provide significant and unprecedented monetary incentives for the production and purchase of qualified ZEVs in the HD market. They also provide incentives for qualifying electric charging infrastructure and hydrogen, which will further support a rapid increase in market penetration of HD ZEVs. As a few examples, over the next five years, BIL provisions include $5 billion to fund the replacement of school buses with zero- or low-emission buses and $5.6 billion to support the purchase of zero- or low-emission transit buses and associated infrastructure, with up to $7.5 billion to help build out a national network of EV charging and hydrogen refueling infrastructure, some of which may be used for refueling of heavy duty vehicles. The IRA creates a tax credit of up to $40,000 per vehicle for vehicles over 14,000 pounds (and up to $7,500 per vehicle for vehicles under 14,000 pounds) for the purchase of qualified commercial clean vehicles and provides tax credits for the production and sale of battery cells and modules of up to $45 per kilowatt-hour (kWh). The wide array of incentives in both laws will help to reduce the costs to manufacture, purchase, and operate ZEVs, thereby bolstering their adoption in the market.

Third, there have been multiple actions by states to accelerate the adoption of HD ZEVs. The State of California and other states have adopted the ACT program that includes a manufacturer requirement for zero-emission truck sales.[23] [24] The ACT program would require that ''manufacturers who certify Class 2b-8 chassis or complete vehicles with combustion engines would be required to sell zero-emission trucks as an

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[18] 74 FR 66496 (Dec. 15, 2009).

[19] 76 FR 57106 (Sept. 15, 2011); 81 FR 73478 (Oct. 25, 2016).

[20] Mulholland, Eamonn. ''Cost of electric commercial vans and pickup trucks in the United States through 2040.'' Page 7. January 2022. Available at *https://theicct.org/wp-content/uploads/2022/01/cost-ev-vans-pickups-us-2040-jan22.pdf.*

[21] Sharpe, Ben and Hussein Basma. ''A meta-study of purchase costs for zero-emission trucks''. The International Council on Clean Transportation, Working Paper 2022–09 (February 2022). Available online: *https://theicct.org/publication/purchase-cost-ze-trucks-feb22/.*

[22] Environmental Defense Fund (2022) September 2022 Electric Vehicle Market Update: Manufacturer Commitments and Public Policy Initiatives Supporting Electric Mobility in the U.S. and Worldwide, available online at: *https://blogs.edf.org/climate411/files/2022/09/ERM-EDF-Electric-Vehicle-Market-Report_September2022.pdf.*

[23] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

[24] See, *e.g.,* Final Advanced Clean Truck Amendments, 1461 Mass. Reg. 29 (Jan. 21, 2022) (Massachusetts). Medium- and Heavy-Duty (MHD) Zero Emission Truck Annual Sales Requirements and Large Entity Reporting, 44 N.Y. Reg. 8 (Jan. 19, 2022) (New York), available at *https://dos.ny.gov/system/files/documents/2022/01/011922.pdf.* Advanced Clean Trucks Program and Fleet Reporting Requirements, 53 N.J.R. 2148(a) (Dec. 20, 2021) (New Jersey), available at *https://www.nj.gov/dep/rules/adoptions/adopt_20211220a.pdf* (pre-publication version). Clean Trucks Rule 2021, DEQ–17–2021 (Nov. 17, 2021), available at *http://records.sos.state.or.us/ORSOSWebDrawer/Recordhtml/8581405* (Oregon). Low emission vehicles, Wash. Admin. Code. § 173–423–070 (2021), available at *https://app.leg.wa.gov/wac/default.aspx?cite=173-423-070*; 2021 Wash. Reg. 587356 (Dec. 15, 2021); Wash. Reg. 21–24–059 (Nov. 29, 2021) (amending Wash. Admin. Code. §§ 173–423 and 173–400), available at *https://lawfilesext.leg.wa.gov/law/wsrpdf/2021/24/21-24-059.pdf* (Washington).

increasing percentage of their annual [state] sales from 2024 to 2035.''[25][26] In addition, 17 states and the District of Columbia have signed a Memorandum of Understanding establishing goals to support widespread electrification of the HD vehicle market.[27] We discuss these factors further in Section I.

Recognizing the need for additional GHG reductions from HD vehicles and the growth of ZEV technologies in the HD market, last year we proposed strengthening certain existing MY 2027 HD vehicle CO_2 standards as part of the HD2027 NPRM. We received many comments on the proposed updates to those HD vehicle CO_2 emission standards.[28] Many commenters suggested that EPA should further strengthen HD vehicle CO_2 emission standards in MYs 2027 through 2029 beyond the HD2027 NPRM proposed levels because of the accelerating adoption of HD ZEV technologies, and some commenters provided a number of reports that evaluate the potential of electrification of the HD sector in terms of adoption rates, costs, and other factors. Some commenters raised concerns with the HD2027 NPRM proposed changes to certain HD GHG Phase 2 CO_2 emission standards, asserting the significant investment and lead time required for development and verification of the durability of ZEV technologies, especially given the diverse range of applications in the HD market.

In the HD2027 NPRM, EPA also requested comment on several approaches to modify the existing Advanced Technology Credit Multipliers (''credit multipliers'') under the HD GHG Phase 2 program. Many commenters supported limiting the credits in some fashion, such as eliminating credit multipliers for ZEVs produced due to state requirements or phasing out the credit multipliers earlier than MY 2027, which was the last model year that multipliers could be applied under HD GHG Phase 2. Some of the commenters opposed any changes to the existing credit multipliers, indicating that the multipliers are necessary for the development of these new and higher-cost technologies into existing and new markets. We considered the concerns and information provided in these comments when developing this proposal, as discussed in Sections II and III. Commenters who would like EPA to further consider in this rulemaking any relevant comments that they provided on the HD2027 NPRM regarding proposed HD vehicle GHG standards for the MYs at issue in this proposal must resubmit those comments to EPA during this proposal's comment period.[29]

EPA believes the increased application of ZEV technologies in the HD sector presents an opportunity to strengthen GHG standards, which can result in significant reductions in heavy-duty vehicle emissions. Based on an in-depth analysis of the potential for the development and application of ZEV technologies in the HD sector, we are proposing in this Phase 3 NPRM more stringent GHG standards for MYs 2027 through 2032 and later HD vehicles heavy-duty vehicles that are appropriate and feasible considering lead time, costs, and other factors. These proposed Phase 3 standards include (1) revised GHG standards for many MY 2027 HD vehicles, with a subset of standards that would not change, and (2) new GHG standards starting in MYs 2028 through 2032, of which the MY 2032 standards would remain in place for MY 2033 and later. For the purposes of this preamble, we refer to the Phase 3 NPRM standards generally as applying to MYs 2027 through 2032 and later HD vehicles. In this NPRM, we are also requesting comment on setting additional new, progressively more stringent GHG standards beyond the MYs proposed and starting in MYs 2033 through 2035. In consideration of concerns from manufacturers about lead time needed for technology development and market investments, we request comment in this NPRM on an alternative set of GHG standards starting in MYs 2027 through 2032 that are lower than those proposed yet still more stringent than the Phase 2 standards. We also request comment, including supporting data and analysis, if there are certain market segments, such as heavy-haul vocational trucks or long-haul tractors which may require significant energy content for their intended use, for which it may be appropriate to set standards less stringent than the alternative for the specific corresponding regulatory subcategories in order to provide additional lead time to develop and introduce ZEV or other low emissions technology for those specific vehicle applications. In consideration of the environmental impacts of HD vehicles and the need for significant emission reductions, as well as the views expressed by stakeholders such as environmental justice communities, environmental nonprofit organizations, and state and local organizations for rapid and aggressive reductions in GHG emissions, we are also requesting comment on a more stringent set of GHG standards starting in MYs 2027 through 2032 whose values would go beyond the proposed standards, such as values that would reflect the level of ZEV adoption (*i.e.,* percent of ZEVs in production volumes) used in California's ACT program, values in between these proposed standards and those that would reflect ZEV adoption levels in ACT, and values beyond those that would reflect ZEV adoption levels in ACT, such as the 50–60 percent ZEV adoption range represented by the publicly stated goals of several major OEMs for 2030.[30][31][32][33][34]

After considering the state of electrification of the HD market, new incentives, and comments received on the HD2027 NPRM regarding credit multipliers, EPA believes that the HD GHG Phase 2 levels of incentives for electrification are no longer appropriate for certain segments of the HD vehicle market. We are proposing in this document to end credit multipliers for BEVs and PHEVs one year earlier than provided in the existing HD GHG Phase 2 program (*i.e.,* no credit multipliers for BEVs and PHEVs in MYs 2027 and later).

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[25] California Air Resources Board, Advanced Clean Trucks Fact Sheet (August 20, 2021), available at *https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet.* See also California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

[26] EPA granted the ACT rule waiver requested by California under CAA section 209(b) on March 30, 2023. 88 FR 20688, April 6, 2023 (signed by the Administrator on March 30, 2023).

[27] Multi-State MOU, available at *https://www.nescaum.org/documents/mhdv-zev-mou-20220329.pdf/.*

[28] U.S. EPA, ''Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards—Response to Comments.'' Section 28. Docket EPA–HQ–OAR–2019–0055.

[29] Note, comments regarding aspects of the HD program besides those GHG standards and compliance requirements in this proposal are outside the scope of this rulemaking.

[30] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

[31] Scania, 'Scania's Electrification Roadmap,' Scania Group, November 24, 2021, *https://www.scania.com/group/en/home/newsroom/news/2021/Scanias-electrification-roadmap.html.*

[32] AB Volvo, 'Volvo Trucks Launches Electric Truck with Longer Range,' Volvo Group, January 14, 2022, *https://www.volvogroup.com/en/news-and-media/news/2022/jan/news-4158927.html.*

[33] Deborah Lockridge, 'What Does Daimler Truck Spin-off Mean for North America?,' Trucking Info (November 11, 2021). *https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america.*

[34] Navistar presentation at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 9–11, 2022).

C. Summary of the Major Provisions in the Regulatory Action

Our proposed program features several key provisions that include, based on consideration of updated data and information, updating the existing MY 2027 GHG emission standards and promulgating new GHG emission standards starting in MYs 2028 through 2032 for HD vehicles. Specifically, we are proposing to set progressively more stringent GHG emission standards that would apply to MYs 2027, 2028, 2029, 2030, 2031, and 2032 and later for numerous vocational vehicle and tractor subcategories. The proposed standards for MY 2032 and later are shown in Table ES–1 and Table ES–2 and are described in detail in Section II, while the proposed standards for MYs 2027 through 2031 are shown in Section II.F.[35] As described in Section II of this preamble, our analysis shows that the proposed revisions to HD GHG Phase 2 CO_2 standards for MY 2027 and the proposed new, progressively lower numeric values of the CO_2 standards starting in MYs 2028 through 2032 are appropriate considering feasibility, lead time, costs, and other factors. We seek comment on these proposed Phase 3 standards starting in MYs 2027 through 2032.

TABLE ES–1—PROPOSED MY 2032 AND LATER VOCATIONAL VEHICLE CO_2 EMISSION STANDARDS (GRAMS/TON-MILE) BY REGULATORY SUBCATEGORY

	CI light heavy	CI medium heavy	CI heavy heavy	SI light heavy	SI medium heavy
Urban Vehicles	179	176	177	225	215
Multi-Purpose Vehicles	142	153	138	184	186
Regional Vehicles	103	136	97	131	165

Note: Please see Section II.F.4 for the full set of proposed standards, including for optional custom chassis vehicles.

TABLE ES–2—PROPOSED MY 2032 AND LATER TRACTOR CO_2 EMISSION STANDARDS (GRAMS/TON-MILE) BY REGULATORY SUBCATEGORY

	Class 7 all cab styles	Class 8 day cab	Class 8 sleeper cab
Low Roof Tractor	63.5	48.4	48.1
Mid Roof Tractor	68.2	51.5	52.2
High Roof Tractor	66.0	50.0	48.2

Note: Please see Section II.F.4 for the full set of proposed standards, including for heavy-haul tractors.

The proposed standards do not mandate the use of a specific technology, and EPA anticipates that a compliant fleet under the proposed standards would include a diverse range of technologies (*e.g.,* transmission technologies, aerodynamic improvements, engine technologies, battery electric powertrains, hydrogen fuel cell powertrains, etc.). The technologies that have played a fundamental role in meeting the Phase 2 GHG standards will continue to play an important role going forward as they remain key to reducing the GHG emissions of HD vehicles powered by internal combustion engines (referred to in this proposal as ICE vehicles). In developing the proposed standards, EPA has also considered the key issues associated with growth in penetration of zero-emission vehicles, including charging infrastructure and hydrogen production. In our assessment that supports the appropriateness and feasibility of these proposed standards, we developed a technology pathway that could be used to meet each of the standards. The technology package includes a mix of ICE vehicles with CO_2-reducing technologies and ZEVs. EPA developed an analysis tool to evaluate the design features needed to meet the energy and power demands of various HD vehicle types when using ZEV technologies. The overarching analysis is premised on ensuring each of the ZEVs could perform the same work as its ICE counterpart while oversizing the battery to account for its usable range and that batteries deteriorate over time. The fraction of ZEVs in the technology packages are shown in Table ES–3 and described further in Section II of this preamble.

TABLE ES–3—PROJECTED ZEV ADOPTION RATES IN TECHNOLOGY PACKAGES FOR THE PROPOSED STANDARDS

Regulatory subcategory grouping	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 (%)
Light-Heavy Duty Vocational	22	28	34	39	45	57
Medium Heavy-Duty Vocational	19	21	24	27	30	35
Heavy-Heavy-Duty Vocational	16	18	19	30	33	40
Day Cab Tractors	10	12	15	20	30	34
Sleeper Cab Tractors	0	0	0	10	20	25

Note: Please see Section II.F.1 for the full set of technology packages, including for optional custom chassis vehicles.

We are requesting comment on an alternative set of CO_2 standards that would more gradually increase in stringency than the proposed standards starting in MY 2027 through 2032, further described in Section II.H. We developed a technology pathway that could be used to meet the alternatives standards, which projects the aggregated

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[35] See proposed regulations 40 CFR 1037.105 and 1037.106.

ZEV adoption rates shown in Table ES–4 and described further in Section II of this preamble. As described in more detail in Section II, we also are seeking comment on setting GHG standards starting in MYs 2027 through 2032 that would reflect values less stringent than the lower stringency alternative for certain market segments as well as comment on values in between the proposed standards and the alternative standards. Also described in Section II, we are seeking comment on setting GHG standards starting in MYs 2027 through 2032 that would reflect values above the level of the proposed standards. Some of the HD2027 NPRM commenters provided specific recommendations for ZEV adoption rates to include in our analysis, and these adoption rates are on the order of 40 percent or more electrification by MY 2029.[36] [37] [38] [39] The California Air Resources Board's (CARB's) ACT regulation sets ZEV sales requirements for vocational vehicles at 40 percent and for tractors at 25 percent in MY 2029 (Table ES–4). Announcements by major manufacturers project their HD ZEV sales to be in the 50 percent range for 2030 globally, with one manufacturer projecting sales as high as 60 percent for North America in that year.[40] [41] [42] [43] We request comment and data that would support more stringent GHG standards than we are proposing for MYs 2027 through 2032, including comment and data on different technologies' penetration rates than we included in the technology packages described in Section II of the preamble. Specifically, EPA requests comment on values that would reflect the level of ZEV adoption used in California's ACT program, values in between these proposed standards and those that would reflect ZEV adoption levels in ACT, and values beyond those that would reflect ZEV adoption levels in ACT such as the 50–60 percent ZEV adoption range represented by the publicly stated goals of several major OEMs for 2030.[44] [45] [46] [47] [48] We further request comment on promulgating progressively more stringent standards out through MY 2035.

TABLE ES–4—AGGREGATED PROJECTED ZEV ADOPTION RATES IN TECHNOLOGY PACKAGES FOR THE PROPOSED STANDARDS, AGGREGATED PROJECTED ZEV ADOPTION RATES IN TECHNOLOGY PACKAGES FOR THE ALTERNATIVE STANDARDS, AND CALIFORNIA ACT ZEV SALES REQUIREMENTS

	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 and later (%)
Proposed:						
Vocational	20	25	30	35	40	50
Short-Haul Tractors	10	12	15	20	30	35
Long-Haul Tractors	0	0	0	10	20	25
Alternative:						
Vocational	14	20	25	30	35	40
Short Haul Tractors	5	8	10	15	20	25
Long Haul Tractors	0	0	0	10	15	20
CARB ACT:						
Vocational	20	30	40	50	55	60
Tractors	15	20	25	30	35	40

As discussed in Section II and DRIA Chapters 1 and 2, EPA recognizes that charging and refueling infrastructure for BEVs and FCEVs is critically important for the success in the increasing development and adoption of these vehicle technologies. There are significant efforts already underway to develop and expand heavy-duty electric charging and hydrogen refueling infrastructure. The U.S. government is making large investments through the BIL and the IRA, as discussed in more detail in DRIA Chapter 1.3.2. (*e.g.,* this includes a tax credit for charging or hydrogen refueling infrastructure) as well as billions of additional dollars for programs that could help fund charging infrastructure if purchased alongside an electric vehicle).[49] [50] However, private investments will also play a critical role in meeting future infrastructure needs. We expect many BEV or fleet owners to invest in charging infrastructure for depot charging. (See DRIA Chapter 2.6 for information on our analysis of depot charging needs and costs associated with this proposal.) Manufacturers, charging network providers, energy companies and others are also investing

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[36] ACEEE Comments to the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–2852–A1. Referencing Catherine Ledna et al., 'Decarbonizing Medium-& Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis' (NREL, March 2022), *https://www.nrel.gov/docs/fy22osti/82081.pdf.*

[37] EDF Comments to the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1265–A1, pp. 16–17.

[38] ICCT Comments to the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1211–A1, p. 6.

[39] Moving Forward Network Comments to the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1277–A1, pp. 19–20.

[40] Scania, 'Scania's Electrification Roadmap,' Scania Group, November 24, 2021, *https://www.scania.com/group/en/home/newsroom/news/2021/Scanias-electrification-roadmap.html*; AB Volvo, 'Volvo Trucks Launches Electric Truck with Longer Range,' Volvo Group, January 14, 2022, *https://www.volvogroup.com/en/news-and-media/news/2022/jan/news-4158927.html.*

[41] David Cullen, 'Daimler to Offer Carbon Neutral Trucks by 2039,' (October 25, 2019). *https://www.truckinginfo.com/343243/daimler-aims-to-offer-only-co2-neutral-trucks-by-2039-in-key-markets.*

[42] Deborah Lockridge, 'What Does Daimler Truck Spin-off Mean for North America?,' Trucking Info (November 11, 2021). *https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america.*

[43] Navistar presentation at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 9–11, 2022).

[44] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

[45] Scania, 'Scania's Electrification Roadmap,' Scania Group, November 24, 2021, *https://www.scania.com/group/en/home/newsroom/news/2021/Scanias-electrification-roadmap.html.*

[46] AB Volvo, 'Volvo Trucks Launches Electric Truck with Longer Range,' Volvo Group, January 14, 2022, *https://www.volvogroup.com/en/news-and-media/news/2022/jan/news-4158927.html.*

[47] Deborah Lockridge, 'What Does Daimler Truck Spin-off Mean for North America?,' Trucking Info (November 11, 2021). *https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america.*

[48] Navistar presentation at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 9–11, 2022).

[49] Inflation Reduction Act, Public Law 117–169 (2022).

[50] Bipartisan Infrastructure Law, Public Law 117–58, 135 Stat. 429 (2021).

in high-power public or other stations that could support en-route charging. This includes over a billion dollars for recently announced projects to support electric truck or other commercial vehicle charging in the United States and Europe.[51] For example, Daimler Truck North America is partnering with electric power generation company NextEra Energy Resources and BlackRock Renewable Power to collectively invest $650 million to create a nationwide U.S. charging network for commercial vehicles with a later phase of the project also supporting hydrogen fueling stations.[52] Volvo Group and Pilot recently announced their intent to offer public charging for medium- and heavy-duty BEVs at over 750 Pilot and Flying J North American truck stops and travel plazas.[53] (See DRIA Chapter 1.6.2 for a more detailed discussion of private investments in heavy-duty infrastructure.)

These recent heavy-duty charging announcements come during a period of rapid growth in the broader market for charging infrastructure serving cars or other electric vehicles. BloombergNEF estimates that annual global investment was $62 billion in 2022, nearly twice that of the prior year.[54] Private charging companies have already attracted billions globally in venture capital and mergers and acquisitions.[55] In the United States, there was $200 million or more in mergers and acquisition activity in 2022 according to the capital market data provider Pitchbook,[56] indicating strong interest in the future of the charging industry. Domestic manufacturing capacity is also increasing with over $600 million in announced investments to support the production of charging equipment and components at existing or new U.S. facilities.[57] [58]

These important early actions and market indicators suggest strong growth in charging and refueling ZEV infrastructure in the coming years. Furthermore, as described in Section II of this document, our analysis of charging infrastructure needs and costs supports the feasibility of the future growth of ZEV technology of the magnitude EPA is projecting in this proposal's technology package. EPA has heard from some representatives from the heavy-duty vehicle manufacturing industry both optimism regarding the heavy-duty industry's ability to produce ZEV technologies in future years at high volume, but also concern that a slow growth in ZEV charging and refueling infrastructure can slow the growth of heavy-duty ZEV adoption, and that this may present challenges for vehicle manufacturers ability to comply with future EPA GHG standards. Several heavy-duty vehicle manufacturers have encouraged EPA to consider ways to address this concern both in the development of the Phase 3 program, and in the structure of the Phase 3 program itself. [59] EPA requests comment on this concern, both in the Phase 3 rulemaking process, and in consideration of whether EPA should consider undertaking any future actions related to the Phase 3 standards, if finalized, with respect to the future growth of the charging and refueling infrastructure for ZEVs. EPA has a vested interest in monitoring industry's performance in complying with mobile source emission standards, including the highway heavy-duty industry. EPA monitors industry's performance through a range of approaches, including regular meetings with individual companies and regulatory requirements for data submission as part of the annual certification process. EPA also provides transparency to the public through actions such as publishing industry compliance reports (such as has been done during the heavy-duty GHG Phase 1 program).[60] EPA requests comment on what, if any, additional information and data EPA should consider collecting and monitoring during the implementation of the Phase 3 standards; we also request comment on whether there are additional stakeholders EPA should work with during implementation of the Phase 3 standards, if finalized, and what measures EPA should consider to help ensure success of the Phase 3 program, including with respect to the important issues of refueling and charging infrastructure for ZEVs.

As described in Section III.B of this preamble, we are also proposing updates to the advanced technology incentives in the ABT program for HD GHG Phase 2 for electric vehicles. Given the ZEV-related factors outlined in this section and further described in Sections I and II that have arisen since the adoption of HD GHG Phase 2, EPA believes it is appropriate to limit the availability of credit multipliers, but we also recognize the role these credits play in developing new markets. We are proposing in this action to eliminate the advanced technology vehicle credit multipliers for BEVs and PHEVs for MY 2027, one year before these credit multipliers were set to end under the existing HD GHG Phase 2 program. We propose retaining the existing FCEV credit multipliers, because the HD market for this technology continues to be in the early stage of development. We request comment on this approach. In addition to this preamble, we have also prepared a Draft Regulatory Impact Analysis (DRIA) which is available on our website and in the public docket for this rulemaking. The DRIA provides additional data, analysis, and discussion. We request comment on the analysis and data in the DRIA.

D. Impacts of the Proposed Standards

Our estimated emission reductions, average per-vehicle costs, program costs, and monetized benefits of the proposed program are summarized in this section and detailed in Sections IV through VIII of the preamble and Chapters 3 through 8 of the DRIA. EPA notes that, consistent with CAA section 202, in

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[51] BloombergNEF. ''Zero-Emission Vehicles Factbook A BloombergNEF special report prepared for COP27.'' November 2022. Available online: *https://www.bloomberg.com/professional/download/2022-zero-emissions-vehicle-factbook/*.

[52] NextEra Energy. News Release: ''Daimler Truck North America, NextEra Energy Resources and BlackRock Renewable Power Announce Plans to Accelerate Public Charging Infrastructure for Commercial Vehicles Across The U.S.'' January 31, 2022. Available online: *https://newsroom.nexteraenergy.com/news-releases?item=123840*.

[53] Adler, Alan. ''Pilot and Volvo Group add to public electric charging projects''. FreightWaves. November 16, 2022. Available online: *https://www.freightwaves.com/news/pilot-and-volvo-group-add-to-public-electric-charging-projects*.

[54] BloombergNEF. ''Next $100 Billion EV-Charger Spend to Be Super Fast.'' January 20, 2023. Available online: *https://about.bnef.com/blog/next-100-billion-ev-charger-spend-to-be-super-fast/*.

[55] Hampleton.''Autotech & Mobility M&A market report 1H2023.'' 2023. Available online: *https://www.hampletonpartners.com/fileadmin/user_upload/Report_PDFs/Hampleton-Partners-Autotech-Mobility-Report-1H2023-FINAL.pdf*.

[56] St. John, Alexa, and Nora Naughton.'' Automakers need way more plug-in stations to make their EV plans work. That has sparked a buyer frenzy as big charging players gobble up smaller ones.'' Insider, November 24, 2022. Available online: *https://www.businessinsider.com/ev-charging-industry-merger-acquisition-meet-electric-vehicle-demand-2022-11*.

[57] Joint Office of Energy and Transportation. ''Private Sector Continues to Play Key Part in Accelerating Buildout of EV Charging Networks.'' February 15, 2023. Available online: *https://driveelectric.gov/news/#private-investment*.

[58] North Carolina Office of the Governor. ''Manufacturer of Electric Vehicle Charging Stations Selects Durham County for New Production Facility''. February 7, 2023. Available online: *https://governor.nc.gov/news/press-releases/2023/02/07/manufacturer-electric-vehicle-charging-stations-selects-durham-county-new-production-facility*.

[59] Truck and Engine Manufacturers Association. ''EPA GHG Phase 3 Rulemaking: H–D Vehicle Manufacturers' Perspective'' presentation to the Society of Automotive Engineers Government and Industry Meeting. January 18, 2023.

[60] See EPA Reports EPA–420–R–21–001B covering Model Years 2014–2018, and EPA report EPA–420–R–22–028B covering Model Years 2014—2020, available online at *https://www.epa.gov/compliance-and-fuel-economy-data/epa-heavy-duty-vehicle-and-engine-greenhouse-gas-emissions*.

evaluating potential GHG standards, we carefully weigh the statutory factors, including GHG emissions impacts of the GHG standards, and the feasibility of the standards (including cost of compliance in light of available lead time). We monetize benefits of the proposed GHG standards and evaluate other costs in part to better enable a comparison of costs and benefits pursuant to E.O. 12866, but we recognize that there are benefits that we are currently unable to fully quantify. EPA's consistent practice has been to set standards to achieve improved air quality consistent with CAA section 202, and not to rely on cost-benefit calculations, with their uncertainties and limitations, in identifying the appropriate standards. Nonetheless, our conclusion that the estimated benefits considerably exceed the estimated costs of the proposed program reinforces our view that the proposed GHG standards represent an appropriate weighing of the statutory factors and other relevant considerations.

Our analysis of emissions impacts accounts for downstream emissions, *i.e.,* from emission processes such as engine combustion, engine crankcase exhaust, vehicle evaporative emissions, and vehicle refueling emissions. Vehicle technologies would also affect emissions from upstream sources that occur during, for example, electricity generation and the refining and distribution of fuel. This proposal's analyses include emissions impacts from electrical generating units (EGUs).[61] We also account for refinery emission impacts on non-GHG pollutants in these analyses.

The proposed GHG standards would achieve significant reductions in GHG emissions. As seen in Table ES–5, through 2055 the program would result in significant downstream GHG emission reductions. In addition, considering both downstream and EGU cumulative emissions from calendar years 2027 through 2055, the proposed standards would achieve approximately 1.8 billion metric tons in CO_2 emission reductions (see Section V of the preamble and Chapter 4 of the DRIA for more detail).[62] As discussed in Section VI of this preamble, these GHG emission reductions would make an important contribution to efforts to limit climate change and its anticipated impacts. These GHG reductions would benefit all U.S. residents, including populations such as people of color, low-income populations, indigenous peoples, and/or children that may be especially vulnerable to various forms of damages associated with climate change. We project a cumulative increase from calendar years 2027 through 2055 of approximately 0.4 billion metric tons of CO_2 emissions from EGUs as a result of the increased demand for electricity associated with the proposal, although those projected impacts decrease over time because of projected changes in the future power generation mix, including cleaner combustion technologies and increases in renewables.[63]

TABLE ES–5—CUMULATIVE DOWNSTREAM GHG IMPACTS OF THE PROPOSAL FROM CALENDAR YEARS 2027 THROUGH 2055 IN BILLION METRIC TONS (BMT) [a]

Pollutant	Reduction in BMT	Percent impact (%)
Carbon Dioxide (CO_2)	2.2	−18
Methane (CH_4)	0.00035	−17
Nitrous Oxide (N_2O)	0.00028	−17
CO_2 Equivalent (CO_2e)	*2.3*	*−18*

[a] Downstream emissions processes are those that come directly from a vehicle, such as tailpipe exhaust, crankcase exhaust, evaporative emissions, and refueling emissions.

We expect the proposed GHG emission standards would lead to an increase in HD ZEVs relative to our reference case without the proposed rule, which would also result in reductions of vehicle emissions of non-GHG pollutants that contribute to ambient concentrations of ozone, particulate matter ($PM_{2.5}$), NO_2, CO, and air toxics. Exposure to these non-GHG pollutants is linked to adverse human health impacts such as premature death as well as other adverse public health and environmental effects (see Section VI). As shown in Table ES–6, by 2055, when considering downstream, EGU, and refinery emissions, we estimate a net decrease in emissions from all pollutants modeled (*i.e.,* NO_X, $PM_{2.5}$, VOC, and SO_2). In this year alone, the proposed standards would reduce downstream $PM_{2.5}$ by approximately 970 U.S. tons (about 39 percent of heavy-duty sector downstream $PM_{2.5}$ emissions) and downstream oxides of nitrogen (NO_X) by over 70,000 U.S. tons (about 28 percent of heavy-duty sector downstream NO_X emissions) (see Section V of the preamble and Chapter 4 of the DRIA for more detail). These reductions in non-GHG emissions from vehicles would reduce air pollution near roads. As described in Section VI of this preamble, there is substantial evidence that people who live or attend school near major roadways are more likely to be of a non-White race, Hispanic ethnicity, and/or low socioeconomic status. In addition, emissions from HD vehicles and engines can significantly affect individuals living near truck freight routes. Based on a study EPA conducted of people living near truck routes, an estimated 72 million people live within 200 meters of a truck freight route.[64] Relative to the rest of the population, people of color and those with lower incomes are more likely to live near truck routes.[65] In addition, children who attend school near major roads are disproportionately

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[61] We are continuing and are not reopening the existing approach taken in both HD GHG Phase 1 and Phase 2, that compliance with the vehicle exhaust CO_2 emission standards is based on CO_2 emissions from the vehicle.

[62] As discussed in Section V, in this proposal we estimated refinery emissions impacts only for non-GHG emissions. Were we to estimate impacts on refinery GHG emissions, we expect that the decrease in liquid fuel consumption associated with this rule would lead to a reduction in those emissions, and that the total GHG emissions reductions from this proposal (including downstream, EGU, and refinery) would exceed 1.8 billion metric tons.

[63] We expect IRA incentives, particularly sections 45X, 45Y, and 48E of the Internal Revenue Code (*i.e.,* Title 26) added by sections 13502 (Advanced Manufacturing Production Credit), 13701 (Clean Electricity Production Credit), and 13702 (Clean Electricity Investment Credit), respectively, to contribute significantly to increases in renewables in the future power generation mix.

[64] U.S. EPA (2021). Estimation of Population Size and Demographic Characteristics among People Living Near Truck Routes in the Conterminous United States. Memorandum to the Docket EPA–HQ–OAR–2019–0055.

[65] See Section VI.D for additional discussion on our analysis of environmental justice impacts of this NPRM.

represented by children of color and children from low-income households.[66]

Similar to GHG emissions, we project that non-GHG emissions from EGUs would increase as a result of the increased demand for electricity associated with the proposal, and we expect those projected impacts to decrease over time due to EGU regulations and changes in the future power generation mix, including impacts of the IRA. We also project that non-GHG emissions from refineries would decrease as a result of the lower demand for liquid fuel associated with the proposed GHG standards (Section V and DRIA Chapter 4).

TABLE ES–6—PROJECTED NON-GHG HEAVY-DUTY EMISSION IMPACTS[a] IN CALENDAR YEAR 2055 DUE TO THE PROPOSAL

Pollutant	Downstream (U.S short tons)	EGU (U.S. short tons)	Refinery (U.S. short tons)	Net impact (U.S. short tons)
Nitrogen Oxides (NO_X)	−71,000	790	−1,800	−72,000
Primary Exhaust $PM_{2.5}$	−970	750	−440	−650
Volatile Organic Compounds (VOC)	−21,000	750	−1200	−21,000
Sulfur Dioxide (SO_2)	−520	910	−640	−250

[a] We present emissions reductions as negative numbers and emission increases as positive numbers.

We estimate that the present value, at 3 percent, of costs to manufacturers would be $9 billion dollars before considering the IRA battery tax credits. With those battery tax credits, which we estimate to be $3.3 billion, the cost to manufacturers of compliance with the program would be $5.7 billion. The manufacturer cost of compliance with the proposed rule on a per-vehicle basis are shown in Table ES–7. We estimate that the MY 2032 fleet average per-vehicle cost to manufacturers by regulatory group would range between a cost savings for LHD vocational vehicles to $2,300 for HHD vocational vehicles and between $8,000 and $11,400 per tractor. EPA notes the projected costs per vehicle for this proposal are similar to the fleet average per-vehicle costs projected for the HD GHG Phase 2 rule, where the tractor standards were projected to cost between $10,200 and $13,700 per vehicle (81 FR 73621 (October 25, 2016)) and the MY 2027 vocational vehicle standards were projected to cost between $1,486 and $5,670 per vehicle (81 FR 73718 (October 25, 2016)). For this proposal, EPA finds that the expected the additional vehicle costs are reasonable in light of the GHG emissions reductions.[67]

TABLE ES–7—MANUFACTURER COSTS TO MEET THE PROPOSED MY 2032 STANDARDS RELATIVE TO THE REFERENCE CASE

[2021$]

Regulatory group	Incremental ZEV adoption rate in technology package (%)	Per-ZEV manufacturer RPE on average	Fleet-average per-vehicle manufacturer RPE
Light Heavy-Duty Vocational	45	−$9,515	−$4,326
Medium Heavy-Duty Vocational	24	1,358	326
Heavy Heavy-Duty Vocational	28	8,146	2,300
Day Cab Tractors	30	26,364	8,013
Sleeper Cab Tractors	21	54,712	11,445

The proposed GHG standards would reduce adverse impacts associated with climate change and exposure to non-GHG pollutants and thus would yield significant benefits, including those we can monetize and those we are unable to quantify. Table ES–8 summarizes EPA's estimates of total monetized discounted costs, operational savings, and benefits. The results presented here project the monetized environmental and economic impacts associated with the proposed program during each calendar year through 2055. EPA estimates that the present value of monetized net benefits to society would be approximately $320 billion through the year 2055 (annualized net benefits of $17 billion through 2055), more than 5 times the cost in vehicle technology and associated electric vehicle supply equipment (EVSE) combined. Regarding social costs, EPA estimates that the cost of vehicle technology (not including the vehicle or battery tax credits) and EVSE would be approximately $9 billion and $47 billion respectively, and that the HD industry would save approximately $250 billion in operating costs (*e.g.,* savings that come from less liquid fuel used, lower maintenance and repair costs for ZEV technologies as compared to ICE technologies, etc.). The program would result in significant social benefits including $87 billion in climate benefits (with the average SC–GHGs at a 3 percent discount rate). Between $15 and $29 billion of the estimated total benefits through 2055 are attributable to reduced emissions of non-GHG pollutants, primarily those that contribute to ambient concentrations of

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[66] Kingsley, S., Eliot, M., Carlson, L. et al. Proximity of U.S. schools to major roadways: a nationwide assessment. J Expo Sci Environ Epidemiol 24, 253–259 (2014). *https://doi.org/10.1038/jes.2014.5.*

[67] For illustrative purposes, these average costs would represent an approximate two percent increase for vocational vehicles and 11 percent increase of tractors if we assume an approximate minimum vehicle price of $100,000 for vocational vehicles and $100,000 for tractors (81 FR 73482). We also note that these average upfront costs are taken across the HD vehicle fleet and are not meant as an indicator of average price increase.

$PM_{2.5}$. Finally, the benefits due to reductions in energy security externalities caused by U.S. petroleum consumption and imports would be approximately $12 billion under the proposed program. A more detailed description and breakdown of these benefits can be found in Section VIII of the preamble and Chapter 7 of the DRIA.

Table ES–8—Monetized Discounted Costs, Benefits, and Net Benefits of the Proposed Program for Calendar Years 2027 Through 2055

[Billions of 2021 dollars] [a b c d e]

	Present value		Annualized value	
	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate
Vehicle Technology Costs	$9	$10	$0.47	$0.82
EVSE Costs	47	29	2.5	2.3
Operational Savings	250	120	13	10
Energy Security Benefits	12	6.0	0.62	0.49
GHG Benefits	87	87	4.6	4.6
Non-GHG Benefits	15 to 29	5.8 to 11	0.78 to 1.5	0.47 to 0.91
Net Benefits	320	180	17	12

Notes:

[a] Values rounded to two significant figures; totals may not sum due to rounding. Present and annualized values are based on the stream of annual calendar year costs and benefits included in the analysis (2027–2055) and discounted back to year 2027.

[b] Climate benefits are based on reductions in CO2, CH4, and N2O emissions and are calculated using four different estimates of the social cost of each GHG (SC–GHG model average at 2.5%, 3%, and 5% discount rates; 95th percentile at 3% discount rate), which each increase over time. In this table, we show the benefits associated with the average SC–GHGs at a 3% discount rate, but the Agency does not have a single central SC–GHG point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC–GHG estimates and present them later in this preamble. As discussed in Chapter 7 of the DRIA, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts. We note that in this proposal we are using the SC–GHG estimates presented in the February 2021 Technical Support Document (TSD): Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under E.O. 13990 (IWG 2021). For further discussion of SC–GHG and how EPA accounted for these estimates, please refer to Section VII of this preamble.

[c] The same discount rate used to discount the value of damages from future GHG emissions in this table (SC–GHGs at 3% discount rate) is used to calculate the present and annualized values of climate benefits for internal consistency, while all other costs and benefits are discounted at either 3% or 7%.

[d] Non-GHG health benefits are presented based on two different long-term exposure studies of mortality risk: a Medicare study (Wu et al., 2020) and a National Health Interview Survey study (Pope III et al., 2019). Non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.

[e] Net benefits reflect the operational savings plus benefits minus costs. For presentational clarity, the present and equivalent annualized value of net benefits for a 3 percent discount rate reflect benefits based on the Pope III et al. study while the present and equivalent annualized value of net benefits for a 7 percent discount rate reflect benefits based on the Wu et al. study.

Regarding the costs to purchasers as shown in Table ES–9, for the proposed program we estimated the average upfront incremental cost to purchase a new MY 2032 HD BEV or FCEV relative to an ICE vehicle for a vocational BEV and EVSE, a short-haul tractor BEV and EVSE, a short-haul tractor FCEV, and a long-haul tractor FCEV. These incremental costs account for the IRA tax credits, specifically battery and vehicle tax credits, as discussed in Section II.E.4 and Section IV.C and IV.D. We also estimated the operational savings each year (*i.e.,* savings that come from the lower costs to operate, maintain, and repair BEV technologies) and payback period (*i.e.,* the year the initial cost increase would pay back). Table ES–9 shows that for the vocational vehicle ZEVs, short-haul tractor ZEVs, and long-haul tractor FCEVs the incremental upfront costs (after the tax credits) are recovered through operational savings such that pay back occurs after between one and three years on average for vocational vehicles, after three years for short-haul tractors and after seven years on average for long-haul tractors. We discuss this in more detail in Sections II and IV of this preamble and DRIA Chapters 2 and 3.

Table ES–9—MY 2032 Estimated Average Per-Vehicle Purchaser Upfront Cost and Annual Savings Difference Between BEV/FCEV and ICE Technologies for the Proposed Program

[2021 dollars] [a]

Regulatory group	Upfront vehicle cost difference (including tax credits)	Upfront EVSE costs on average	Total upfront costs on average	Annual incremental operating costs on average	Payback period (year) on average
LHD Vocational	−$9,608	$10,552	$944	−$4,043	1
MHD Vocational	−2,907	14,312	11,405	−5,397	3
HHD Vocational	−8,528	17,233	8,705	−7,436	2
Short Haul (Day Cab) Tractors	582	16,753	17,335	−6,791	3
Long Haul (Sleeper Cab) Tractors	14,712	0	14,712	−2,290	7

[a] Undiscounted dollars.

I. Introduction

A. Brief Overview of the Heavy-Duty Industry

Heavy-duty highway vehicles range from commercial pickup trucks to vocational vehicles that support local and regional transportation, construction, refuse collection, and delivery work, to line-haul tractors (semi trucks) that move freight cross-country. This diverse array of vehicles is categorized into weight classes based on gross vehicle weight ratings (GVWR). These weight classes span Class 2b pickup trucks and vans from 8,500 to 10,000 pounds GVWR through Class 8 line-haul tractors and other commercial vehicles that exceed 33,000 pounds GVWR. While Class 2b and 3 complete pickups and vans are not included in this proposed rulemaking, Class 2b and 3 vocational vehicles are included in this rulemaking (as discussed further in Section III.E.3).[68]

Heavy-duty highway vehicles are powered through an array of different means. Currently, the HD vehicle fleet is primarily powered by diesel-fueled, compression-ignition (CI) engines. However, gasoline-fueled, spark-ignition (SI) engines are common in the lighter weight classes, and smaller numbers of alternative fuel engines (*e.g.,* liquified petroleum gas, compressed natural gas) are found in the heavy-duty fleet. We refer to the vehicles powered by internal combustion engines (ICE, including SI and CI engines) as ICE vehicles throughout this preamble. An increasing number of HD vehicles are powered by zero emission vehicle (ZEV) technologies such as battery electric vehicle (BEV) technology, *e.g.,* EPA certified 380 HD BEVs in MY 2020 but that number jumped to 1,163 HD BEVs in MY 2021. We use the term ZEV technologies throughout the preamble to refer to technologies that result in zero tailpipe emissions, which in this preamble we refer to collectively as ZEVs. Example ZEV technologies include BEVs and fuel cell vehicles (FCEVs). While hybrid vehicles (including plug-in hybrid electric vehicles) include energy storage features such as batteries, they also include an ICE, which do not result in zero tailpipe emissions.

The industry that designs and manufactures HD vehicles is composed of three primary segments: vehicle manufacturers, engine manufacturers and other major component manufacturers, and secondary manufacturers (*i.e.,* body builders). Some vehicle manufacturers are vertically integrated—designing, developing, and testing their engines in-house for use in their vehicles; others purchase some or all of their engines from independent engine suppliers. At the time of this proposal, only one major independent engine manufacturer supports the HD industry, though some vehicle manufacturers sell their engines or ‘‘incomplete vehicles’’ (*i.e.,* chassis that include their engines, the frame, and a transmission) to body builders who design and assemble the final vehicle. Each of these subindustries is often supported by common suppliers for subsystems such as transmissions, axles, engine controls, and emission controls.

In addition to the manufacturers and suppliers responsible for producing HD vehicles, an extended network of dealerships, repair and service facilities, and rebuilding facilities contribute to the sale, maintenance, and extended life of these vehicles and engines. HD vehicle dealerships offer customers a place to order such vehicles from a specific manufacturer and often include service facilities for those vehicles and their engines. Dealership service technicians are generally trained to perform regular maintenance and make repairs, which generally include repairs under warranty and in response to manufacturer recalls. Some trucking fleets, businesses, and large municipalities hire their own technicians to service their vehicles in their own facilities. Many refueling centers along major trucking routes have also expanded their facilities to include roadside assistance and service stations to diagnose and repair common problems.

The end-users for HD vehicles are as diverse as the applications for which these vehicles are purchased. Smaller weight class HD vehicles are commonly purchased by delivery services, contractors, and municipalities. The middle weight class vehicles tend to be used as commercial vehicles for business purposes and municipal work that transport people and goods locally and regionally or provide services such as utilities. Vehicles in the heaviest weight classes are generally purchased by businesses with high load demands, such as construction, towing or refuse collection, or freight delivery fleets and owner-operators for regional and long-haul goods movement. The competitive nature of the businesses and owner-operators that purchase and operate HD vehicles means that any time at which the vehicle is unable to operate due to maintenance or repair (*i.e.,* downtime) can lead to a loss in income. The customers’ need for reliability drives much of the vehicle manufacturers innovation and research efforts.

B. History of Greenhouse Gas Emission Standards for Heavy-Duty Engines and Vehicles

EPA has a longstanding practice of regulating GHG emissions from the HD sector. In 2009, EPA and the U.S. Department of Transportation’s (DOT’s) National Highway Traffic Safety Administration (NHTSA) began working on a joint regulatory program to reduce GHG emissions and fuel consumption from HD vehicles and engines.[69] The first phase of the HD GHG and fuel efficiency program was finalized in 2011 (76 FR 57106, September 15, 2011) (‘‘HD GHG Phase 1’’).[70] The HD GHG Phase 1 program largely adopted approaches consistent with recommendations from the National Academy of Sciences. The HD GHG Phase 1 program, which began in MY 2014 and phased in through MY 2018, included separate standards for HD vehicles and HD engines. The program offered flexibility allowing manufacturers to attain these standards through a mix of technologies and the option to participate in an emissions credit ABT program.

In 2016, EPA and NHTSA finalized the HD GHG Phase 2 program.[71] The HD GHG Phase 2 program included technology-advancing, performance-based emission standards for HD vehicles and HD engines that phase in over the long term, with initial standards for most vehicles and engines commencing in MY 2021, increasing in stringency in MY 2024, and culminating in even more stringent MY 2027 standards. HD GHG Phase 2 built upon the Phase 1 program and set standards

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[68] Class 2b and 3 vehicles with GVWR between 8,500 and 14,000 pounds are primarily commercial pickup trucks and vans and are sometimes referred to as ‘‘medium-duty vehicles’’. The vast majority of Class 2b and 3 vehicles are chassis-certified vehicles, and we intend to include those vehicles in a combined light-duty and medium-duty rulemaking action, consistent with E.O. 14037, Section 2a. Heavy-duty engines and vehicles are also used in nonroad applications, such as construction equipment; nonroad heavy-duty engines, equipment, and vehicles are not within the scope of this NPRM.

[69] Greenhouse gas emissions from heavy-duty vehicles are primarily carbon dioxide (CO_2), but also include methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFC).

[70] National Research Council; Transportation Research Board. The National Academies’ Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; ‘‘Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles.’’ 2010. Available online: *https://www.nap.edu/catalog/12845/technologies-and-approaches-to-reducing-the-fuel-consumption-of-medium-and-heavy-duty-vehicles.*

[71] 81 FR 73478, October 25, 2016.

based not only on then-currently available technologies, but also on technologies that were either still under development or not yet widely deployed at the time of the HD GHG Phase 2 final rule. To ensure adequate time for technology development, HD GHG Phase 2 provided up to 10 years lead time to allow for the development and phase-in of these control technologies. EPA recently finalized technical amendments to the HD GHG Phase 2 rulemaking (''HD Technical Amendments'') that included changes to the test procedures for heavy-duty engines and vehicles to improve accuracy and reduce testing burden.[72]

As with the previous HD GHG Phase 1 and Phase 2 rules and light-duty GHG rules, EPA has coordinated with the DOT and NHTSA during the development of this proposed rule. This included coordination prior to and during the interagency review conducted under E.O. 12866. EPA has also consulted with CARB during the development of this proposal, as EPA also did during the development of the HD GHG Phase 1 and 2 and light-duty rules. See Section I.E for additional detail on EPA's coordination with DOT/NHTSA, CARB, and additional Federal Agencies.

C. What has changed since we finalized the HD GHG Phase 2 rule?

In 2016, we established the HD GHG Phase 2 CO_2 standards on the premise that zero-emission technologies would not be available and cost-competitive in significant volumes in the timeframe of the HD GHG Phase 2 program but would become more widely available in the HD market over time. To encourage that availability at faster pace, we finalized BEV, PHEV, and FCEV advanced technology credit multipliers for HD vehicles. As described in the Executive Summary and Section II of this preamble, we have considered new data and recent policy changes and we are now projecting that ZEV technologies will be readily available and technologically feasible much sooner than we had projected. We list the developments pointing to this increased application of ZEV technologies again in the following paragraphs (and we discuss their impacts on the HD market in more detail in the Sections I.C.1 through I.C.3):

First, the HD market has evolved such that early ZEV models are in use today for some applications and are expected to expand to many more applications, ZEV technologies costs have gone down and are projected to continue to fall, and manufacturers have announced plans to rapidly increase their investments in ZEV technologies over the next decade. For example, in 2022, several manufacturers are producing fully electric HD vehicles in several applications, and these applications are expected to expand (see Section I.C.1 and DRIA Chapter 1). Furthermore, several HD manufacturers have announced their ZEV projections that signify a rapid increase in BEVs over the next decade. This increase in HD ZEVs is in part due to the significant decrease in cost to manufacture lithium-ion batteries, the single most expensive component of a BEV, in the past decade; those costs are projected to continue to fall during this decade, all while the performance of these batteries in terms of energy density has improved and is projected to continue to improve.[73] [74] Many of the manufacturers who produce HD vehicles and firms that purchase HD vehicles have announced billions of dollars' worth of investments in ZEV technologies and significant plans to transition to a zero-carbon fleet over the next ten to fifteen years.[75]

Second, the 2021 BIL and the 2022 IRA laws have been enacted, and together these two laws provide significant and unprecedented monetary incentives for the production and purchase of ZEVs in the HD market, as well as incentives for electric vehicle charging and hydrogen, which will further support a rapid increase in market penetration of ZEVs.

Third, there have been multiple actions by states to accelerate the adoption of HD ZEVs. The State of California and other states have adopted the ACT program that includes a manufacturer requirement for zero-emission truck sales.[76] [77] The ACT program provides that ''manufacturers who certify Class 2b-8 chassis or complete vehicles with combustion engines would be required to sell zero-emission trucks as an increasing percentage of their annual [state] sales from 2024 to 2035.'' [78] [79] In addition, 17 states and the District of Columbia have signed a Memorandum of Understanding establishing goals to support widespread electrification of the HD vehicle market.[80]

We note that the improvements in internal combustion engine technologies that began under the HD GHG Phase 1 program and are being advanced under the HD GHG Phase 2 standards are still necessary for reducing GHG emissions from the HD sector. As we discuss in Section II.D.1, these technology improvements exist today and we believe they will continue to be feasible during the timeframe at issue in this proposed rulemaking.

1. The HD Zero-Emission Vehicle Market

Since 2012, manufacturers have developed a number of prototype and demonstration HD BEV projects, particularly in the State of California, establishing technological feasibility and durability of BEV technology for specific applications used for specific services, as well as building out necessary infrastructure.[81] In 2019, approximately 60 makes and models of HD BEVs were available for purchase, with additional product lines in prototype or other early development stages.[82] [83] [84] According to the Global

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[72] 86 FR 34308, June 29, 2021.

[73] Mulholland, Eamonn. ''Cost of electric commercial vans and pickup trucks in the United States through 2040.'' Page 7. January 2022. Available at *https://theicct.org/wp-content/uploads/2022/01/cost-ev-vans-pickups-us-2040-jan22.pdf.*

[74] Environmental Defense Fund. ''Technical Review of Medium- and Heavy-Duty Electrification Costs for 2027–2030.'' February 2, 2022. Available online at: *https://blogs.edf.org/climate411/files/2022/02/EDF-MDHD-Electrification-v1.6_20220209.pdf.*

[75] Environmental Defense Fund (2022) Electric Vehicle Market Update: Manufacturer Commitments and Public Policy Initiatives Supporting Electric Mobility in the U.S. and Worldwide, September 2022, available online at: *https://blogs.edf.org/climate411/files/2022/09/ERM-EDF-Electric-Vehicle-Market-Report_September2022.pdf.*

[76] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

[77] Oregon adopted ACT on 11/17/2021: *https://www.oregon.gov/deq/rulemaking/Pages/ctr2021.aspx.* Washington adopted ACT on 11/29/2021: *https://ecology.wa.gov/Regulations-Permits/Laws-rules-rulemaking/Rulemaking/WAC-173-423-400.* New York adopted ACT on 12/29/2021: *https://www.dec.ny.gov/regulations/26402.html.* New Jersey adopted ACT on 12/20/2021: *https://www.nj.gov/dep/rules/adoptions.html.* Massachusetts adopted ACT on 12/30/2021: *https://www.mass.gov/regulations/310-CMR-700-air-pollution-control#proposed-amendments-public-comment.*

[78] California Air Resources Board, Advanced Clean Trucks Fact Sheet (August 20, 2021), available at *https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet.* See also California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

[79] EPA granted the ACT rule waiver requested by California under CAA section 209(b) on March 30, 2023.

[80] Multi-State MOU, available at *https://www.nescaum.org/documents/mhdv-zev-mou-20220329.pdf/.*

[81] NACFE (2019) ''Guidance Report: Viable Class ⅞ Electric, Hybrid and Alternative Fuel Tractors'', available online at: *https://nacfe.org/downloads/viable-class-7-8-alternative-vehicles/.*

[82] Nadel, S. and Junga, E. (2020). ''Electrifying Trucks: From Delivery Vans to Buses to 18-

Continued

Commercial Vehicle Drive to Zero Zero-Emission Technology Inventory (ZETI), 160 BEV models were commercially available on the market in the United States and Canada region in 2021, and around 200 BEV models are projected to be available by 2024.[85] DRIA Chapter 1 provides a snapshot of BEV models in the HD vehicle market.

Current production volumes of HD BEVs originally started increasing in the transit bus market, where electric bus sales grew from 300 to 650 in the United States between 2018 to 2019.[86] [87] In 2020, the market continued to expand beyond transit, with approximately 900 HD BEVs sold in the United States and Canada combined, consisting of transit buses (54 percent), school buses (33 percent), and straight trucks (13 percent).[88] By 2021, M.J. Bradley's analysis of the HD BEV market found that 30 manufacturers had at least one BEV model for sale and an additional nine companies had made announcements to begin BEV production by 2025.[89] In April 2022, the Environmental Defense Fund (EDF) projected deployments and major orders of electric trucks and buses in the United States to rise to 54,000 by 2025 based on an analysis of formal statements and announcements by auto manufacturers, as well as analysis of the automotive press and data from financial and market analysis firms that regularly cover the auto industry.[90] Given the dynamic nature of the BEV market, the number and types of vehicles available are increasing fairly rapidly.[91]

The current market for HD FCEVs is not as developed as the market for HD BEVs, but models are being designed, tested, and readied for purchase in the coming years. According to ZETI,[92] at least 16 HD FCEV models are expected to become commercially available for production in the United States and Canada region by 2024, as listed in DRIA Chapter 1. The Hydrogen Fuel Cell Partnership reports that fuel cell electric buses have been in commercial development for 20 years and, as of May 2020, over 100 buses are in operation or in planning in the United States.[93] Foothill Transit in Los Angeles County ordered 33 transit buses that they expect to be operating in early 2023.[94] Ten Toyota-Kenworth Class 8 fuel cell tractors were successfully tested in the Port of Los Angeles and surrounding area through 2022.[95] Hyundai is scheduled to test 30 Class 8 tractors in the Port of Oakland in 2023.[96] Nikola has agreements with fleets to purchase or lease over 200 Class 8 trucks upon satisfactory completion of demonstrations [97] [98] [99] and is building a manufacturing facility in Coolidge, Arizona, with an expected production capacity of up to 20,000 BEV and FCEV trucks by the end of 2023.[100]

For this proposed rulemaking, EPA conducted an analysis of manufacturer-supplied end-of-year production reports provided to us as a requirement of the process to certify HD vehicles to our GHG emission standards.[101] Based on the end-of-year production reports for MY 2019, manufacturers produced approximately 350 certified HD BEVs. This is out of nearly 615,000 HD diesel ICE vehicles produced in MY 2019 and represents approximately 0.06 percent of the HD vehicles market. In MY 2020, 380 HD BEVs were certified, an increase of 30 BEVs from 2019. The BEVs were certified in a variety of the Phase 1 vehicle subcategories, including light, medium, and heavy heavy-duty vocational vehicles and vocational tractors. Out of the 380 HD BEVs certified in MY 2020, a total of 177 unique makes and models were available for purchase by 52 manufacturers in Classes 3–8. In MY 2021, EPA certified 1,163 heavy-duty BEVs, representing 0.2 percent of the HD vehicles. There were no HD FCEVs certified through MY 2021. We note that these HD BEV certifications preceded implementation of incentives in the 2022 IRA, which we expect to increase adoption (and certification) of BEV and FCEV technology in the heavy-duty sector.

Based on current trends, manufacturer announcements, the 2021 BIL and 2022 IRA, and state-level actions, electrification of the HD market is

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Wheelers.” American Council for an Energy-Efficient Economy White Paper, available at: *https://aceee.org/white-paper/electrifying-trucks-delivery-vans-buses-18*.

[83] The composition of all-electric truck models was: 36 buses, 10 vocational trucks, 9 step vans, 3 tractors, 2 street sweepers, and 1 refuse truck (Nadel and Junga (2020) citing AFDC (Alternative Fuels Data Center). 2018. “Average Annual Vehicle Miles Traveled by Major Vehicle Categories.” *www.afdc.energy.gov/data/widgets/10309*.

[84] Note that there are varying estimates of BEV and FCEV models in the market; NACFE (2019) “Guidance Report: Viable Class 7/8 Electric, Hybrid and Alternative Fuel Tractors”, available at: *https://nacfe.org/downloads/viable-class-7-8-alternative-vehicles/*. (NACFE 2019) provided slightly lower estimates than those included here from Nadel and Junga 2020. A recent NREL study suggests that there may be more models available, but it is unclear how many are no longer on the market since the inventory includes vehicles introduced and used in commerce starting in 2012 (Smith et al. 2019).

[85] Global Commercial Vehicle Drive to Zero. “ZETI Data Explorer”. CALSTART. Version 1.1, accessed February 2023. Available online: *https://globaldrivetozero.org/tools/zeti-data-explorer/*.

[86] Tigue, K. (2019) “U.S. Electric Bus Demand Outpaces Production as Cities Add to Their Fleets” Inside Climate News, November 14. *https://insideclimatenews.org/news/14112019/electric-bus-cost-savings-health-fuel-charging*.

[87] Note that ICCT (2020) estimates 440 electric buses were sold in the U.S. and Canada in 2019, with 10 of those products being FCEV pilots. The difference in estimates of number of electric buses available in the U.S. may lie in different sources looking at production vs. sales of units.

[88] International Council on Clean Transportation. “Fact Sheet: Zero-Emission Bus and Truck Market in the United States and Canada: A 2020 Update.” Pages 3–4. May 2021.

[89] M.J. Bradley and Associates (2021) “Medium- and Heavy-Duty Vehicles: Market Structure, Environmental Impact, and EV Readiness.” Page 21. July 2021.

[90] Environmental Defense Fund. “Electric Vehicle Market Update: Manufacturer Commitments and Public Policy Initiatives Supporting Electric Mobility in the U.S. and Worldwide”. April 2022. Available online: *https://blogs.edf.org/climate411/files/2022/04/electric_vehicle_market_report_v6_april2022.pdf*.

[91] Union of Concerned Scientists (2019) “Ready for Work: Now Is the Time for Heavy-Duty Electric Vehicles,” available at *www.ucsusa.org/resources/ready-work*.

[92] Global Commercial Vehicle Drive to Zero. “ZETI (Zero-Emission Technology Inventory)”. CALSTART. Version 8.0, accessed November 2022. Available online: *https://globaldrivetozero.org/tools/zeti/*.

[93] Hydrogen Fuel Cell Partnership. “Buses & Trucks”. Available online: *https://h2fcp.org/buses_trucks*.

[94] Scauzillo, Steve. “First hydrogen-powered transit bus in LA County hits streets in December, starting new trend”. San Gabriel Valley Tribune. November 22, 2022. Available online: *https://ourcommunitynow.com/post/first-hydrogen-powered-transit-bus-in-la-county-hits-streets-in-december-starting-new-trend*.

[95] Heavy Duty Trucking. “FCEV Drayage Trucks Prove Themselves in LA Port Demonstration Project.” HDT Truckinginfo. September 22, 2022. Available online: *https://www.truckinginfo.com/10181655/fcev-drayage-trucks-prove-themselves-in-la-port-demonstration-project*.

[96] Hyundai. “Hyundai Motors Details Plans to Expand into U.S. Market with Hydrogen-powered XCIENT Fuel Cells at ACT Expo.” May 10, 2022. Available online: *https://www.hyundai.com/worldwide/en/company/newsroom/hyundai-motor-details-plans-to-expand-into-u.s.-market-with-hydrogen-powered-xcient-fuel-cells-at-act-expo-0000016825*.

[97] Heavy Duty Trucking. “Pennsylvania Flatbed Carrier to Lease 100 Nikola Tre FCEVs.” HDT Truckinginfo. October 14, 2021. Available online: *https://www.truckinginfo.com/10153974/pennsylvania-flatbed-carrier-to-lease-100-nikola-tre-evs*.

[98] Green Car Congress. “Covenant Logistics Group signs letter of intent for 10 Nikola Tre BEVs and 40 Tre FCEVs.” January 12, 2022. Available online: *https://www.greencarcongress.com/2022/01/20220112-covenant.html*.

[99] Adler, Alan. “Plug Power will buy up to 75 Nikola fuel cell trucks.” Freightwaves. December 15, 2022. Available online; *https://www.freightwaves.com/news/plug-power-will-buy-up-to-75-nikola-fuel-cell-trucks*.

[100] Nikola. “Nikola Corporation Celebrates the Customer Launch of Serial Production in Coolidge, Arizona.” April 27, 2022. Available online: *https://nikolamotor.com/press_releases/nikola-corporation-celebrates-the-customer-launch-of-serial-production-in-coolidge-arizona-163#:~:text=Phase%201%20of%20the%20Coolidge,per%20year%20on%20two%20shifts*.

[101] Memo to Docket. Heavy-Duty Greenhouse Gas Emissions Certification Data. March 2023. Docket EPA–HQ–OAR–2022–0985.

expected to substantially increase over the next decade from current levels. The projected rate of growth in electrification of the HD vehicle sector currently varies widely. After passage of the IRA, EDF's September 2022 report update projected deployments and major orders of electric trucks and buses to rise to 166,000 by the end of 2022.[102] ERM updated an analysis for EDF that projected five scenarios that span a range of between 13 and 48 percent Class 4–8 ZEV sales in 2029, with an average of 29 percent.[103] The International Council for Clean Transportation (ICCT) and Energy Innovation conducted an analysis of the impact of the IRA on electric vehicle uptake, projecting between 39 and 48 percent Class 4–8 ZEV sales in 2030 across three scenarios and between 47 and 56 percent in 2035.[104]

One of the most important factors influencing the extent to which BEVs are available for purchase and able to enter the market is the cost of lithium-ion batteries, the single most expensive component of a BEV. According to Bloomberg New Energy Finance, average lithium-ion battery costs have decreased by more than 85 percent since 2010, primarily due to global investments in battery production and ongoing improvements in battery technology.[105] A number of studies, including the Sharpe and Basma meta-study of direct manufacturing costs from a variety of papers, show that battery pack costs are projected to continue to fall during this decade.[106] [107] [108] Cost reductions in battery packs for electric trucks are anticipated due to continued improvement of cell and battery pack performance and advancements in technology associated with energy density, materials for cells, and battery packaging and integration.[109]

Currently, the fuel cell stack is the most expensive component of a HD FCEV, due primarily to the technological requirements of manufacturing rather than raw material costs.[110] Projected costs are expected to decrease as manufacturing matures and materials improve.[111] Larger production volumes are anticipated as global demand increases for fuel cell systems for HD vehicles, which would improve economies of scale.[112] Costs of the onboard hydrogen storage tank, another component unique to a FCEV, are also projected to drop due to lighter weight and lower cost carbon fiber-reinforced materials, technology improvements, and economies of scale.[113]

As the cost of components has come down, manufacturers have increasingly announced their projections for zero-emission HD vehicles, and these projections signify a rapid increase in BEVs and FCEVs over the next decade. For example, Volvo Trucks and Scania announced a global electrification target of 50 percent of trucks sold being electric by 2030.[114] Daimler Trucks North America has committed to offering only what they refer to as ''carbon-neutral'' trucks in the United States. by 2039 and expects that by 2030 as much as 60 percent of its sales will be ZEVs.[115] [116] Navistar has a goal of having 50 percent of its sales volume be ZEVs by 2030, and it has committed to achieve 100 percent zero emissions by 2040.[117] Cummins targets net-zero carbon emissions by 2050.[118] [119]

On a parallel path, large private HD fleet owners are also increasingly committing to expanding their electric fleets.[120] A report by the International Energy Agency (IEA) provides a comprehensive accounting of recent announcements made by UPS, FedEx, DHL, Walmart, Anheuser-Busch, Amazon, and PepsiCo for fleet electrification.[121] Amazon and UPS, for example, placed orders in 2020 for 10,000 BEV delivery vans from EV start-ups Rivian and Arrival, respectively, and Amazon has plans to scale up to 100,000 BEV vans by 2030.[122] [123]

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[102] Environmental Defense Fund. ''Electric Vehicle Market Update: Manufacturer Commitments and Public Policy Initiatives Supporting Electric Mobility in the U.S. and Worldwide''. September 2022. Available online: *https://blogs.edf.org/climate411/files/2022/09/ERM-EDF-Electric-Vehicle-Market-Report_September2022.pdf*.

[103] Robo, Ellen and Dave Seamonds. Technical Memo to Environmental Defense Fund: Investment Reduction Act Supplemental Assessment: Analysis of Alternative Medium- and Heavy-Duty Zero-Emission Vehicle Business-As-Usual Scenarios. ERM. August 19, 2022. Available online: *https://www.erm.com/contentassets/154d08e0d0674752925cd82c66b3e2b1/edf-zev-baseline-technical-memo-addendum.pdf*.

[104] ICCT and Energy Innovation. ''Analyzing the Impact of the Inflation Reduction Act on Electric Vehicle Uptake in the United States''. January 2023. Available online: *https://theicct.org/wp-content/uploads/2023/01/ira-impact-evs-us-jan23-2.pdf*.

[105] Bloomberg. ''Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh''. Available online: *https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/*.

[106] Mulholland, Eamonn. ''Cost of electric commercial vans and pickup trucks in the United States through 2040.'' Page 7. January 2022. Available at *https://theicct.org/wp-content/uploads/2022/01/cost-ev-vans-pickups-us-2040-jan22.pdf*.

[107] Environmental Defense Fund. ''Technical Review of Medium- and Heavy-Duty Electrification Costs for 2027–2030.'' February 2, 2022. Available online: *https://blogs.edf.org/climate411/files/2022/02/EDF-MDHD-Electrification-v1.6_20220209.pdf*.

[108] Sharpe, Ben and Hussein Basma. ''A meta-study of purchase costs for zero-emission trucks''. The International Council on Clean Transportation, Working Paper 2022–09 (February 2022). Available online: *https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf*.

[109] Sharpe, Ben and Hussein Basma. ''A meta-study of purchase costs for zero-emission trucks''. The International Council on Clean Transportation. *https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf*.

[110] Deloitte China. ''Fueling the Future of Mobility: Hydrogen and fuel cell solutions for transportation, Volume 1''. 2020. Available online: *https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf*.

[111] Sharpe, Ben and Hussein Basma. ''A Meta-Study of Purchase Costs for Zero-Emission Trucks''. The International Council on Clean Transportation. February 2022. Available online: *https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf*.

[112] Deloitte China. ''Fueling the Future of Mobility: Hydrogen and fuel cell solutions for transportation, Volume 1''. 2020. Available online: *https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf*.

[113] *Ibid*.

[114] Scania, 'Scania's Electrification Roadmap,' Scania Group, November 24, 2021, *https://www.scania.com/group/en/home/newsroom/news/2021/Scanias-electrification-roadmap.html*; AB Volvo, 'Volvo Trucks Launches Electric Truck with Longer Range,' Volvo Group, January 14, 2022, *https://www.volvogroup.com/en/news-and-media/news/2022/jan/news-4158927.html*.

[115] David Cullen, 'Daimler to Offer Carbon Neutral Trucks by 2039,' (October 25, 2019). *https://www.truckinginfo.com/343243/daimler-aims-to-offer-only-co2-neutral-trucks-by-2039-in-key-markets*.

[116] Deborah Lockridge, 'What Does Daimler Truck Spin-off Mean for North America?,' Trucking Info (November 11, 2021). *https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america*.

[117] Navistar presentation at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 9–11, 2022).

[118] Cummins, Inc. ''Cummins Unveils New Environmental Sustainability Strategy to Address Climate Change, Conserve Natural Resources.'' November 14, 2019. Last accessed on September 10, 2021 at *https://www.cummins.com/news/releases/2019/11/14/cummins-unveils-new-environmental-sustainability-strategy-address-climate*.

[119] Environmental Defense Fund (2022) September 2022 Electric Vehicle Market Update: Manufacturer Commitments and Public Policy Initiatives Supporting Electric Mobility in the U.S. and Worldwide, available online at: *https://blogs.edf.org/climate411/files/2022/09/ERM-EDF-Electric-Vehicle-Market-Report_September2022.pdf*.

[120] Environmental Defense Fund (2021) EDF analysis finds American fleets are embracing electric trucks. July 28, 2021. Available online at: *https://blogs.edf.org/energyexchange/2021/07/28/edf-analysis-finds-american-fleets-are-embracing-electric-trucks/*.

[121] International Energy Association. Global EV Outlook 2021. April 2021. Available online at: *https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf*.

[122] Amazon, Inc. ''Introducing Amazon's first custom electric delivery vehicle.'' October 8, 2020. Last accessed on October 18, 2022 at *https://www.aboutamazon.com/news/transportation/introducing-amazons-first-custom-electric-delivery-vehicle*.

[123] Arrival Ltd. ''UPS invests in Arrival and orders 10,000 Generation 2 Electric Vehicles.'' April 24, 2020. Last accessed on October 18, 2022 at

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Likewise, in December 2022, PepsiCo added the first of 100 planned Tesla Semis to its fleet.[124] These announcements include not only orders for electric delivery vans and semi-trucks, but more specific targets and dates to full electrification or net-zero emissions. Amazon, FedEx, DHL, and Walmart have set a commitment to fleet electrification and/or achieving net-zero emissions by 2040.[125] [126] [127] [128] We recognize that certain delivery vans will likely fall into the Class 2b and 3 regulatory category, the vast majority of which are not covered in this rule's proposed updates; we intend to address this category in a separate light and medium-duty vehicle rulemaking.[129]

Amazon and Walmart are among fleets owners and operators that are also considering hydrogen. Amazon signed an agreement with Plug Power,[130] a company building an end-to-end hydrogen ecosystem, to supply hydrogen for up to 800 HD long-haul trucks or 30,000 forklifts (which are commonly powered using hydrogen) starting in 2025 through 2040.[131] Walmart is purchasing hydrogen from Plug Power [132] and plans to expand pilots of fuel cell forklifts, yard trucks, and possibly HD long-haul trucks by 2040.[133] Plug Power has agreed to purchase up to 75 Nikola Class 8 fuel cell trucks over the next three years in exchange for supplying the company with hydrogen fuel.[134]

The lifetime total cost of ownership (TCO), which includes maintenance and fuel costs, is likely a primary factor for HD vehicle and fleet owners considering BEV and FCEV purchases. In fact, a 2018 survey of fleet owners showed ''lower cost of ownership'' as the second most important motivator for electrifying their fleet.[135] An ICCT analysis from 2019 suggests that TCO for light and medium heavy-duty BEVs could reach cost parity with comparable diesel ICE vehicles in the early 2020s, while heavy HD BEVs and FCEVs are likely to reach cost parity with comparable diesel ICE vehicles closer to the 2030 timeframe.[136] Recent findings from Phadke et al. suggest that BEV TCO could be 13 percent less than that of a comparable diesel ICE vehicle if electricity pricing is optimized.[137] These studies do not consider the IRA. The Rocky Mountain Institute found that because of the IRA, the TCO of electric trucks will be lower than the TCO of comparable diesel trucks about five years faster than without the IRA. They expect cost parity as soon as 2023 for urban and regional duty cycles that travel up to 250 miles and 2027 for long-hauls that travel over 250 miles.[138]

As the ICCT and Phadke et al. studies suggest, fuel costs are an important part of TCO. While assumptions about vehicle weight and size can make direct comparisons between HD ZEVs and ICE vehicles challenging, data show greater energy efficiency of battery-electric and fuel cell technology relative to ICE technologies.[139] [140] Better energy efficiency leads to lower electricity or hydrogen fuel costs for ZEVs relative to ICE fuel costs.[141] [142] Maintenance and service costs are also an important component within TCO; although there is limited data available on actual maintenance costs for HD ZEVs, early experience with BEV medium HD vehicles and transit buses suggests the potential for lower maintenance costs after an initial period of learning to refine both component durability and maintenance procedures.[143] We expect similar trends for FCEVs, as discussed in Chapter 2 of the DRIA. To facilitate HD fleets transitioning to ZEVs, some manufacturers are currently including maintenance in leasing agreements with fleets; it is unclear the extent to which a full-service leasing model will persist or will be transitioned to a more

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https://arrival.com/us/en/news/ups-invests-in-arrival-and-orders-10000-generation-2-electric-vehicles.

[124] Akash Sriram. ''Musk delivers first Tesla truck, but no update on output, pricing.'' Reuters. December 2, 2022. Last accessed on January 4, 2023 at *https://www.reuters.com/business/autos-transportation/musk-delivers-first-tesla-semi-trucks-2022-12-02/*.

[125] Robo, Ellen and Dave Seamonds. Technical Memo to Environmental Defense Fund: Investment Reduction Act Supplemental Assessment: Analysis of Alternative Medium- and Heavy-Duty Zero-Emission Vehicle Business-As-Usual Scenarios. ERM. August 19, 2022. Available online: *https://www.erm.com/contentassets/154d08e0d0674752925cd82c66b3e2b1/edf-zev-baseline-technical-memo-addendum.pdf*.

[126] FedEx Corp. ''FedEx Commits to Carbon-Neutral Operations by 2040.'' March 3, 2021. Last accessed on October 18, 2022 at *https://newsroom.fedex.com/newsroom/asia-english/sustainability2021*.

[127] Deutsche Post DHL Group. ''Zero emissions by 2050: DHL announces ambitious new environmental protection target.'' March 2017. Last accessed on October 18, 2022 at *https://www.dhl.com/global-en/delivered/sustainability/zero-emissions-by-2050.html*.

[128] Walmart Inc. ''Walmart Sets Goal to Become a Regenerative Company.'' September 21, 2020. Last accessed on October 18, 2022 at *https://corporate.walmart.com/newsroom/2020/09/21/walmart-sets-goal-to-become-a-regenerative-company*.

[129] Complete heavy-duty vehicles at or below 14,000 pounds. GVWR are chassis-certified under 40 CFR part 86, while incomplete vehicles at or below 14,000 pounds. GVWR may be certified to either 40 CFR part 86 (meeting standards under subpart S) or 40 CFR part 1037 (installed engines would then need to be certified under 40 CFR part 1036). Class 2b and 3 vehicles are primarily chassis-certified complete commercial pickup trucks and vans. We intend to pursue a combined light-duty and medium-duty rulemaking to set more stringent standards for complete and incomplete vehicles at or below 14,000 pounds. GVWR that are certified under 40 CFR part 86, subpart S. The standards proposed in this rule would apply for all heavy-duty vehicles above 14,000 pounds. GVWR, except as noted in 40 CFR 1037.150(l). The proposed standards in this rule would also apply for incomplete heavy-duty vehicles at or below 14,000 pounds. GVWR if vehicle manufacturers opt to certify those vehicles under 40 CFR part 1037 instead of certifying under 40 CFR part 86, subpart S.

[130] Plug Power. ''Plug and Amazon Sign Green Hydrogen Agreement''. Available online: *https://www.ir.plugpower.com/press-releases/news-details/2022/Plug-and-Amazon-Sign-Green-Hydrogen-Agreement/default.aspx*.

[131] Amazon. ''Amazon adopts green hydrogen to help decarbonize its operations''. August 25, 2022. Available online: *https://www.aboutamazon.com/news/sustainability/amazon-adopts-green-hydrogen-to-help-decarbonize-its-operations*.

[132] Plug Power. ''Plug Supplies Walmart with Green Hydrogen to Fuel Retailer's Fleet of Material Handling Lift Trucks''. April 19, 2022. Available online: *https://www.ir.plugpower.com/press-releases/news-details/2022/Plug-Supplies-Walmart-with-Green-Hydrogen-to-Fuel-Retailers-Fleet-of-Material-Handling-Lift-Trucks/default.aspx*.

[133] Proactive. ''WalMart eyes benefits of hydrogen delivery vehicles in wider trials''. Proactive 13:17. June 8, 2022. Available online: *https://www.proactiveinvestors.co.uk/companies/news/984360/walmart-eyes-benefits-of-hydrogen-delivery-vehicles-in-wider-trials-984360.html*.

[134] Adler, Alan. ''Plug Power will buy up to 75 Nikola fuel cell trucks''. Freightwaves. December 15, 2022. Available online: *https://www.freightwaves.com/news/plug-power-will-buy-up-to-75-nikola-fuel-cell-trucks*.

[135] The primary motivator for fleet managers was ''Sustainability and environmental goals''; the survey was conducted by UPS and GreenBiz.

[136] ICCT (2019) ''Estimating the infrastructure needs and costs for the launch of zero-emissions trucks''; available online at: *https://theicct.org/publications/zero-emission-truck-infrastructure*.

[137] Phadke, A., et. al. (2021) ''Why Regional and Long-Haul Trucks are Primed for Electrification Now''; available online at: *https://eta-publications.lbl.gov/sites/default/files/updated_5_final_ehdv_report_033121.pdf*.

[138] Kahn, Ari, et. al. ''The Inflation Reduction Act Will Help Electrify Heavy-Duty Trucking''. Rocky Mountain Institute. August 25, 2022. Available online: *https://rmi.org/inflation-reduction-act-will-help-electrify-heavy-duty-trucking/*.

[139] NACFE (2019) ''Guidance Report: Viable Class 7/8 Electric, Hybrid and Alternative Fuel Tractors'', available online at: *https://nacfe.org/downloads/viable-class-7-8-alternative-vehicles/*.

[140] Nadel, S. and Junga, E. (2020) ''Electrifying Trucks: From Delivery Vans to Buses to 18-Wheelers''. American Council for an Energy-Efficient Economy White Paper, available online at: *https://aceee.org/white-paper/electrifying-trucks-delivery-vans-buses-18*.

[141] NACFE (2019) ''Guidance Report: Viable Class 7/8 Electric, Hybrid and Alternative Fuel Tractors'', available online at: *https://nacfe.org/downloads/viable-class-7-8-alternative-vehicles/*.

[142] Nadel, S. and Junga, E. (2020) ''Electrifying Trucks: From Delivery Vans to Buses to 18-Wheelers''. American Council for an Energy-Efficient Economy White Paper, available online at: *https://aceee.org/white-paper/electrifying-trucks-delivery-vans-buses-18*.

[143] U.S. Department of Energy Alternative Fuels Data Center (AFDC), ''Developing Infrastructure to Charge Plug-In Electric Vehicles'', *https://afdc.energy.gov/fuels/electricity_infrastructure.html* (accessed 2–27–20).

traditional purchase model after an initial period of learning.[144] [145]

The growth in incentive programs will continue to play an important role in the HD ZEV market. For example, as discussed in more detail in this section, FHWA-approved plans providing $1.5 billion in funding for expanding charging on over 75,000 miles of highway encourages states to consider station designs and power levels that could support heavy-duty vehicles. In a 2017 survey of fleet managers, upfront purchase price was listed as the primary barrier to HD fleet electrification. This suggests that federal incentive programs like those in the BIL and IRA (discussed in Section I.C.2) to offset ZEV purchase costs, as well as state and local incentives and investments, can be influential in the near term, with improvements in BEV and FCEV component costs playing an increasing role in reducing costs in the longer term.[146] [147] For example, BEV incentive programs for transit and school buses have experienced growth and are projected to continue to influence BEV markets. The Los Angeles Department of Transportation (LADOT) is one of the first transit organizations in the country to develop a program committed to transitioning its transit fleets to ZEVs by 2030—a target that is 10 years sooner than CARB's Innovative Clean Transportation (ICT) regulation requiring all public transit to be electric by 2040.[148] Since these announcements, LADOT has purchased 27 BEV transit and school buses from BYD and Proterra; by 2030, the number of BEV buses in the LADOT fleet is expected to grow to 492 buses. Outside of California, major metropolitan areas including Chicago, Seattle, New York City, and Washington, DC, have zero-emissions transit programs with 100 percent ZEV target dates ranging from 2040 to 2045.[149] [150] [151] [152] EV school bus programs, frequently in partnership with local utilities, are also being piloted across the country and are expanding under EPA's Clean School Bus Program (CSB).[153] These programs initially included school districts in, but not limited to, California, Virginia, Massachusetts, Michigan, Maryland, Illinois, New York, and Pennsylvania.[154] [155] [156] [157] [158] Going forward, they will continue to expand with BIL funding of over $5 billion over the next five years (FY 2022–2026) to replace existing school buses with zero-emission and low-emission models, as discussed more in Section I.C.2.

In summary, the HD ZEV market is growing rapidly, and ZEV technologies are expected to expand to many applications across the HD sector. As the industry is dynamic and changing rapidly, the examples presented here represent only a sampling of the ZEV HD investment policies and markets. DRIA Chapter 1 provides a more detailed characterization of the HD ZEV technologies in the current and projected ZEV market. We request comment on our assessment of the HD ZEV market and any additional data sources we should consider.

2. Bipartisan Infrastructure Law and Inflation Reduction Act

i. BIL

The BIL[159] was enacted on November 15, 2021, and contains provisions to support the deployment of low- and zero-emission transit buses, school buses, and trucks that service ports, as well as electric vehicle charging infrastructure and hydrogen. These provisions include Section 71101 funding for EPA's Clean School Bus Program,[160] with $5 billion to fund the replacement of ICE school buses with clean and zero-emission buses over the next five years. In its first phase of funding for the Clean School Bus Program, EPA is issuing nearly $1 billion in rebates (up to a maximum of $375,000 per bus, depending on the bus fuel type, bus size, and school district prioritization status)[161] for replacement clean and zero-emission buses and associated infrastructure costs.[162] [163] The BIL also includes funding for DOT's Federal Transit Administration (FTA) Low- or No-Emission Grant Program,[164] with over $5.6 billion over the next five years to support the purchase of zero- or low-emission transit buses and associated infrastructure.[165]

The BIL includes up to $7.5 billion to help build out a national network of EV

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[144] Fisher, J. (2019) ''Volvo's First Electric VNR Ready for the Road.'' Fleet Owner, September 17. *www.fleetowner.com/blue-fleets/volvo-s-first-electric-vnr-ready-road.*

[145] Gnaticov, C. (2018). ''Nikola One Hydrogen Electric Semi Hits the Road in Official Film.'' *Carscoops,* Jan. 26. *www.carscoops.com/2018/01/nikola-one-hydrogen-electric-semi-hits-road-official-film/.*

[146] Other barriers that fleet managers prioritized for fleet electrification included: Inadequate charging infrastructure—our facilities, inadequate product availability, inadequate charging infrastructure—public; for the full list of top barriers see Nadel and Junga (2020), citing UPS and GreenBiz 2018.

[147] Nadel, S. and Junga, E. (2020) ''Electrifying Trucks: From Delivery Vans to Buses to 18-Wheelers''. American Council for an Energy-Efficient Economy White Paper, available online at: *https://aceee.org/white-paper/electrifying-trucks-delivery-vans-buses-18.*

[148] LADOT, (2020). ''LADOT Transit Zero-Emission Bus Rollout Plan'' *https://ww2.arb.ca.gov/sites/default/files/2020-12/LADOT_ROP_Reso_ADA12172020.pdf.*

[149] Sustainable Bus. ''CTA Chicago tests electric buses and pursues 100% e-fleet by 2040''. April 29, 2021. Available online: *https://www.sustainable-bus.com/electric-bus/cta-chicago-electric-buses/.*

[150] Pascale, Jordan. ''Metro Approves Plans For Fully Electric Bus Fleet By 2045''. DCist. June 10, 2021. Available online: *https://dcist.com/story/21/06/10/metro-goal-entirely-electric-bus-fleet-2045/.*

[151] King County Metro. ''Transitioning to a zero-emissions fleet''. Available online: *https://kingcounty.gov/depts/transportation/metro/programs-projects/innovation-technology/zero-emission-fleet.aspx.*

[152] Hallum, Mark. ''MTA's recent purchase of zero emissions buses will be 33% bigger than expected''. AMNY. May 25, 2021. Available online: *https://www.amny.com/transit/mta-says-45-to-60-more-buses-in-recent-procurement-will-be-zero-emissions/.*

[153] U.S. Environmental Protection Agency. ''Clean School Bus Program''. Available online: *https://www.epa.gov/cleanschoolbus.*

[154] Commonwealth of Massachusetts. ''EV Programs & Incentives''. Available online: *https://www.mass.gov/info-details/ev-programs-incentives.*

[155] Morris, Charles. ''NYC's new school bus contract includes electric bus pilot''. *Charged—Electric Vehicles Magazine.* July 7, 2021. Available online: *https://chargedevs.com/newswire/nycs-new-school-bus-contract-includes-electric-bus-pilot/.*

[156] Soneji, Hitesh, et. al. ''Pittsburg USD Electric School Bus Final Project Report''. Olivine, Inc. September 23, 2020. Available online: *https://olivineinc.com/wp-content/uploads/2020/10/Pittsburg-USD-Electric-School-Bus-Final-Project-Report-Final.pdf.*

[157] Shahan, Cynthia. ''Largest Electric School Bus Program in United States Launching in Virginia''. *CleanTechnica.* January 12, 2020. Available online: *https://cleantechnica.com/2020/01/12/largest-electric-school-bus-program-in-united-states-launching-in-virginia/.*

[158] St. John, Jeff. ''Highland Electric Raises $235M, Lands Biggest Electric School Bus Contract in the US''. *gtm.* February 25, 2021. Available online: *https://www.greentechmedia.com/articles/read/on-heels-of-253m-raise-highland-electric-lands-biggest-electric-school-bus-contract-in-the-u.s.*

[159] United States, Congress. Public Law 117–58. Infrastructure Investment and Jobs Act of 2021. *Congress.gov, www.congress.gov/bill/117th-congress/house-bill/3684/text.* 117th Congress, House Resolution 3684, passed 15 Nov. 2021.

[160] U.S. Environmental Protection Agency. ''Clean School Bus Program''. Available online: *https://www.epa.gov/cleanschoolbus.*

[161] U.S. Environmental Protection Agency. ''2022 Clean School Bus (CSB) Rebates Program Guide''. May 2022. Available online: *https://nepis.epa.gov/Exe/ZyPDF.cgi/P1014WNH.PDF?Dockey=P1014WNH.PDF.*

[162] Some recipients are able to claim up to $20,000 per bus for charging infrastructure.

[163] U.S. Environmental Protection Agency, ''EPA Clean School Bus Program Second Report to Congress Fiscal Year 2022,'' EPA–420–R–23–002, February 2023. Available online: *https://www.epa.gov/system/files/documents/2023-02/420r23002.pdf* (last accessed February 9, 2023).

[164] U.S. Department of Transportation, Federal Transit Administration. ''Low or No Emission Vehicle Program—5339(c)''. Available online: *https://www.transit.dot.gov/lowno* (last accessed February 10, 2023).

[165] U.S. Department of Transportation, Federal Transit Administration. ''Bipartisan Infrastructure Law Fact Sheet: Grants for Buses and Bus Facilities''. Available online: *https://www.transit.dot.gov/funding/grants/fact-sheet-buses-and-bus-facilities-program* (last accessed February 10, 2023).

charging and hydrogen fueling through DOT's Federal Highway Administration (FHWA). This includes $2.5 billion in discretionary grant programs for charging and fueling infrastructure [166] along designated alternative fuel corridors and in communities (Section 11401) [167] and $5 billion for the National Electric Vehicle Infrastructure (NEVI) Formula Program (under Division J, Title VIII).[168] In September 2022, the FHWA approved the first set of plans for the NEVI program covering all 50 states, Washington, DC, and Puerto Rico. The approved plans provide $1.5 billion in funding for fiscal years (FY) 2022 and 2023 to expand charging on over 75,000 miles of highway.[169] While jurisdictions are not required to build stations specifically for heavy-duty vehicles, FHWA's guidance encourages states to consider station designs and power levels that could support heavy-duty vehicles.[170]

The BIL funds other programs that could support HD vehicle electrification. For example, there is continued funding of the Congestion Mitigation and Air Quality (CMAQ) Improvement Program, with more than $2.5 billion authorized for FY 2022 through FY 2026. The BIL (Section 11115) amended the CMAQ Improvement Program to add, among other things, ''the purchase of medium- or heavy-duty zero emission vehicles and related charging equipment'' to the list of activities eligible for funding. The BIL establishes a program under Section 11402 ''Reduction of Truck Emissions at Port Facilities'' that includes grants to be administered through FHWA aimed at reducing port emissions, including through electrification. In addition, the BIL includes funding for DOT's Maritime Administration (MARAD) Port Infrastructure Development Program; [171] and DOT's Federal Highway Administration (FHWA) Carbon Reduction Program.[172]

The BIL also targets batteries used for electric vehicles. It funds DOE's Battery Materials Processing and Battery Manufacturing program,[173] which grants funds to promote U.S. processing and manufacturing of batteries for automotive and electric grid use through demonstration projects, the construction of new facilities, and the retooling, retrofitting, and expansion of existing facilities. This includes a total of $3 billion for battery material processing and $3 billion for battery manufacturing and recycling, with additional funding for a lithium-ion battery recycling prize competition, research and development activities in battery recycling, state and local programs, and the development of a collection system for used batteries. In addition, the BIL includes $200 million for the Electric Drive Vehicle Battery Recycling and Second-Life Application Program for research, development, and demonstration of battery recycling and second-life applications.

Hydrogen provisions of the BIL include funding for several programs to accelerate progress towards the Hydrogen Shot goal, launched on June 7, 2021, to reduce the cost of clean hydrogen [174] production by 80 percent to $1 for 1 kg in 1 decade [175] and jumpstart the hydrogen market in the United States. This includes $8 billion for the Department of Energy's Regional Clean Hydrogen Hubs Program to establish networks of clean hydrogen producers, potential consumers, and connective infrastructure in close proximity; $1 billion for a Clean Hydrogen Electrolysis Program; and $500 million for Clean Hydrogen Manufacturing and Recycling Initiatives.[176] The BIL also called for development of a Clean Hydrogen Production Standard to guide DOE hub and Research, Development, Deployment, and Diffusion (RDD&D) actions; and a National Clean Hydrogen Strategy and Roadmap to facilitate widescale production, processing, delivery, storage, and use of clean hydrogen. These BIL programs are currently under development, and further details are expected over the course of calendar year (CY) 2023.

ii. IRA Sections 13502 and 13403

The IRA,[177] which was enacted on August 16, 2022, contains several provisions relevant to vehicle electrification and the associated infrastructure via tax credits, grants, rebates, and loans through CY 2032, including two key provisions that provide a tax credit to reduce the cost of producing qualified batteries (battery tax credit) and to reduce the cost of purchasing qualified ZEVs (vehicle tax credit). The battery tax credit in ''Advanced Manufacturing Production Credit'' in IRA section 13502 and the ''Qualified Commercial Clean Vehicles'' vehicle tax credit in IRA section 13403 are included quantitatively in our analysis.

IRA section 13502, ''Advanced Manufacturing Production Credit,'' provides tax credits for the production and sale of battery cells and modules of up to $45 per kilowatt-hour (kWh), and for 10 percent of the cost of producing applicable critical minerals (including those found in batteries and fuel cells, provided that the minerals meet certain specifications), when such components or minerals are produced in the United States. These credits begin in CY 2023 and phase down starting in CY 2030, ending after CY 2032. With projected direct manufacturing costs for heavy-

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[166] Fueling infrastructure includes hydrogen, propane, and natural gas.

[167] U.S. Department of Transportation, Federal Highway Administration, ''The National Electric Vehicle Infrastructure (NEVI) Formula Program Guidance,'' February 10, 2022. Available online: *https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/nominations/90d_nevi_formula_program_guidance.pdf* (last accessed February 10, 2023).

[168] U.S. Department of Transportation, Federal Highway Administration. ''Bipartisan Infrastructure Law, Fact Sheets: National Electric Vehicle Infrastructure Formula Program''. February 10, 2022. Available online: *https://www.fhwa.dot.gov/bipartisan-infrastructure-law/nevi_formula_program.cfm*.

[169] U.S. Department of Transportation. ''Historic Step: All Fifty States Plus DC and Puerto Rico Grenlit to Move EV Charging Networks Forward, Covering 75,000 miles of Highway''. Available online: *https://www.transportation.gov/briefing-room/historic-step-all-fifty-states-plus-dc-and-puerto-rico-greenlit-move-ev-charging*.

[170] U.S. Department of Transportation, Federal Highway Administration. ''National Electric Vehicle Infrastructure Formula Program: Bipartisan Infrastructure Law—Program Guidance''. February 10, 2022. Available online: *https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/nominations/90d_nevi_formula_program_guidance.pdf*.

[171] U.S. Department of Transportation, Maritime Administration. ''Bipartisan Infrastructure Law: Maritime Administration''. Available online: *https://www.maritime.dot.gov/about-us/bipartisan-infrastructure-law-maritime-administration*.

[172] U.S. Department of Transportation, Federal Highway Administration. ''Bipartisan Infrastructure Law, Fact Sheets: Carbon Reduction Program (CRP)''. April 20, 2022. Available online: *https://www.fhwa.dot.gov/bipartisan-infrastructure-law/crp_fact_sheet.cfm*.

[173] U.S. Department of Energy. ''Biden Administration Announces $3.16 Billion From Bipartisan Infrastructure Law to Boost Domestic Battery Manufacturing and Supply Chains. May 2, 2022. Available online: *https://www.energy.gov/articles/biden-administration-announces-316-billion-bipartisan-infrastructure-law-boost-domestic*.

[174] The BIL defines ''clean hydrogen'' as hydrogen produced in compliance with the GHG emissions standard established under 42 U.S. Code section 16166(a), including production from any fuel source, where the standard developed shall define the term to mean hydrogen produced with a carbon intensity equal to or less than 2 kilograms of carbon dioxide-equivalent produced at the site of production per kilogram of hydrogen produced.

[175] Satyapal, Sunita. ''2022 AMR Plenary Session''. U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office. June 6, 2022. Available online: *https://www.energy.gov/sites/default/files/2022-06/hfto-amr-plenary-satyapal-2022-1.pdf*.

[176] U.S. Department of Energy. ''DOE Establishes Bipartisan Infrastructure Law's $9.5 Billion Clean Hydrogen Initiatives''. February 15, 2022. Available online: *https://www.energy.gov/articles/doe-establishes-bipartisan-infrastructure-laws-95-billion-clean-hydrogen-initiatives*.

[177] Inflation Reduction Act of 2022, Public Law 117–169, 136 Stat. 1818 (2022) (''Inflation Reduction Act'' or ''IRA''), available at *https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf*.

duty vehicle batteries on the order of $65 to $275/kWh in the 2025–2030 timeframe,[178] this tax credit has the potential to noticeably reduce the cost of qualifying batteries and, by extension, the cost of BEVs and FCEVs with qualifying batteries. We did not include a detailed cost breakdown of fuel cells quantitatively in our analysis, but the potential impact on fuel cells may also be significant because platinum (an applicable critical mineral commonly used in fuel cells) is a major contributor to the cost of fuel cells.[179]

We limited our assessment of this tax credit in our DRIA Chapter 2 analysis to the tax credits for battery cells and modules. Pursuant to the IRA, qualifying battery cells must have an energy density of not less than 100 watt-hours per liter, and we expect that batteries for heavy-duty BEVs and FCEVs will exceed this requirement as described in DRIA Chapter 2.4.2.2. Qualifying battery cells must be capable of storing at least 12 watt-hours of energy and qualifying battery modules must have an aggregate capacity of not less than 7 kWh (or, for FCEVs, not less than 1 kWh); typical battery cells and modules for motor vehicles also exceed these requirements.[180] Additionally, the ratio of the capacity of qualifying cells and modules to their maximum discharge amount shall not exceed 100:1. We expect that battery cells and modules in heavy-duty BEVs and FCEVs will also meet this requirement because the high costs and weight of the batteries and the competitiveness of the heavy-duty industry will pressure manufacturers to allow as much of their batteries to be useable as possible. We did not consider the tax credits for critical minerals quantitatively in our analysis. However, we note that any applicability of the critical mineral tax credit may further reduce the costs of batteries.

We included this battery tax credit by reducing the direct manufacturing costs of batteries in BEVs and FCEVs, but not the associated indirect costs. At present, there are few manufacturing plants for HD vehicle batteries in the United States, which means that few batteries would qualify for the tax credit now. We expect that the industry will respond to this tax credit incentive by building more domestic battery manufacturing capacity in the coming years, but this will take several years to come to fruition. Thus, we have chosen to model this tax credit by assuming that HD BEV and FCEV manufacturers fully utilize the module tax credit (which provides $10 per kWh) and gradually increase their utilization of the cell tax credit (which provides $35 per kWh) for MY 2027–2029 until MY 2030 and beyond, when they earn 100 percent of the available cell and module tax credits. Further discussion of this battery tax credit and our battery costs can be found in DRIA Chapter 2.4.3.1.

IRA section 13403, ''Qualified Commercial Clean Vehicles,'' creates a tax credit of up to $40,000 per Class 4 through 8 HD vehicle (up to $7,500 per Class 2b or 3 vehicle) for the purchase or lease of a qualified commercial clean vehicle. This tax credit is available from CY 2023 through CY 2032 and is based on the lesser of the incremental cost of the clean vehicle over a comparable ICE vehicle or the specified percentage of the basis of the clean vehicle, up to the maximum applicable limitation. By effectively reducing the price a vehicle owner must pay for a HD ZEV and the incremental difference in cost between it and a comparable ICE vehicle—by $40,000 in many cases—more vehicle purchasers will be poised to take advantage of the cost savings anticipated from total cost of ownership, including operational cost savings from fuel and maintenance and repair compared with ICE vehicles. Among other specifications, these vehicles must be on-road vehicles (or mobile machinery) that are propelled to a significant extent by a battery-powered electric motor or are qualified fuel cell motor vehicles (also known as fuel cell electric vehicles, FCEVs). For the former, the battery must have a capacity of at least 15 kWh (or 7 kWh if it has a gross vehicle weight rating of less than 14,000 pounds (Class 3 or below)) and must be rechargeable from an external source of electricity. This limits the qualified vehicles to BEVs and plug-in hybrid electric vehicles (PHEVs), in addition to FCEVs. Since this tax credit overlaps with the model years for which we are proposing standards (MYs 2027 through 2032), we included it in our calculations for each of those years in our feasibility analysis for our proposed standards (see DRIA Chapter 2).

For BEVs and FCEVs, the per-vehicle tax credit is equal to the lesser of the following, up to the cap limitation: (A) 30 percent of the BEV or FCEV cost, or (B) the incremental cost of the BEV or FCEV when compared to a comparable (in size and use) ICE vehicle. The limitation on this tax credit is $40,000 for vehicles with a gross vehicle weight rating of equal to or greater than 14,000 pounds (Class 4–8 commercial vehicles) and $7,500 for vehicles with a gross vehicle weight rating of less than 14,000 pounds (commercial vehicles Class 3 and below). For example, if a BEV with a gross vehicle weight rating of equal to or greater than 14,000 pounds costs $350,000 and a comparable ICE vehicle costs $150,000,[181] the tax credit would be the lesser of the following, subject to the limitation: (A) 30 percent × $350,000 = $105,000 or (B) $350,000 − $150,000 = $200,000. (A) is less than (B), but (A) exceeds the limit of $40,000, so the tax credit would be $40,000. For PHEVs, the per-vehicle tax credit follows the same calculation and cap limitation as for BEVs and FCEVs except that (A) is 15 percent of the PHEV cost.

In order to estimate the impact of this tax credit in our feasibility analysis for BEVs and FCEVs, we first applied a retail price equivalent to our direct manufacturing costs for BEVs, FCEVs, and ICE vehicles. Note that the direct manufacturing costs of BEVs and FCEVs were reduced by the amount of the battery tax credit in IRA section 13502, as described in DRIA Chapter 2.4.3.1. We calculated the purchaser's incremental cost of BEVs and FCEVs compared to ICE vehicles and not the full cost of vehicles in our analysis. We based our calculation of the tax credit on this incremental cost. When the incremental cost exceeded the tax credit limitation (determined by gross vehicle weight rating as described in the previous paragraph), we decreased the incremental cost by the tax credit limitation. When the incremental cost was between $0 and the tax credit limitation, we reduced the incremental cost to $0 (*i.e.,* the tax credit received by the purchaser was equal to the incremental cost). When the incremental cost was negative (*i.e.,* the BEV or FCEV was cheaper to purchase than the ICE vehicle), no tax credit was given. In order for this calculation to be appropriate, we determined that all

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[178] Sharpe, B., Basma, H. ''A meta-study of purchase costs for zero-emission trucks''. International Council on Clean Transportation. February 17, 2022. Available online: *https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf.*

[179] Leader, Alexandra & Gaustad, Gabrielle & Babbitt, Callie. (2019). The effect of critical material prices on the competitiveness of clean energy technologies. Materials for Renewable and Sustainable Energy. 8. 10.1007/s40243–019–0146–z.

[180] Islam, Ehsan Sabri, Ram Vijayagopal, Aymeric Rousseau. ''A Comprehensive Simulation Study to Evaluate Future Vehicle Energy and Cost Reduction Potential'', Report to the U.S. Department of Energy, Contract ANL/ESD–22/6, October 2022. See Medium- and heavy-duty vehicles (techno-economic analysis with BEAN). Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

[181] Sharpe, B., Basma, H. ''A meta-study of purchase costs for zero-emission trucks''. International Council on Clean Transportation. February 17, 2022. Available online: *https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf.*

Class 4–8 BEVs and FCEVs must cost more than $133,333 such that 30 percent of the cost is at least $40,000 (or $25,000 and $7,500, respectively, for BEVs and FCEVs Class 3 and below), which is reasonable based on our review of the literature on the costs of BEVs and FCEVs.[182] The tax credit amounts for each vehicle type included in our analysis in MYs 2027 and 2032 are shown in DRIA Chapter 2.8.2.

We project that the impact of the IRA vehicle tax credit will be significant, as shown in DRIA Chapter 2.8.2. In many cases, the incremental cost (with the tax credit) of a BEV compared to an ICE vehicle is eliminated, leaving only the cost of the electric vehicle supply equipment (EVSE) as an added upfront cost to the BEV owner. Similarly, in some cases, the tax credit eliminates the upfront cost of a FCEV compared to an ICE vehicle.

iii. Other IRA Provisions

There are many other provisions of the IRA that we expect will support electrification of the heavy-duty fleet. Importantly, these other provisions do not serve to reduce ZEV adoption rates from our current projections. Due to the complexity of analyzing the combined potential impact of these provisions, we did not quantify their potential impact in our assessment of costs and feasibility, but we note that they may help to reduce many obstacles to electrification of HDVs and may further support or even increase ZEV adoption rates beyond the levels we currently project. Our assessment of the impacts of these provisions of the IRA on ZEV adoption rates are, therefore, somewhat conservative.

Section 13404, ''Alternative Fuel Refueling Property Credit,'' modifies an existing tax credit that applies to alternative fuel refueling property (*e.g.,* electric vehicle chargers and hydrogen fueling stations) and extends the tax credit through CY 2032. The credit also applies to refueling property that stores or dispenses specified clean-burning fuels, including at least 85 percent hydrogen, into the fuel tank of a motor vehicle. Starting in CY 2023, this provision provides a tax credit of up to 30 percent of the cost of the qualified alternative fuel refueling property (*e.g.,* HD BEV charger), and up to $100,000 when located in low-income or non-urban area census tracts and certain other requirements are met. We expect that many HD BEV owners will need chargers installed in their depots for overnight charging, and this tax credit will effectively reduce the costs of installing charging infrastructure and, in turn, further effectively reduce the total costs associated with owning a BEV for many HD vehicle owners. Additionally, this tax credit may offset some of the costs of installing very high-powered public and private chargers that are necessary to recharge HD BEVs with minimal downtime during the day. Similarly, we expect that this tax credit will reduce the costs associated with refueling heavy-duty FCEVs, whose owners may rely on public hydrogen refueling stations or those installed in their depots. We expect that this tax credit will help incentivize the build out of the charging and hydrogen refueling infrastructure necessary for high BEV and FCEV adoption, which may further support increased BEV and FCEV uptake.

Section 60101, ''Clean Heavy-duty Vehicles,'' amends the CAA to add new section 132 (42 U.S.C. 7432) and appropriates $1 billion to the Administrator, including $600 million generally for carrying out CAA section 132 (3 percent of which must be reserved for administrative costs necessary to carry out the section's provisions) and $400 million to make awards under CAA section 132 to eligible recipients/contractors that propose to replace eligible vehicles to serve one or more communities located in an air quality area designated pursuant to CAA section 107 as nonattainment for any air pollutant, in FY 2022 and available through FY 2031. CAA section 132 requires the Administrator to implement a program to make awards of grants and rebates to eligible recipients (defined as States, municipalities, Indian tribes, and nonprofit school transportation associations), and to make awards of contracts to eligible contractors for providing rebates, for up to 100 percent of costs for: (1) the incremental costs of replacing a Class 6 or Class 7 heavy-duty vehicle that is not a zero-emission vehicle with a zero-emission vehicle (as determined by the Administrator based on the market value of the vehicles); (2) purchasing, installing, operating, and maintaining infrastructure needed to charge, fuel, or maintain zero-emission vehicles; (3) workforce development and training to support the maintenance, charging, fueling, and operation of zero-emission vehicles; and (4) planning and technical activities to support the adoption and deployment of zero-emission vehicles.

Section 60102, ''Grants to Reduce Air Pollution at Ports,'' amends the CAA to add a new section 133 (42 U.S.C. 7433) and appropriates $3 billion (2 percent of which must be reserved for administrative costs necessary to carry out the section's provisions), $750 million of which is for projects located in areas of nonattainment for any air pollutant, in FY 2022 and available through FY 2027, to reduce air pollution at ports. Competitive rebates or grants are to be awarded for the purchase or installation of zero-emission port equipment or technology for use at, or to directly serve, one or more ports; to conduct any relevant planning or permitting in connection with the purchase or permitting of zero-emission port equipment or technology; and to develop qualified climate action plans. The zero-emission equipment or technology either (1) produces zero emissions of GHGs, listed criteria pollutants, and hazardous air pollutants or (2) it captures 100 percent of the emissions produced by an ocean-going vessel at berth.

Section 60103, ''Greenhouse Gas Reduction Fund,'' amends the CAA to add a new section 134 (42 U.S.C. 7434) and appropriates $27 billion, $15 billion of which is for low-income and disadvantaged communities, in FY 2022 and available through FY 2024, for a GHG reduction grant program. The program supports direct investments in qualified projects at the national, regional, State, and local levels, and indirect investments to establish new or support existing public, quasi-public, not-for-profit, or nonprofit entities that provide financial assistance to qualified projects. The program focuses on the rapid deployment of low- and zero-emission products, technologies, and services to reduce or avoid GHG emissions and other forms of air pollution.

Section 60104, ''Diesel Emissions Reductions,'' appropriates $60 million (2 percent of which must be reserved for administrative costs necessary to carry out the section's provisions), in FY 2022 and available through FY 2031, for grants, rebates, and loans under section 792 of the Energy Policy Act of 2005 (42 U.S.C. 16132) to identify and reduce diesel emissions resulting from goods movement facilities and vehicles servicing goods movement facilities in low-income and disadvantaged communities to address the health impacts of such emissions on such communities.

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[182] Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M. A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., Boloor, M. ''Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains''. Argonne National Laboratory. April 1, 2021. Available at *https://publications.anl.gov/anlpubs/2021/05/167399.pdf.*

Section 70002 appropriates $3 billion in FY 2022 and available through FY 2031 for the U.S. Postal Service to purchase ZEVs ($1.29 billion) and to purchase, design, and install infrastructure to support zero-emission delivery vehicles at facilities that the U.S. Postal Service owns or leases from non-Federal entities ($1.71 billion).

Section 13501, ''Extension of the Advanced Energy Project Credit,'' allocates $10 billion in tax credits for facilities to domestically manufacture advanced energy technologies, subject to certain application and other requirements and limitations. Qualifying properties now include light-, medium-, or heavy-duty electric or fuel cell vehicles along with the technologies, components, or materials for such vehicles and the associated charging or refueling infrastructure. They also include hybrid vehicles with a gross vehicle weight rating of not less than 14,000 pounds along with the technologies, components, or materials for them.

Sections 50142, 50143, 50144, 50145, 50151, 50152, and 50153 collectively appropriate nearly $13 billion to support low- and zero-emission vehicle manufacturing and energy infrastructure. These provisions are intended to help accelerate the ability for industry to meet the demands spurred by the previously mentioned IRA sections, both for manufacturing vehicles, including BEVs and FCEVs, and for energy infrastructure.

Section 13204, ''Clean Hydrogen,'' amends section 45V of the Internal Revenue Code (*i.e.,* Title 26) to offer a tax credit to produce hydrogen for qualified clean production facilities that use a process that results in a lifecycle GHG emissions rate of not greater than 4 kg of CO_2e per kg of hydrogen. This credit is eligible for qualified clean hydrogen production facilities whose construction begins before January 1, 2033, and is available during the 10-year period beginning on the date such facility was originally placed in service. The credit increases to a maximum of $3 per kilogram produced as the lifecycle GHG emissions rate is reduced to less than 0.45 kg of CO_2e per kg of hydrogen. Facilities that received credit for the construction of carbon capture and direct air capture equipment or facilities (*i.e.,* under 45Q) do not qualify, and prevailing wage and apprenticeship requirements apply. Section 60113, ''Methane Emissions Reduction Program,'' amends the CAA by adding Section 136 and appropriates $850 million to EPA to support methane mitigation and monitoring, plus authorizes a new fee of $900 per ton on ''waste'' methane emissions that escalates after two years to $1,500 per ton. These combined incentives promote the production of hydrogen in a manner that minimizes its potential greenhouse gas impact.

While there are challenges facing greater adoption of heavy-duty ZEV technologies, the IRA provides many financial incentives to overcome these challenges and thus would also support our proposed rulemaking. We expect IRA sections 13502 and 13403 to support the adoption of HD ZEV technologies in the market, as detailed in our assessment of the appropriate GHG standards we are proposing. Additionally, we expect IRA sections 13404, 60101–60104, 70002, 13501, 50142–50145, 50151–50153, and 13204 to further accelerate ZEV adoption, but we are not including them quantitatively in our analyses.

As described in Section II of the proposed rule, EPA has considered the potential impacts of the BIL and the IRA in our assessment of the appropriate proposed GHG standards both quantitatively and qualitatively, and we request comment on our approach.

3. States' Efforts To Increase Adoption of HD ZEVs

HD vehicle sales and on-road vehicle populations are significant in the state of California. Approximately ten percent of U.S. HD ICE vehicles in 2016 were registered in California.[183] California adopted the ACT program in 2020, which will also influence the market trajectory for BEV and FCEV technologies.[184] [185] [186] The ACT program requires manufacturers who certify HD vehicles for sale in California to sell a certain percentage of zero-emission HD vehicles (BEVs or FCEVs) in California for each model year, beginning with MY 2024.[187] As shown in Table I–1, the sales requirements vary by vehicle class, starting at 5 to 9 percent of total MY 2024 HD vehicle sales in California and increasing to 40 to 75 percent of a total MY's HD vehicle sales in California in MYs 2035 and later.[188]

TABLE I–1—CARB'S ACT ZEV SALES REQUIREMENTS FOR CLASS 4–8 HEAVY-DUTY VEHICLES BY MODEL YEAR [1]

Model year (MY)	Class 4–8 (%)	Class 7–8 tractors (%)
2024	9	5
2025	11	7
2026	13	10
2027 [2]	20	15
2028 [2]	30	20
2029 [2]	40	25
2030 [2]	50	30
2031 [2]	55	35
2032 [2]	60	40
2033	65	40
2034	70	40
2035+	75	40

Notes:

[1] The CARB ACT program also includes ZEV sales requirements for Class 2b and 3 vehicles with GVWR between 8,500 and 14,000 pounds. These vehicles are primarily commercial pickup trucks and vans and are sometimes referred to as ''medium-duty vehicles.'' The majority of Class 2b and 3 vehicles are chassis-certified vehicles and EPA is addressing these vehicles in a separate regulatory action, along with light-duty vehicles, consistent with E.O. 14037, Section 2a.

[2] We are proposing GHG emission standards for these MYs in this action.

Outside of California, a number of states have signaled interest in greater adoption of HD ZEV technologies and/or establishing specific goals to increase the HD electric vehicle market. As one example, the Memorandum of Understanding (MOU), ''Multi-State Medium- and Heavy-Duty Zero Emission Vehicle,'' (Multi-State MOU) organized by Northeast States for Coordinated Air Use Management (NESCAUM), sets targets ''to make all sales of new medium- and heavy-duty vehicles [in the jurisdictions of the signatory states and the District of Columbia] zero emission vehicles by no later than 2050'' with an interim goal of 30 percent of all sales of new medium- and heavy-duty vehicles being zero emission vehicles no later than 2030.[189]

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[183] FHWA. U.S. Highway Statistics. Available online at: *https://www.fhwa.dot.gov/policyinformation/statistics.cfm.*

[184] CAA section 209(a) generally preempts states from adopting emission control standards for new motor vehicles. But Congress created an important exception from preemption. Under CAA section 209(b), the State of California may seek a waiver of preemption, and EPA must grant it unless the Agency makes one of three statutory findings. California's waiver of preemption for its motor vehicle emissions standards allows other States to adopt and enforce identical standards pursuant to CAA section 177. Since the CAA was enacted, EPA has granted California dozens of waivers of preemption, permitting California to enforce its own motor vehicle emission standards.

[185] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

[186] EPA granted the ACT rule waiver requested by California under CAA section 209(b) on March 30, 2023.

[187] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf* at § 1963.1, tbl. A–1, ''ZEV Sales Percentage Schedule''.

[188] *Ibid.*

[189] Northeast States for Coordinated Air Use Management (NESCAUM), Multi-state Medium-

Continued

The Multi-State MOU was signed by the governors of 17 states including California, Colorado, Connecticut, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Nevada, Oregon, Pennsylvania, Rhode Island, Vermont, Virginia, and Washington, as well as the mayor of the District of Columbia. The Multi-State MOU outlines these jurisdictions' more specific commitments to move toward ZEVs through the Multi-State ZEV Task Force and provides an action plan for zero-emission medium- and heavy-duty vehicles with measurable sales targets and a focus on overburdened and underserved communities. Several states that signed the Multi-State MOU have since adopted California's ACT program, pursuant to CAA section 177, and we anticipate more jurisdictions will follow with similar proposals.[190]

D. EPA Statutory Authority for the Proposal

This section briefly summarizes the statutory authority for the proposed rule. Statutory authority for the GHG standards EPA is proposing is found in CAA section 202(a)(1) (2), 42 U.S.C. 7521(a)(1)–(2), which requires EPA to establish standards applicable to emissions of air pollutants from new motor vehicles and engines which cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. Additional statutory authority for the proposed action is found in CAA sections 202–209, 216, and 301, 42 U.S.C. 7521–7543, 7550, and 7601. We discuss some key aspects of these sections in relation to this proposed action immediately below.

Title II of the Clean Air Act provides for comprehensive regulation of mobile sources, authorizing EPA to regulate emissions of air pollutants from all mobile source categories, including motor vehicles under CAA section 202(a). In turn, CAA section 216(2) defines ''motor vehicle'' as ''any self-propelled vehicle designed for transporting persons or property on a street or highway.'' Congress has intentionally and consistently used the broad term ''any self-propelled vehicle'' since the Motor Vehicle Air Pollution Control Act of 1965 so as not to limit standards adopted under CAA section 202 to vehicles running on a particular fuel, power source, or system of propulsion. Congress's focus was on emissions from classes of motor vehicles and the ''requisite technologies'' that could feasibly reduce those emissions giving appropriate consideration to cost of compliance and lead time, as opposed to being limited to any particular type of vehicle.

Section 202(a)(1) of the CAA states that ''the Administrator shall by regulation prescribe (and from time to time revise) . . . standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles . . . which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.'' CAA section 202(a)(1) also requires that any standards promulgated thereunder ''shall be applicable to such vehicles and engines for their useful life (as determined under [CAA section 202(d)], relating to useful life of vehicles for purposes of certification), whether such vehicle and engines are designed as complete systems or incorporate devices to prevent or control such pollution.'' CAA section 202(d) directs EPA to prescribe regulations under which the ''useful life'' of vehicles and engines shall be determined for the purpose of setting standards under CAA section 202(a)(1). For HD highway vehicles and engines, CAA section 202(d) establishes ''useful life'' minimum values of 10 years or 100,000 miles, whichever occurs first, unless EPA determines that greater values are appropriate.[191]

While emission standards set by the EPA under CAA section 202(a)(1) generally do not mandate use of particular technologies, they are technology-based, as the levels chosen must be premised on a finding of technological feasibility. Thus, standards promulgated under CAA section 202(a) are to take effect only ''after such period as the Administrator finds necessary to permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period.'' CAA section 202(a)(2); see also *NRDC* v. *EPA,* 655 F. 2d 318, 322 (D.C. Cir. 1981). EPA must consider costs to those entities which are directly subject to the standards. *Motor & Equipment Mfrs. Ass'n Inc.* v. *EPA*, 627 F. 2d 1095, 1118 (D.C. Cir. 1979). Thus, ''the [s]ection 202(a)(2) reference to compliance costs encompasses only the cost to the motor-vehicle industry to come into compliance with the new emission standards, and does not mandate consideration of costs to other entities not directly subject to the proposed standards.'' *Coalition for Responsible Regulation* v. *EPA,* 684 F.3d 120, 128 (D.C. Cir. 2012). EPA is afforded considerable discretion under section 202(a) when assessing issues of technical feasibility and availability of lead time to implement new technology. Such determinations are ''subject to the restraints of reasonableness,'' which ''does not open the door to 'crystal ball' inquiry.'' NRDC, 655 F. 2d at 328, quoting International *Harvester Co.* v. *Ruckelshaus*, 478 F. 2d 615, 629 (D.C. Cir. 1973); *see also Growth Energy* v. *EPA,* 5 F.4th 1, 15 (D.C. Cir. 2021) (''The court is 'particularly deferential' to agencies' predictive judgments, requiring only that 'the agency acknowledge factual uncertainties and identify the considerations it found persuasive.' EPA cleared that modest bar.'') (internal citations omitted). Moreover, ''EPA is not obliged to provide detailed solutions to every engineering problem posed in the perfection of [a particular device]. In the absence of theoretical objections to the technology, the agency need only identify the major steps necessary for development of the device, and give plausible reasons for its belief that the industry will be able to solve those problems in the time remaining. The EPA is not required to rebut all

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and Heavy-duty Zero Emission Vehicle Memorandum of Understanding, available at *https://www.nescaum.org/documents/mhdv-zev-mou-20220329.pdf/* (hereinafter ''Multi-State MOU'').

[190] *See, e.g.,* Final Advanced Clean Truck Amendments, 1461 Mass. Reg. 29 (Jan. 21, 2022) (Massachusetts). Medium- and Heavy-Duty (MHD) Zero Emission Truck Annual Sales Requirements and Large Entity Reporting, 44 N.Y. Reg. 8 (Jan. 19, 2022) (New York), available at *https://dos.ny.gov/system/files/documents/2022/01/011922.pdf.* Advanced Clean Trucks Program and Fleet Reporting Requirements, 53 N.J.R. 2148(a) (Dec. 20, 2021) (New Jersey), available at *https://www.nj.gov/dep/rules/adoptions/adopt_20211220a.pdf* (pre-publication version). Clean Trucks Rule 2021, DEQ–17–2021 (Nov. 17, 2021), available at *http://records.sos.state.or.us/ORSOSWebDrawer/Recordhtml/8581405* (Oregon). Low emission vehicles, Wash. Admin. Code. § 173–423–070 (2021), available at *https://app.leg.wa.gov/wac/default.aspx?cite=173-423-070;* 2021 Wash. Reg. 587356 (Dec. 15, 2021); Wash. Reg. 21–24–059 (Nov. 29, 2021) (amending Wash. Admin. Code. §§ 173–423 and 173–400), available at *https://lawfilesext.leg.wa.gov/law/wsrpdf/2021/24/21-24-059.pdf.* (Washington).

[191] In 1983, EPA adopted useful life periods to apply for HD engines criteria pollutant standards (48 FR 52170, November 16, 1983). The useful life mileage for heavy HD engines criteria pollutant standards was subsequently increased for 2004 and later model years (62 FR 54694, October 21, 1997). In the GHG Phase 2 rule (81 FR 73496, October 25, 2016), EPA set the same useful life periods to apply for HD engines and vehicles greenhouse gas emission standards, except that the spark-ignition HD engine standards and the standards for model year 2021 and later light HD engines apply over a useful life of 15 years or 150,000 miles, whichever comes first. In the HD2027 rule (88 FR 4359, January 24, 2023), EPA lengthened useful life periods for all 2027 and later model year HD engines criteria pollutant standards. See also 40 CFR 1036.104(e), 1036.108(d), 1037.105(e), and 1037.106(e).

speculation that unspecified factors may hinder 'real world' emission control.'' NRDC, 655 F. 2d at 333–34. In developing such technology-based standards, EPA has the discretion to consider different standards for appropriate groupings of vehicles (''class or classes of new motor vehicles''), or a single standard for a larger grouping of motor vehicles. NRDC, 655 F.2d at 338.[192]

Although standards under CAA section 202(a)(1) are technology-based, they are not based exclusively on technological capability. Pursuant to the broad grant of authority in section 202, when setting GHG emission standards for HD vehicles, EPA must consider certain factors and may also consider other factors and has done so previously when setting such standards. For instance, in HD GHG Phase 1 and Phase 2, EPA explained that when acting under this authority EPA has considered such issues as technology effectiveness, its cost (including per vehicle, per manufacturer, and per purchaser), the lead time necessary to implement the technology, and based on this the feasibility and practicability of potential standards; the impacts of potential standards on emissions reductions; the impacts of standards on oil conservation and energy security; the impacts of standards on fuel savings by vehicle operators; the impacts of standards on the heavy-duty vehicle industry; as well as other relevant factors such as impacts on safety.[193] [194]

In addition, EPA has clear authority to set standards under CAA section 202(a)(1)–(2) that are technology forcing when EPA considers that to be appropriate, but is not required to do so (as compared to standards under provisions such as section 202(a)(3), which require the greatest degree of emissions reduction achievable, giving appropriate consideration to cost, energy and safety factors). CAA section 202(a) does not specify the degree of weight to apply to each factor, and EPA accordingly has discretion in choosing an appropriate balance among factors. *See Sierra Club* v. *EPA,* 325 F.3d 374, 378 (D.C. Cir. 2003) (even where a provision is technology-forcing, the provision ''does not resolve how the Administrator should weigh all [the statutory] factors in the process of finding the 'greatest emission reduction achievable'''); *National Petrochemical and Refiners Ass'n* v. *EPA,* 287 F.3d 1130, 1135 (D.C. Cir. 2002) (EPA decisions, under CAA provision authorizing technology-forcing standards, based on complex scientific or technical analysis are accorded particularly great deference); see also *Husqvarna AB* v. *EPA,* 254 F. 3d 195, 200 (D.C. Cir. 2001) (great discretion to balance statutory factors in considering level of technology-based standard, and statutory requirement ''to [give appropriate] consideration to the cost of applying . . . technology'' does not mandate a specific method of cost analysis); *Hercules Inc.* v. *EPA,* 598 F. 2d 91, 106 (D.C. Cir. 1978) (''In reviewing a numerical standard we must ask whether the agency's numbers are within a zone of reasonableness, not whether its numbers are precisely right.'').[195]

As noted previously in this section, there are also other provisions of the CAA that provide authority for EPA's proposed action, including CAA sections 203, 206, and 207. Under section 203 of the CAA, sales of vehicles are prohibited unless the vehicle is covered by a certificate of conformity, and EPA issues certificates of conformity pursuant to section 206 of the CAA. Certificates of conformity are based on (necessarily) pre-sale testing conducted either by EPA or by the manufacturer. Compliance with standards is required not only at certification but throughout a vehicle's useful life, so that testing requirements may continue post-certification. To assure each engine and vehicle complies during its useful life, EPA may apply an adjustment factor to account for vehicle emission control deterioration or variability in use (section 206(a)). EPA establishes the test procedures under which compliance with the CAA emissions standards is measured. EPA's testing authority under the CAA is broad and flexible.

Under CAA section 207, manufacturers are required to provide emission-related warranties. The emission-related warranty period for HD engines and vehicles under CAA section 207(i) is ''the period established by the Administrator by regulation (promulgated prior to November 15, 1990) for such purposes unless the Administrator subsequently modifies such regulation.'' For HD vehicles, part 1037 currently specifies that the emission-related warranty for Light HD vehicles is 5 years or 50,000 miles and for Medium HD and Heavy HD vehicles is 5 years or 100,000 miles, and specifies the components covered for such vehicles.[196] Section 207 of the CAA also grants EPA broad authority to require manufacturers to remedy nonconformity if EPA determines there are a substantial number of noncomplying vehicles. Additional aspects of EPA's legal authority are more fully discussed in the HD GHG Phase 1 final rule.[197] Further discussion of EPA's authority under CAA section 202(a)(1)–(2) may also be found in the HD GHG Phase 1 final rule.

With regard to the specific technologies that could be used to meet the emission standards promulgated under the statutory authorities discussed in this Section I.D, EPA's rules have historically not required the use of any particular technology, but rather have allowed manufacturers to use any technology that demonstrates the engine or vehicle meets the standards over the applicable test procedures. Similarly, in determining the standards, EPA appropriately considers updated data and analysis on pollution control technologies, without a priori limiting its consideration to a particular set of technologies. Given the continuous development of pollution control technologies since the early days of the CAA, this approach means that EPA routinely considers novel and projected technologies developed or refined since the time of the CAA's enactment, including for instance, electric vehicle technologies. In requiring EPA to consider lead time that takes into consideration development and application of technology when setting standards before such standards may take effect, Congress directed EPA to consider future technological advancements and innovation rather than limiting the Agency to setting standards that reflect only technologies in place at the time the standards are developed. This forward-looking regulatory approach keeps pace with real-world technological developments that have the potential to reduce emissions and comports with Congressional intent.

Section 202 does not specify or expect any particular type of motor vehicle propulsion system to remain prevalent, and it was clear as early as the 1960s that ICE vehicles might be inadequate to achieve the country's air quality goals.

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[192] Additionally, with respect to regulation of vehicular GHG emissions, EPA is not ''required to treat NHTSA's . . . regulations as establishing the baseline for the [section 202(a) standards].'' Coalition for Responsible Regulation, 684 F.3d at 127 (noting that the section 202(a) standards provide ''benefits above and beyond those resulting from NHTSA's fuel-economy standards'').

[193] 76 FR 57129, September 15, 2011.

[194] 81 FR 73478, 73512, October 25, 2016.

[195] See also; Permian Basin Area Rate Cases, 390 U.S. 747, 797 (1968) (same); *Federal Power Commission* v. *Conway Corp.,* 426 U.S. 271, 278 (1976) (same); *Exxon Mobil Gas Marketing Co.* v. *Federal Energy Regulatory Comm'n,* 297 F. 3d 1071, 1084 (D.C. Cir. 2002) (same).

[196] See 40 CFR 1037.120.

[197] 76 FR 57129–57130, September 15, 2011.

In 1967, the Senate Committees on Commerce and Public Works held five days of hearings on ''electric vehicles and other alternatives to the internal combustion engine,'' which Chairman Magnuson opened by saying ''The electric will help alleviate air pollution. . . . The electric car does not mean a new way of life, but rather it is a new technology to help solve the new problems of our age.''[198] In a 1970 message to Congress seeking a stronger CAA, President Nixon stated he was initiating a program to develop ''an unconventionally powered, virtually pollution free automobile'' because of the possibility that ''the sheer number of cars in densely populated areas will begin outrunning the technological limits of our capacity to reduce pollution from the internal combustion engine.''[199]

Since the earliest days of the CAA, Congress has emphasized that the goal of section 202 is to address air quality hazards from motor vehicles, not to simply reduce emissions from internal combustion engines to the extent feasible. In the Senate Report accompanying the 1970 CAA Amendments, Congress made clear the EPA ''is expected to press for the development and application of improved technology rather than be limited by that which exists'' and identified several ''unconventional'' technologies that could successfully meet air quality-based emissions targets for motor vehicles.[200] In the 1970 amendments Congress further demonstrated its recognition that developing new technology to ensure that pollution control keeps pace with economic development is not merely a matter of refining the ICE, but requires considering new types of motor vehicle propulsion. Congress provided EPA with authority to fund the development of ''low emission alternatives to the present internal combustion engine'' as well as a program to encourage Federal purchases of ''low-emission vehicles.'' *See* CAA section 104(a)(2) (previously codified as CAA section 212). Congress also adopted section 202(e) expressly to grant the Administrator discretion regarding the certification of vehicles and engines based on ''new power sources or propulsion system[s],'' that is to say, power sources and propulsion systems beyond the existing internal combustion engine and fuels available at the time of the statute's enactment, if those vehicles emitted pollutants which the Administrator judged contributed to dangerous air pollution but had not yet established standards for under section 202(a). As the D.C. Circuit stated in 1975, ''We may also note that it is the belief of many experts—both in and out of the automobile industry—that air pollution cannot be effectively checked until the industry finds a substitute for the conventional automotive power plant–the reciprocating internal combustion (*i.e.,* ''piston'') engine. . . . It is clear from the legislative history that Congress expected the Clean Air Amendments to force the industry to broaden the scope of its research—to study new types of engines and new control systems.'' *International Harvester Co.* v. *Ruckelshaus,* 478 F.2d 615, 634–35 (D.C. Cir. 1975).

Since that time, Congress has continued to emphasize the importance of technology development to achieving the goals of the CAA. In the 1990 amendments, Congress instituted a clean fuel vehicles program to promote further progress in emissions reductions, which also applied to motor vehicles as defined under section 216, see CAA section 241(1), and explicitly defined motor vehicles qualifying under the program as including vehicles running on an alternative fuel or ''power source (including electricity),'' CAA section 241(2). Congress also directed EPA to phase-in certain section 202(a) standards, see CAA section 202(g)–(j),[201] which confirms EPA's authority to promulgate standards, such as fleet averages, phase-ins, and averaging, banking, and trading programs, that are fulfilled through compliance over an entire fleet, or a portion thereof, rather than through compliance by individual vehicles. As previously noted in the Executive Summary of this preamble, EPA has long included averaging provisions for complying with emission standards in the HD program and in upholding the first HD final rule that included such a provision the D.C. Circuit rejected petitioner's challenge in the absence of any clear evidence that Congress meant to prohibit averaging. *NRDC* v. *Thomas,* 805 F.2d 410, 425 (D.C. Cir. 1986). In the subsequent 1990 amendments, Congress, noting *NRDC* v. *Thomas,* opted to let the existing law ''remain in effect,'' reflecting that ''[t]he intention was to retain the status quo,'' *i.e.,* EPA's existing authority to allow averaging.[202] Averaging, banking, and trading is discussed further in Sections II and III of this preamble; additional history of ABT is discussed in EPA's Answering Brief in *Texas* v. *EPA* (D.C. Cir., 22–1031, at § IV.A–B).

The recently-enacted IRA[203] ''reinforces the longstanding authority and responsibility of [EPA] to regulate GHGs as air pollutants under the Clean Air Act,''[204] and ''the IRA clearly and deliberately instructs EPA to use'' this authority by ''combin[ing] economic incentives to reduce climate pollution with regulatory drivers to spur greater reductions under EPA's CAA authorities.''[205] To assist with this, as described in Section I.C.2, the IRA provided a number of economic incentives for HD ZEVs and the infrastructure necessary to support them, and specifically affirms Congress's previously articulated statements that non-ICE technologies will be a key component of achieving emissions reductions from the mobile source sector, including the HD industry sector.[206] The Congressional Record reflects that ''Congress recognizes EPA's longstanding authority under CAA Section 202 to adopt standards that rely on zero emission technologies, and Congress expects that future EPA regulations will increasingly rely on and incentivize zero-emission vehicles as appropriate.''[207]

Consistent with Congress's intent, EPA's CAA Title II emission standards have been based on and stimulated the development of a broad set of advanced technologies, such as electronic fuel injection systems, gasoline catalytic convertors, diesel particulate filters, diesel NO_X reduction catalysts, gasoline direct injection fuel systems, active aerodynamic grill shutters, and advanced transmission technologies, which have been the building blocks of

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[198] *Electric Vehicles and Other Alternatives to the Internal Combustion Engine: Joint Hearings before the Comm. On Commerce and the Subcomm. On Air and Water Pollution of the Comm. On Pub. Works,* 90th Cong. (1967).

[199] Richard Nixon, Special Message to the Congress on Environmental Quality (Feb. 10, 1970), *https://www.presidency.ucsb.edu/documents/special-message-the-congress-environmental-quality.*

[200] S. Rep. No. 91–1196, at 24–27 (1970).

[201] See, *e.g.,* CAA section 202(h), which requires that the regulations EPA promulgates under CAA section 202(a) for light-duty trucks over 6,000 pounds. GVWR must contain standards that provide that the specified numeric emission standards will be met by specified percentages of each manufacturer's sales volume of such trucks, depending on the MY (*e.g.,* 50% for MY 1996).

[202] 136 Cong. Rec. 36,713, 1990 WL 1222468 at *1136 Cong. Rec. 35,367, 1990 WL 1222469 at *1.

[203] Inflation Reduction Act, Public Law 117–169, 136 Stat. 1818, (2022), available at *https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf.*

[204] 168 Cong. Rec. E868–02 (daily ed. Aug. 12, 2022) (statement of Rep. Pallone).

[205] 168 Cong. Rec. E879–02, at 880 (daily ed. Aug. 26, 2022) (statement of Rep. Pallone).

[206] *See* Inflation Reduction Act, Public Law 117–169, at §§ 13204, 13403, 13404, 13501, 13502, 50142–50145, 50151–50153, 60101–60104, 70002 136 Stat. 1818, (2022), available at *https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf.*

[207] 168 Cong. Rec. E879–02, at 880 (daily ed. Aug. 26, 2022) (statement of Rep. Pallone).

heavy-duty vehicle designs and have yielded not only lower pollutant emissions, but improved vehicle performance, reliability, and durability. As previously discussed, beginning in 2011, EPA has set HD vehicle and engine standards under section 202(a)(1)–(2) for GHGs.[208] Manufacturers have responded to standards over the past decade by continuing to develop and deploy a wide range of technologies, including more efficient engine designs, transmissions, aerodynamics, and tires, air conditioning systems that contribute to lower GHG emissions, as well as vehicles based on methods of propulsion beyond diesel- and gasoline-fueled ICE vehicles, including ICE running on alternative fuels (such as natural gas, biodiesel, renewable diesel, methanol, and other fuels), as well as various levels of electrified vehicle technologies from mild hybrids, to strong hybrids, and up through battery electric vehicles and fuel cell electric vehicles. In addition, the continued application of performance-based standards take into consideration averaging provisions that provide an opportunity for all technology improvements and innovation to be reflected in a vehicle manufacturers' compliance results.

With regard to EPA's proposed revised preemption regulations regarding locomotives described in Section X of the preamble, statutory authority is found in CAA section 209. CAA section 209(e)(1)(B), 42 U.S.C. 7543(e)(1)(B), prohibits states and political subdivisions thereof from adopting or attempting to enforce any standard or other requirement relating to the control of emissions from new locomotives or new engines used in locomotives. However, CAA section 209(e)(2)(A)–(B), 42 U.S.C. 7543(e)(2)(A)–(B), requires EPA to authorize, after notice and an opportunity for public hearing, California to adopt and enforce standards and other requirements relating to control of emissions from other nonroad vehicles or engines provided certain criteria are met, and allows states other than California to adopt and enforce, after notice to EPA, such standards provided they are equivalent to California's authorized standards. CAA section 209(e)(2)(B) then requires EPA to issue regulations to implement subsection 209(e).

E. Coordination With Federal and State Partners

Executive Order 14037 directs EPA and DOT to coordinate, as appropriate and consistent with applicable law, during consideration of this rulemaking. EPA has coordinated and consulted with DOT/NHTSA, both on a bilateral level during the development of the proposed program as well as through the interagency review of the EPA proposal led by the Office of Management and Budget. EPA has set some previous heavy-duty vehicle GHG emission standards in joint rulemakings where NHTSA also established heavy-duty fuel efficiency standards. In the light-duty GHG emission rulemaking establishing standards for model years 2023 through 2026, EPA and NHTSA concluded that it was appropriate to coordinate and consult but not to engage in joint rulemaking. EPA has similarly concluded that it is not necessary for this EPA proposal to be issued in a joint action with NHTSA. In reaching this conclusion, EPA notes there is no statutory requirement for joint rulemaking and that the agencies have different statutory mandates and their respective programs have always reflected those differences. As the Supreme Court has noted, ''EPA has been charged with protecting the public's 'health' and 'welfare,' a statutory obligation wholly independent of DOT's mandate to promote energy efficiency.'' [209] Although there is no statutory requirement for EPA to consult with NHTSA, EPA has consulted with NHTSA in the development of this proposal. For example, staff of the two agencies met frequently to discuss various technical issues and to share technical information.

EPA also has consulted with other federal agencies in developing this proposal, including the Federal Energy Regulatory Commission, the Department of Energy and several national labs. EPA collaborates with DOE and Argonne National Laboratory on battery cost analyses and critical materials forecasting. EPA also coordinates with the Joint Office of Energy and Transportation on charging infrastructure. EPA and the Oak Ridge National Laboratory collaborate on energy security issues. EPA also participates in the Federal Consortium for Advanced Batteries led by DOE and the Joint Office of Energy and Transportation. EPA and DOE also have entered into a Joint Memorandum of Understanding to provide a framework for interagency cooperation and consultation on electric sector resource adequacy and operational reliability.[210]

E.O. 14037 also directs EPA to coordinate with California and other states that are leading the way in reducing vehicle emissions, as appropriate and consistent with applicable law, during consideration of this rulemaking. EPA has engaged with the California Air Resources Board on technical issues in developing this proposal. EPA has considered certain aspects of the CARB Advanced Clean Trucks Rule, as discussed elsewhere in this document. We also have engaged with other states, including members of the National Association of Clean Air Agencies, the Association of Air Pollution Control Agencies, the Northeast States for Coordinated Air Use Management, and the Ozone Transport Commission.

F. Stakeholder Engagement

EPA has conducted extensive engagement with a diverse range of interested stakeholders in developing this proposal. We have engaged with those groups with whom E.O. 14037 specifically directs EPA to engage, including labor unions, states, industry, environmental justice organizations and public health experts. In addition, we have engaged with environmental NGOs, vehicle manufacturers, technology suppliers, dealers, utilities, charging providers, Tribal governments, and other organizations. For example, in April–May 2022, EPA held a series of engagement sessions with organizations representing all of these stakeholder groups so that EPA could hear early input in developing its proposal. EPA has continued engagement with many of these stakeholders throughout the development of this proposal. EPA looks forward to hearing from all stakeholders through comments on this proposal and during the public hearing.

II. Proposed CO_2 Emission Standards

Under our CAA section 202(a)(1)–(2) authority, and consistent with E.O. 14037, we are proposing new GHG standards for MYs 2027 through 2032 and later HD vehicles. We are retaining and not reopening the nitrous oxide (N_2O), methane (CH_4), and CO_2 emission standards that apply to heavy-duty engines, the HFC emission standards that apply to heavy-duty vehicles, and the general compliance structure of existing 40 CFR part 1037 except for some proposed revisions described in

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[208] 76 FR 57106, September 15, 2011.

[209] *Massachusetts* v. *EPA,* 549 U.S. at 532.

[210] Joint Memorandum on Interagency Communication and Consultation on Electric Reliability, U.S. Department of Energy and U.S. Environmental Protection Agency, March 8, 2023.

Section III.[211] In this Section II, we describe our assessment that these stringent standards are appropriate and feasible considering lead time, costs, and other factors. These proposed Phase 3 standards include (1) revised GHG standards for many MY 2027 HD vehicles, and (2) new GHG standards starting in MYs 2028 through 2032. The proposed standards do not mandate the use of a specific technology, and EPA anticipates that a compliant fleet under the proposed standards would include a diverse range of technologies, including ZEV and ICE vehicle technologies. In developing the proposed standards, EPA has considered the key issues associated with growth in penetration of zero-emission vehicles, including charging infrastructure and hydrogen production. In this section, we describe our assessment of the appropriateness and feasibility of these proposed standards and present a technology pathway for achieving each of those standards through increased ZEV adoption. In this section, we also present and request comment on an alternative that would provide a more gradual phase-in of the standards. As described in Section II.H., EPA also requests comment on setting GHG standards starting in MYs 2027 through 2032 that would reflect: values less stringent than the lower stringency alternative for certain market segments, values in between the proposed standards and the alternative standards, values in between the proposed standards and those that would reflect ZEV adoption levels (*i.e.,* percent of ZEVs in production volumes) used in California's ACT, values that would reflect the level of ZEV adoption in the ACT program, and values beyond those that would reflect ZEV adoption levels in ACT such as the 50- to 60-percent ZEV adoption range.

In the beginning of this section, we first describe the public health and welfare need for GHG emission reductions (Section II.A). In Section II.B, we provide an overview of the comments the Agency received in response to the GHG standards previously proposed as part of the HD2027 NPRM. In Section II.C, we provide a brief overview of the existing CO_2 emission standards that we promulgated in HD GHG Phase 2. Section II.D contains our technology assessment and Section II.E includes our assessment of technology costs, EVSE costs, operating costs, and payback. Section II.F includes the proposed standards and the analysis demonstrating the feasibility and Section II.G discusses the feasibility and appropriateness of the proposed emission standards under the Clean Air Act. Section II.H presents potential alternatives to the proposed standards, including requests for comment on standards other than those proposed. Finally, Section II.I summarizes our consideration of small businesses.

A. Public Health and Welfare Need for GHG Emission Reductions

The transportation sector is the largest U.S. source of GHG emissions, representing 27 percent of total GHG emissions.[212] Within the transportation sector, heavy-duty vehicles are the second largest contributor, at 25 percent.[213] GHG emissions have significant impacts on public health and welfare as set forth in EPA's 2009 Endangerment and Cause or Contribute Findings under CAA section 202(a) and as evidenced by the well-documented scientific record.[214]

Elevated concentrations of GHGs have been warming the planet, leading to changes in the Earth's climate including changes in the frequency and intensity of heat waves, precipitation, and extreme weather events; rising seas; and retreating snow and ice. The changes taking place in the atmosphere as a result of the well-documented buildup of GHGs due to human activities are altering the climate at a pace and in a way that threatens human health, society, and the natural environment. While EPA is not making any new scientific or factual findings with regard to the well-documented impact of GHG emissions on public health and welfare in support of this rule, EPA is providing some scientific background on climate change to offer additional context for this rulemaking and to increase the public's understanding of the environmental impacts of GHGs.

Extensive additional information on climate change is available in the scientific assessments and the EPA documents that are briefly described in this section, as well as in the technical and scientific information supporting them. One of those documents is EPA's 2009 Endangerment and Cause or Contribute Findings for Greenhouse Gases Under section 202(a) of the CAA (74 FR 66496, December 15, 2009). In the 2009 Endangerment Finding, the Administrator found under section 202(a) of the CAA that elevated atmospheric concentrations of six key well-mixed GHGs—CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—''may reasonably be anticipated to endanger the public health and welfare of current and future generations'' (74 FR 66523). The 2009 Endangerment Finding, together with the extensive scientific and technical evidence in the supporting record, documented that climate change caused by human emissions of GHGs (including HFCs) threatens the public health of the U.S. population. It explained that by raising average temperatures, climate change increases the likelihood of heat waves, which are associated with increased deaths and illnesses (74 FR 66497). While climate change also increases the likelihood of reductions in cold-related mortality, evidence indicates that the increases in heat mortality will be larger than the decreases in cold mortality in the United States (74 FR 66525). The 2009 Endangerment Finding further explained that compared with a future without climate change, climate change is expected to increase tropospheric ozone pollution over broad areas of the United States., including in the largest metropolitan areas with the worst tropospheric ozone problems, and thereby increase the risk of adverse effects on public health (74 FR 66525). Climate change is also expected to cause more intense hurricanes and more frequent and intense storms of other types and heavy precipitation, with impacts on other areas of public health, such as the potential for increased deaths, injuries, infectious and waterborne diseases, and stress-related disorders (74 FR 66525). Children, the elderly, and the poor are among the most vulnerable to these climate-related health effects (74 FR 66498).

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[211] See the HD GHG Phase 2 rule (81 FR 73478, October 25, 2016), the Heavy-Duty Engine and Vehicle Technical Amendment rule (86 FR 34308, June 29, 2021), and the HD2027 rule (88 FR 4296, January 24, 2023). In this rulemaking, EPA is not reopening any portion of our heavy-duty compliance provisions, flexibilities, and testing procedures, including those in 40 CFR parts 1037, 1036, and 1065, other than those specifically identified in this document as the subject of our proposal or a solicitation for comment. For example, while EPA is proposing to revise discrete elements of the HD ABT program, EPA is not reopening the general availability of ABT.

[212] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2020 (EPA–430–R–22–003), published April 2022.

[213] *Ibid.*

[214] *See* 74 FR 66496, December 15, 2009; see also EPA's Denial of Petitions Relating to the Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, *available at https://www.epa.gov/system/files/documents/2022-04/decision_document.pdf.*

The 2009 Endangerment Finding also documented, together with the extensive scientific and technical evidence in the supporting record, that climate change touches nearly every aspect of public welfare[215] in the United States., including: changes in water supply and quality due to changes in drought and extreme rainfall events; increased risk of storm surge and flooding in coastal areas and land loss due to inundation; increases in peak electricity demand and risks to electricity infrastructure; and the potential for significant agricultural disruptions and crop failures (though offset to a lesser extent by carbon fertilization). These impacts are also global and may exacerbate problems outside the United States. that raise humanitarian, trade, and national security issues for the U.S. (74 FR 66530).

The most recent information demonstrates that the climate is continuing to change in response to the human-induced buildup of GHGs in the atmosphere. Recent scientific assessments show that atmospheric concentrations of GHGs have risen to a level that has no precedent in human history and that they continue to climb, primarily because of both historic and current anthropogenic emissions, and that these elevated concentrations endanger our health by affecting our food and water sources, the air we breathe, the weather we experience, and our interactions with the natural and built environments.

Global average temperature has increased by about 1.1 degrees Celsius (°C) (2.0 degrees Fahrenheit (°F)) in the 2011–2020 decade relative to 1850–1900. The IPCC determined with medium confidence that this past decade was warmer than any multi-century period in at least the past 100,000 years. Global average sea level has risen by about 8 inches (about 21 centimeters (cm)) from 1901 to 2018, with the rate from 2006 to 2018 (0.15 inches/year or 3.7 millimeters (mm)/year) almost twice the rate over the 1971 to 2006 period, and three times the rate of the 1901 to 2018 period. The rate of sea level rise during the 20th Century was higher than in any other century in at least the last 2,800 years. The CO_2 being absorbed by the ocean has resulted in changes in ocean chemistry due to acidification of a magnitude not seen in 65 million years[216] putting many marine species—particularly calcifying species—at risk. Human-induced climate change has led to heatwaves and heavy precipitation becoming more frequent and more intense, along with increases in agricultural and ecological droughts[217] in many regions.[218] The NCA4 found that it is very likely (greater than 90 percent likelihood) that by mid-century, the Arctic Ocean will be almost entirely free of sea ice by late summer for the first time in about 2 million years.[219] Coral reefs will be at risk for almost complete (99 percent) losses with 1 °C (1.8 °F) of additional warming from today (2 °C or 3.6 °F since preindustrial). At this temperature, between 8 and 18 percent of animal, plant, and insect species could lose over half of the geographic area with suitable climate for their survival, and 7 to 10 percent of rangeland livestock would be projected to be lost. The IPCC similarly found that climate change has caused substantial damages and increasingly irreversible losses in terrestrial, freshwater, and coastal and open ocean marine ecosystems.[220]

In 2016, the Administrator issued a similar finding for GHG emissions from aircraft under section 231(a)(2)(A) of the CAA.[221] In the 2016 Endangerment Finding, the Administrator found that the body of scientific evidence amassed in the record for the 2009 Endangerment Finding compellingly supported a similar endangerment finding under CAA section 231(a)(2)(A), and also found that the science assessments released between the 2009 and the 2016 Findings ''strengthen and further support the judgment that GHGs in the atmosphere may reasonably be anticipated to endanger the public health and welfare of current and future generations'' (81 FR 54424). Pursuant to the 2009 Endangerment and Cause or Contribute Findings, CAA section 202(a) requires EPA to issue standards applicable to emissions of those pollutants from new motor vehicles. See *Coalition for Responsible Regulation,* 684 F.3d at 116–125, 126–27; Massachusetts, 549 U.S. at 533. *See also Coalition for Responsible Regulation,* 684 F.3d at 127–29 (upholding EPA's light-duty GHG emission standards for MYs 2012–2016 in their entirety).[222] Since the 2016 Endangerment Finding, the climate has continued to change, with new observational records being set for several climate indicators such as global average surface temperatures, GHG concentrations, and sea level rise. Additionally, major scientific assessments continue to be released that further advance our understanding of the climate system and the impacts that GHGs have on public health and welfare both for current and future generations. These updated observations and projections document the rapid rate of current and future climate change both globally and in the United States.[223] [224] [225] [226]

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[215] The CAA states in section 302(h) that ''[a]ll language referring to effects on welfare includes, but is not limited to, effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being, whether caused by transformation, conversion, or combination with other air pollutants.'' 42 U.S.C. 7602(h).

[216] IPCC (2018): Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Portner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Pe´an, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].

[217] These are drought measures based on soil moisture.

[218] IPCC (2021): Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Pe´an, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press.

[219] USGCRP (2018): Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

[220] IPCC (2022): Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.

[221] ''Finding that Greenhouse Gas Emissions from Aircraft Cause or Contribute to Air Pollution That May Reasonably Be Anticipated To Endanger Public Health and Welfare.'' 81 FR 54422, August 15, 2016. (''2016 Endangerment Finding'').

[222] See also EPA's Denial of Petitions Relating to the Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act (Apr. 2022), available at *https://www.epa.gov/system/files/documents/2022-04/decision_document.pdf.*

[223] USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018. *https://nca2018.globalchange.gov.*

[224] Roy, J., P. Tschakert, H. Waisman, S. Abdul Halim, P. Antwi-Agyei, P. Dasgupta, B. Hayward,

Continued

B. Summary of Comments Received From HD2027 NPRM

We received a significant number of comments to the proposed updates to the HD GHG emission standards proposed as part of the HD2027 NPRM.[227] A number of commenters provided support and reasoning for revising the HD CO_2 standards while a number of other commenters expressed concerns about reopening the HD GHG Phase 2 program. This Section II.B includes a summary of the comments received. Commenters who would like EPA to further consider in this rulemaking any relevant comments that they provided on the HD2027 NPRM regarding proposed HD vehicle GHG standards for the MYs at issue in this proposal must resubmit those comments to EPA during this proposal's comment period. EPA considered the comments received in response to the HD2027 NPRM when developing this Phase 3 proposal. The proposed standards were developed based on a more in-depth analysis of the potential for electrification of the heavy-duty sector and attendant emissions reductions than was used in the HD2027 NPRM analysis and is described in Sections II.D through II.F. This analysis addresses many of the concerns raised in comments summarized in the following subsections, such as the need to consider a wide range of HD applications, technology and operating costs of BEVs, the impact of heating and cooling on the energy demands of electric vehicles, infrastructure concerns, and the potential impact of weight and space for packaging of batteries. This analysis also includes consideration of the IRA provisions that provide significant financial incentives for the heavy-duty ZEV market and reduce or eliminate the cost difference between ICE vehicles and ZEVs. In consideration of some commenters' concerns about the time needed for research plans, product development, manufacturing investment, and charging infrastructure, we discuss these topics in our technical analysis supporting this NPRM. As described in Section II.H., EPA also requests comment on setting GHG standards starting in MYs 2027 through 2032 that would reflect: values less stringent than the lower stringency alternative for certain market segments, values in between the proposed standards and the alternative standards, values in between the proposed standards and those that would reflect ZEV adoption levels (*i.e.,* percent of ZEVs in production volumes) used in California's ACT, values that would reflect the level of ZEV adoption in the ACT program, and values beyond those that would reflect ZEV adoption levels in ACT such as the 50- to 60-percent ZEV adoption range.

1. Summary of Comments in Support of Revising the Phase 2 GHG Emission Standards for MY 2027

Many commenters, including non-governmental organizations, states, and mass comment campaigns, provided support for revising the targeted HD vehicle MY 2027 CO_2 emission standards to reflect the increase in electrification of the HD market and attendant potential for additional emission reductions. Additionally, many commenters suggested that EPA should further reduce the emission standards in MYs 2027 through 2029 beyond the levels proposed because of the accelerating adoption of HD ZEVs. Many commenters also highlighted that five additional states besides California adopted the California ACT program in late 2021 and noted that this would also drive additional electrification in the HD segment of the transportation sector.[228] Finally, some commenters pointed to the "Multi-State Medium and Heavy-Duty Zero Emission Vehicle Memorandum of Understanding" (Multi-State MOU) signed by 17 states and the District of Columbia establishing goals to increase HD electric vehicle sales in those jurisdictions to 30 percent by 2030 and 100 percent by 2050. Commenters also provided a number of reports that evaluate the potential of electrification of the HD sector in terms of adoption rates, costs, and other factors.

Some of the commenters provided specific recommendations for HD ZEV adoption rates in the MYs 2027 through 2029 timeframe. For example, the American Council for an Energy-Efficient Economy (ACEEE) suggested that, based on a recent NREL study, EPA could set standards that reflect 20 percent electrification in MY 2027 and up to 40 percent in MY 2029.[229] The Environmental Defense Fund (EDF) suggested standards to achieve 80 percent sales of ZEVs for new school and transit buses and 40 percent of new Class 4–7 vehicles and Class 8 short-haul vehicles by MY 2029.[230] EDF also referenced an analysis from Environmental Resources Management (ERM) that included a range of scenarios, with midpoint scenarios projecting HD ZEV deployment in excess of 20 percent in MY 2029 and more optimistic scenarios projecting HD ZEV sales of over 33 percent of all Class 4–8 single unit trucks, short-haul tractors, and school and transit buses in MY 2029.[231] The ICCT suggested HD ZEV ranges of 15 to 40 percent depending on the vehicle segment in MY 2027, increasing up to 40 to 80 percent in MY 2029.[232] Moving Forward Network suggested that ZEVs could comprise 20 percent of new sales in MY 2027 and increase 10 percent each year, with a goal of 100 percent by MY 2035.[233] Tesla referenced a NREL study, a forecast from Americas Commercial Transportation Research Co. (ACT Research) that projected a 26 percent sales share of HD ZEVs nationwide in 2030, and another study that projected 25 percent of the global HD fleet will be electric by 2030.[234] Other commenters,

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M. Kanninen, D. Liverman, C. Okereke, P.F. Pinho, K. Riahi, and A.G. Suarez Rodriguez, 2018: Sustainable Development, Poverty Eradication and Reducing Inequalities. In: Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press. *https://www.ipcc.ch/sr15/chapter/chapter-5.*

[225] National Academies of Sciences, Engineering, and Medicine. 2019. Climate Change and Ecosystems. Washington, DC: The National Academies Press. *https://doi.org/10.17226/25504.*

[226] NOAA National Centers for Environmental Information, State of the Climate: Global Climate Report for Annual 2020, published online January 2021, retrieved on February 10, 2021, from *https://www.ncdc.noaa.gov/sotc/global/202013.*

[227] For the complete set of comments, please see U.S. EPA, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards—Response to Comments." (RTC) Section 28. Docket EPA–HQ–OAR–201 9–0055.

[228] *Ibid.* Many commenters in HD2027 RTC Section 28.1.1 pointed to ACT.

[229] ACEEE comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–2852–A1. Referencing Catherine Ledna et al., 'Decarbonizing Medium-& Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis' (NREL, March 2022), available at *https://www.nrel.gov/docs/fy22osti/82081.pdf.*

[230] EDF comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1265–A1, pp.16–17.

[231] EDF comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1265–A1 (citing Rachel MacIntosh, Sophie Tolomiczenko, Grace Van Horn. April 2022. Electric Vehicle Market Update: Manufacturer Commitments and Public Policy Initiatives Supporting Electric Mobility in the U.S. and Worldwide, ERM for EDF, Version 6 (April 2022), available at *http://blogs.edf.org/climate411/files/2022/04/electric_vehicle_market_report_v6_april2022.pdf.*

[232] ICCT Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1211–A1, p. 6.

[233] Moving Forward Network Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1277–A1, pp. 19–20.

[234] Tesla Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1219–A1,

such as AMPLY Power (rebranded to bp plus), suggest that the federal CO_2 emission standards should achieve ZEV deployments on par with California's ACT program.[235]

Some commenters also referred to manufacturer statements regarding such manufacturers' projections for HD electrification. For example, ACEEE pointed to Volvo's and Scania's announcements for global electrification targets of 50 percent by 2030.[236] EDF pointed to several manufacturer's statements.[237] First, EDF noted Daimler Trucks North America has committed to offering only carbon-neutral trucks in the United States by 2039 and expects that by 2030, as much as 60 percent of its sales will be ZEVs.[238] Second, EDF noted Navistar has a goal of having 50 percent of its sales volume be ZEVs by 2030, and its commitment to achieve 100 percent zero emissions by 2040 across all operations and carbon-neutrality by 2050.[239]

Finally, some commenters discussed hydrogen-powered ICEs and asserted that there are benefits associated with that technology as a potential CO_2-reducing technology for the HD segment of the transportation sector.[240]

2. Summary of Comments Expressing Concern With Revising the Phase 2 GHG Emission Standards for MY 2027

Some commenters raised concerns with the HD2027 NPRM proposed changes to certain HD GHG Phase 2 CO_2 emission standards. Some highlighted the significant investment and lead time required for development and verification of durability of ZEVs and stated EPA should not adopt standards that project broad adoption of heavy-duty ZEVs.

Some commenters stated that EPA should not reopen the HD GHG Phase 2 emission standards.[241] Several manufacturers and suppliers pointed to the need for regulatory certainty and stability, stating that reopening the Phase 2 standards would threaten their long-term investments and production planning. Some commenters went further and stated that certain technologies that EPA projected for use to meet the existing Phase 2 emission standards are seeing lower-than-expected penetration rates in MY 2021; these commenters suggested that EPA relax the Phase 2 standards.[242] The technologies highlighted by the commenters suggesting that EPA relax Phase 2 standards include tamper-resistant automatic shutdown systems, neutral idle, low rolling resistance tires, stop-start, and advanced transmission shift strategies.

Commenters also stated that it takes time to develop ZEV technologies for the wide range of HD applications. They also raised concerns regarding asserted high costs and long lead times associated with the necessary charging infrastructure, the weight impact of batteries, the impact of battery degradation and ambient temperatures on the range of electric vehicles, and the impact on operations due to the time required to charge. Commenters also raised issues regarding the upstream and lifecycle emissions impact of ZEVs, including minerals and battery manufacturing, battery disposal and recycling, potential higher tire and brake wear from electric vehicles, and the availability of minerals and other supply chain issues.

Some commenters raised concerns about the approach used in the HD2027 NPRM to project ZEV sales in MY 2027. Concerns raised by commenters include the uncertainty of the actual production levels needed to meet California ACT program requirements; that EPA has not approved a waiver for the California ACT program and, therefore, should not consider full implementation of that program; and that the current HD ZEVs are expensive.

One commenter raised concerns related to small businesses. The commenter stated that its less diverse product mix and low sales volume present challenges in meeting the proposed GHG standards in the HD2027 NPRM.

C. Background on the CO_2 Emission Standards in the HD GHG Phase 2 Program

In the Phase 2 Heavy-Duty GHG rule, we finalized GHG emission standards tailored to three regulatory categories of HD vehicles—heavy-duty pickups and vans, vocational vehicles, and combination tractors.[243] In addition, we set separate standards for the engines that power combination tractors and for the engines that power vocational vehicles. The heavy-duty vehicle CO_2 emission standards are in grams per ton-mile, which represents the grams of CO_2 emitted to move one ton of payload a distance of one mile. In promulgating the Phase 2 standards, we explained that the stringency of the Phase 2 standards were derived on a fleet average technology mix basis and that the emission averaging provisions of ABT meant that the regulations did not require all vehicles to meet the standards (contrasted with the banking and trading provisions of the HD GHG Phase 2 ABT program which were not relied upon in selecting the stringency the HD GHG Phase 2 standards). For example, we projected that diversified manufacturers would continue to use the averaging provisions in the ABT program to meet the standards on average for each of their vehicle families. In addition, the Phase 2 program established subcategories of vehicles (*i.e.,* custom chassis vocational

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p.9 (citing HDT Truckinginfo, ACT: Third of Class 4–8 Vehicles to be Battery-Electric in 10 Year (June 4, 2021); Fleet Owner, Disruption in trucking technology (Jan. 13, 2020); and MJ Bradley, Medium- & Heavy-Duty Vehicles: Market Structure, Environmental Impact, and EV Readiness (Aug. 11, 2022)).

[235] AMPLY Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1236–A1, p. 1.

[236] ACEEE Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–0055–2852–A1. Citing Scania, 'Scania's Electrification Roadmap,' Scania Group, November 24, 2021, *https://www.scania.com/group/en/home/newsroom/news/2021/Scanias-electrification-roadmap.html*; AB Volvo, 'Volvo Trucks Launches Electric Truck with Longer Range,' Volvo Group, January 14, 2022, *https://www.volvogroup.com/en/news-and-media/news/2022/jan/news-4158927.html.*

[237] EDF comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1265–A1.

[238] EDF comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1265–A1 (citing David Cullen, ''Daimler to Offer Carbon Neutral Trucks by 2039,'' (October 25, 2019), *https://www.truckinginfo.com/343243/daimler-aims-to-offer-only-co2-neutral-trucks-by-2039-in-key-markets* (last accessed October 2022) and Deborah Lockridge, ''What Does Daimler Truck Spin-off Mean for North America?,'' Trucking Info (November 11, 2021), *https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america* (last accessed October 2022)).

[239] EDF comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1265–A1 (citing Navistar presentation at the Advanced Clean Transportation Expo, Long Beach, CA (May 9–11, 2022)).

[240] BorgWarner comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1234–A1, p. 3; Westport Fuel Systems comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1278–A1, p. 5.

[241] Daimler Trucks comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1168–A1, p.112; Navistar Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1318–A1, p. 6; PACCAR Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1346–A1, p. 3; Truck and Engine Manufacturer's Association Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1203–A1, pp. 7–8; Volvo Group Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1324–A1, p. 7.

[242] Truck and Engine Manufacturer's Association Comments on the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1203–A1, p. 108.

[243] We also set standards for certain types of trailers used in combination with tractors (see 81 FR 73639, October 25, 2016). As described in Section III of this preamble, we are proposing to remove the regulatory provisions related to trailers in 40 CFR part 1037 to carry out a decision by the U.S. Court of Appeals for the D.C. Circuit, which vacated the portions of the HD GHG Phase 2 final rule that apply to trailers. *Truck Trailer Manufacturers Association* v. *EPA*, 17 F.4th 1198 (D.C. Cir. 2021).

vehicles and heavy-haul tractors) that were specifically designed to recognize the limitations of certain vehicle applications to adopt some technologies due to specialized operating characteristics or generally low sales volumes with prohibitively long payback periods. The vehicles certified to the custom chassis vocational vehicle standards are not permitted to bank or trade credits and some have limited averaging provisions under the HD GHG Phase 2 ABT program.[244]

In this proposal, we continue to expect averaging would play an important role in manufacturer strategies to meet the proposed standards. In Section II.F, we are proposing new standards for vocational vehicles and combination tractors, which we project are feasible to meet through a technology pathway where vehicle manufacturers would adopt ZEV technologies for a portion of their product lines. This Section II.C includes additional background information on these two vehicle categories. At this time, we are not proposing to update engine standards in 40 CFR 1036.108. Additionally, we intend to separately pursue a combined light-duty and medium-duty rulemaking to propose more stringent standards for complete and incomplete vehicles at or below 14,000 pounds. GVWR that are certified under 40 CFR part 86, subpart S. Manufacturers of incomplete vehicles at or below 14,000 pounds GVWR would continue to have the option of either meeting the greenhouse gas standards under 40 CFR parts 1036 and 1037, or instead meeting the greenhouse gas standards with chassis-based measurement procedures under 40 CFR part 86, subpart S.

We are continuing and are not reopening the existing approach taken in both HD GHG Phase 1 and Phase 2, that compliance with the vehicle exhaust CO_2 emission standards is based on CO_2 emissions from the vehicle. See 76 FR 57123 (September 15, 2011); see also 77 FR 51705 (August 24, 2012), 77 FR 51500 (August 27, 2012), and 81 FR 75300 (October 25, 2016). EPA's heavy-duty standards have been in place as engine- and vehicle-based standards for decades, for all engine and vehicle technologies. We estimated the upstream emission impact of the proposed standards for heavy-duty vehicles on both the refinery and electricity generation sectors, as shown in Section V, and those analyses also support the proposed CO_2 emission standards.

1. Vocational Vehicles

Vocational vehicles include a wide variety of vehicle types, spanning Class 2b-8, and serve a wide range of functions. We define vocational vehicles as all heavy-duty vehicles greater than 8,500 lb GVWR that are not certified under 40 CFR part 86, subpart S, or a combination tractor under 40 CFR 1037.106.[245] Some examples of vocational vehicles include urban delivery trucks, refuse haulers, utility service trucks, dump trucks, concrete mixers, transit buses, shuttle buses, school buses, emergency vehicles, motor homes, and tow trucks. The HD GHG Phase 2 vocational vehicle program also includes a special regulatory subcategory called vocational tractors, which covers vehicles that are technically tractors but generally operate more like vocational vehicles than line-haul tractors. These vocational tractors include those designed to operate off-road and in certain intra-city delivery routes.

The existing HD GHG Phase 2 CO_2 standards for vocational vehicles are based on the performance of a wide array of control technologies. In particular, the HD GHG Phase 2 vocational vehicle standards recognize detailed characteristics of vehicle powertrains and drivelines. Driveline improvements present a significant opportunity for reducing fuel consumption and CO_2 emissions from vocational vehicles. However, there is no single package of driveline technologies that will be equally suitable for all vocational vehicles, because there is an extremely broad range of driveline configurations available in the market. This is due in part to the variety of final vehicle build configurations, ranging from a purpose-built custom chassis to a commercial chassis that may be intended as a multi-purpose stock vehicle. Furthermore, the wide range of applications and driving patterns of these vocational vehicles leads manufacturers to offer a variety of drivelines, as each performs differently in use.

In the final HD GHG Phase 2 rule, we recognized the diversity of vocational vehicle applications by setting unique CO_2 emission standards evaluated over composite drive cycles for 23 different regulatory subcategories. The program includes vocational vehicle standards that allow the technologies that perform best at highway speeds and those that perform best in urban driving to each be properly recognized over appropriate drive cycles, while avoiding potential unintended results of forcing vocational vehicles that are designed to serve in different applications to be measured against a single drive cycle. The vehicle CO_2 emissions are evaluated using EPA's Greenhouse Gas Emissions Model (GEM) over three drive cycles, where the composite weightings vary by subcategory, with the intent of balancing the competing pressures to recognize the varying performance of technologies, serve the wide range of customer needs, and maintain a workable regulatory program.[246] The HD GHG Phase 2 primary vocational standards, therefore, contain subcategories for Regional, Multi-purpose, and Urban drive cycles in each of the three weight classes (Light Heavy-Duty (Class 2b-5), Medium Heavy-Duty (Class 6–7) and Heavy Heavy-Duty (Class 8)), for a total of nine unique subcategories.[247] These nine subcategories apply for compression-ignition (CI) vehicles. We separately, but similarly, established six subcategories of spark-ignition (SI) vehicles. In other words, there are 15 separate numerical performance-based emission standards for each model year.

EPA also established optional custom chassis categories in the Phase 2 rule in recognition of the unique technical characteristics of these applications. These categories also recognize that many manufacturers of these custom chassis are not full-line heavy-duty vehicle companies and thus do not have the same flexibilities as other firms in the use of the Phase 2 program emissions averaging program which could lead to challenges in meeting the standards EPA established for the overall vocational vehicle and combination tractor program. We therefore established optional custom chassis CO_2 emission standards for Motorhomes, Refuse Haulers, Coach Buses, School Buses, Transit Buses, Concrete Mixers, Mixed Use Vehicles, and Emergency Vehicles.[248] In total, EPA set CO_2 emission standards for 15 subcategories of vocational vehicles and eight subcategories of specialty vehicle

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[244] See 40 CFR 1037.105(h)(2).

[245] See 40 CFR 1037.105(a).

[246] GEM is an EPA vehicle simulation tool used to certify HD vehicles. A detailed description of GEM can be found in the Phase 2 Regulatory Impacts Analysis or at *https://www.epa.gov/regulations-emissions-vehicles-and-engines/greenhouse-gas-emissions-model-gem-medium-and-heavy-duty*.

[247] See 40 CFR 1037.140(g) and (h).

[248] The numeric values of the optional custom chassis standards are not directly comparable to the primary vocational vehicle standards. As explained in the HD GHG Phase 2 rule, there are simplifications in GEM that produce higher or lower CO_2 emissions. 81 FR 73686–73688. October 25, 2016.

types for a total of 23 vocational vehicle subcategories.

The HD GHG Phase 2 standards phase in over a period of seven years, beginning with MY 2021. The HD GHG Phase 2 program progresses in three-year stages with an intermediate set of standards in MY 2024 and final standards in MY 2027 and later. In the HD GHG Phase 2 final rule, we identified a potential technology path for complying with each of the three increasingly stringent stages of the HD GHG Phase 2 program standards. These standards are based on the performance of more efficient engines, workday idle reduction technologies, improved transmissions including mild hybrid powertrains, axle technologies, weight reduction, electrified accessories, tire pressure systems, and tire rolling resistance improvements. We developed the Phase 2 vocational vehicle standards using the methodology where we applied fleet average technology mixes to fleet average baseline vehicle configurations, and each average baseline and technology mix was unique for each vehicle subcategory.[249] When the HD GHG Phase 2 final rule was promulgated in 2016, we established CO_2 standards on the premise that electrification of the heavy-duty market would occur in the future but was unlikely to occur at significant sales volumes in the timeframe of the program. As a result, the Phase 2 vocational vehicle CO_2 standards were not in any way premised on the application of ZEV technologies. Instead, we finalized BEV, PHEV, and FCEV advanced technology credit multipliers within the HD GHG ABT program to incentivize a transition to these technologies (see Section III of this preamble for further discussion on this program and proposed changes). Details regarding the HD GHG Phase 2 standards can be found in the HD GHG Phase 2 final rule preamble, and the HD GHG Phase 2 vocational vehicle standards are codified at 40 CFR part 1037.[250]

2. Combination Tractors

The tractor regulatory structure is attribute-based in terms of dividing the tractor category into ten subcategories based on the tractor's weight rating, cab configuration, and roof height. The tractors are subdivided into three weight ratings—Class 7 with a gross vehicle weight rating (GVWR) of 26,001 to 35,000 pounds; Class 8 with a GVWR over 33,000 pounds; and Heavy-haul with a gross combined weight rating of greater than or equal to 120,000 pounds.[251] The Class 7 and 8 tractor cab configurations are either day cab or sleeper cab. Day cab tractors are typically used for shorter haul operations, whereas sleeper cabs are often used in long haul operations. EPA set CO_2 emission standards for 10 tractor subcategories.

Similar to the vocational program, implementation of the HD GHG Phase 2 tractor standards began in MY 2021 and will be fully phased in for MY 2027. In the HD GHG Phase 2 final rule, EPA analyzed the feasibility of achieving the CO_2 standards and identified technology pathways for achieving the standards. The existing HD GHG Phase 2 CO_2 emission standards for combination tractors reflect reductions that can be achieved through improvements in the tractor's powertrain, aerodynamics, tires, idle reduction, and other vehicle systems as demonstrated using GEM. As we did for vocational vehicles, we developed a potential technology package for each of the tractor subcategories that represented a fleet average application of a mix of technologies to demonstrate the feasibility of the standard for each MY.[252] EPA did not premise the HD GHG Phase 2 CO_2 tractor emission standards on application of hybrid powertrains or ZEV technologies. However, we predicted some limited use of these technologies in MY 2021 and beyond and we finalized BEV, PHEV, and FCEV advanced technology credit multipliers within the HD GHG ABT program to incentivize a transition to these technologies (see Section III of this preamble for further discussion on this program and proposed changes). More details can be found in the HD GHG Phase 2 final rule preamble, and the HD GHG Phase 2 tractor standards are codified at 40 CFR part 1037.[253]

3. Heavy-Duty Engines

In HD GHG Phase 1, we developed a regulatory structure for CO_2, nitrous oxide (N2O), and methane (CH4) emission standards that apply to the engine, separate from the HD vocational vehicle and tractor. The regulatory structure includes separate standards for spark-ignition engines (such as gasoline engines) and compression-ignition engines (such as diesel engines), and for heavy heavy-duty (HHD), medium heavy-duty (MHD) and light heavy-duty (LHD) engines, that also apply to alternative fuel engines. We also used this regulatory structure for HD engines in HD GHG Phase 2. More details can be found in the HD GHG Phase 2 final rule preamble, and the HD GHG Phase 2 engine standards are codified at 40 CFR part 1036.[254]

4. Heavy-Duty Vehicle Average, Banking, and Trading Program

Beginning in HD GHG Phase 1, EPA adopted an averaging, banking, and trading (ABT) program for CO_2 emission credits that allows ABT within a vehicle weight class.[255] For the HD GHG Phase 2 ABT program, the three credit averaging sets for HD vehicles are Light Heavy-Duty Vehicles, Medium Heavy-Duty Vehicles, and Heavy Heavy-Duty Vehicles. This approach allows ABT between CI-powered vehicles, SI-powered vehicles, BEVs, FCEVs, and hybrid vehicles in the same weight class, which have the same regulatory useful life. Although the vocational vehicle emission standards are subdivided by Urban, Multi-purpose, and Regional regulatory subcategories, credit exchanges are currently allowed between them within the same weight class. However, these averaging sets currently exclude vehicles certified to the separate optional custom chassis standards. Finally, the ABT program currently allows credits to exchange between vocational vehicles and tractors within a weight class.

ABT is commonly used by vehicle manufacturers for the HD GHG Phase 2 program. In MY 2022, 93 percent of the vehicle families (256 out of 276 families) certified used ABT.[256] Similarly, 29 out of 40 manufacturers in MY 2022 used ABT to certify some or all of their vehicle families. Most of the manufacturers that did not use ABT produced vehicles that were certified to the optional custom chassis standards where the banking and trading components of ABT are not allowed, and averaging is limited.[257]

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[249] 81 FR 73715, October 25, 2016.

[250] 81 FR 73677–73725, October 25, 2016.

[251] See 40 CFR 1037.801.

[252] 81 FR 73602–73611, October 25, 2016.

[253] 81 FR 73571, October 25, 2016.

[254] 81 FR 73553–73571, October 25, 2016.

[255] 40 CFR 1037.701 through 1037.750.

[256] U.S. EPA Heavy-Duty Vehicle Certification Data. Last accessed on January 25, 2023 at *https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment*.

[257] See 40 CFR 1037.105(h)(2) for details.

D. Vehicle Technologies

As explained in Section ES.B, EPA is both proposing to revise the MY 2027 HD vehicle CO_2 emission standards and proposing new CO_2 emission standards that phase in annually from MY 2028 through 2032 for HD vocational vehicles and tractors. We are proposing that these Phase 3 vehicle standards are appropriate and feasible, including consideration of cost of compliance and other factors, for their respective MYs and vehicle subcategories through technology improvements in several areas. To support the feasibility and appropriateness of the proposed standards, we evaluated each technology and estimated a potential technology adoption rate in each vehicle subcategory per MY (our technology packages) that EPA projects is achievable based on nationwide production volumes, considering lead time, technical feasibility, cost, and other factors. At the same time, the proposed standards are performance-based and do not mandate any specific technology for any manufacturer or any vehicle subcategory. The following subsections describe the GHG emission-reducing technologies for HD vehicles considered in the proposal, including those for HD vehicles with ICE (Section II.D.1), BEVs (Section II.D.2), and FCEVs (Section II.D.3), as well as a summary of the technology assessment that supports the feasibility of the proposed Phase 3 standards (Section II.D.4) and the primary inputs we used in our new technology assessment tool, Heavy-Duty Technology Resource Use Case Scenario (HD TRUCS), that we developed to evaluate the design features needed to meet the power and energy demands of various HD vehicles when using ZEV technologies, as well as costs related to manufacturing, purchasing and operating ICE and ZEV technologies (Section II.D.5).

We are not proposing changes to the existing Phase 2 GHG emission standards for HD engines and are not reopening those standards in this rulemaking. As noted in the following section and DRIA Chapter 1.4, there are technologies available that can reduce GHG emissions from HD engines, and we anticipate that many of them will be used to meet the MY 2024 and MY 2027 CO_2 emission standards, while development is underway to meet the new low NO_X standards for MY 2027.[258] At this time, we believe that additional GHG reductions would be best driven through more stringent vehicle-level CO_2 emission standards as we are proposing in this rulemaking, which also account for the engine's CO_2 emissions, instead of also proposing new CO_2 emission standards that apply to heavy-duty engines.

1. Technologies To Reduce GHG Emissions From HD Vehicles With ICEs

The CO_2 emissions of HD vehicles vary depending on the configuration of the vehicle. Many aspects of the vehicle impact its emissions performance, including the engine, transmission, drive axle, aerodynamics, and rolling resistance. For this proposed rule, as we did for HD Phase 1 and Phase 2, we are proposing more stringent CO_2 emissions standards for each of the regulatory subcategories based on the performance of a package of technologies that reduce CO_2 emissions. And in this rule, we developed technology packages that include both ICE vehicle and ZEV technologies.

For each regulatory subcategory, we selected a theoretical ICE vehicle with CO_2-reducing technologies to represent the average MY 2027 vehicle that meets the existing MY 2027 Phase 2 standards. These vehicles are used as baselines from which to evaluate costs and effectiveness of additional technologies and more stringent standards on a per-vehicle basis. The MY 2027 technology package for tractors include technologies such as improved aerodynamics; low rolling resistance tires; tire inflation systems; efficient engines, transmissions, and drivetrains, and accessories; and extended idle reduction for sleeper cabs, The GEM inputs for the individual technologies that make up the fleet average technology package that meets the existing MY 2027 CO_2 tractor emission standards are shown in Table II–1.[259] The comparable table for vocational vehicles is shown in Table II–2.[260] The technology package for vocational vehicles include technologies such as low rolling resistance tires; tire inflation systems; efficient engines, transmissions, and drivetrains; weight reduction; and idle reduction technologies. Note that the HD GHG Phase 2 standards are performance-based; EPA does not require this specific technology mix, rather the technologies shown in Table II–1 and II–2 are potential pathways for compliance.

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[258] 40 CFR 1036.104.

[259] 81 FR 73616, October 25, 2016.

[260] 81 FR 73714, October 25, 2016.

TABLE II–1—GEM INPUTS FOR MY 2027 VEHICLES MEETING THE EXISTING MY 2027 TRACTOR CO_2 EMISSION STANDARDS

Class 7			Class 8					
Day cab			Day cab			Sleeper cab		
Low roof	Mid roof	High roof	Low roof	Mid roof	High roof	Low roof	Mid roof	High roof
Engine Fuel Map								
2027MY 11L Engine 350 HP	2027MY 11L Engine 350 HP	2027MY 11L Engine 350 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP
Aerodynamics (C_dA in m^2)								
5.12	6.21	5.67	5.12	6.21	5.67	5.08	6.21	5.26
Steer Tire Rolling Resistance (CRR in kg/metric ton)								
5.8	5.8	5.6	5.8	5.8	5.6	5.8	5.8	5.6
Drive Tire Rolling Resistance (CRR in kg/metric ton)								
6.2	6.2	5.8	6.2	6.2	5.8	6.2	6.2	5.8
Extended Idle Reduction Weighted Effectiveness								
N/A	N/A	N/A	N/A	N/A	N/A	3%	3%	3%
Transmission = 10 speed Manual Transmission Gear Ratios = 12.8, 9.25, 6.76, 4.90, 3.58, 2.61, 1.89, 1.38, 1.00, 0.73								
Drive Axle Ratio = 3.21 for day cabs, 3.16 for sleeper cabs								
6 x 2 Axle Weighted Effectiveness								
N/A	N/A	N/A	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
Transmission Type Weighted Effectiveness = 1.6%								
Neutral Idle Weighted Effectiveness								
0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.03%	0.03%	0.03%
Direct Drive Weighted Effectiveness = 1.0%								
Transmission Efficiency Weighted Effectiveness = 0.7%								
Axle Efficiency Improvement = 1.6%								
Air Conditioner Efficiency Improvements = 0.3%								
Accessory Improvements = 0.2%								
Predictive Cruise Control = 0.8%								
Automatic Tire Inflation Systems = 0.4%								
Tire Pressure Monitoring System = 0.7%								

TABLE II–2—GEM INPUTS FOR MY 2027 VEHICLES MEETING THE EXISTING MY 2027 VOCATIONAL VEHICLE CO_2 EMISSION STANDARDS

LHD (Class 2b–5)			MHD (Class 6–7)			HHD (Class 8)		
Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
SI Engine Fuel Map								
2018 MY 6.8L, 300 hp engine								
CI Engine Fuel Map								
2027 MY 7L, 200 hp Engine			2027 MY 7L, 270 hp Engine			2027 MY 11L, 350 hp Engine	2027 MY 11L, 350 hp Engine and 2027 MY 15L 455hp Engine	
Torque Converter Lockup in 1st Gear (adoption rate)								
50%	50%	50%	50%	50%	50%	30%	30%	0%
6×2 Disconnect Axle (adoption rate)								
0%	0%	0%	0%	0%	0%	0%	25%	30%

TABLE II–2—GEM INPUTS FOR MY 2027 VEHICLES MEETING THE EXISTING MY 2027 VOCATIONAL VEHICLE CO_2 EMISSION STANDARDS—CONTINUED

LHD (Class 2b–5)			MHD (Class 6–7)			HHD (Class 8)		
Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
Automatic Engine Shutdown (adoption rate)								
70%	70%	90%	70%	70%	90%	70%	70%	90%
Stop-Start (adoption rate)								
30%	30%	0%	30%	30%	0%	20%	20%	0%
Neutral Idle (adoption rate)								
60%	60%	0%	60%	60%	0%	70%	70%	0%
Steer Tire Rolling Resistance (CRR kg/metric ton)								
6.8	6.2	6.2	6.7	6.2	6.2	6.2	6.2	6.2
Drive Tire Rolling Resistance (CRR kg/metric ton)								
6.9	6.9	6.9	7.5	6.9	6.9	7.5	6.9	6.9
Weight Reduction (lb)								
75	75	75	75	75	75	125	125	125

Technologies exist today and continue to evolve to improve the efficiency of the engine, transmission, drivetrain, aerodynamics, and tire rolling resistance in HD vehicles and therefore reduce their CO_2 emissions. As discussed in the preamble to the HD GHG Phase 2 program and shown in Table II–1 and Table II–2, there are a variety of such technologies. In developing the Phase 2 CO_2 emission standards, we developed technology packages that were premised on technology adoption rates of less than 100 percent. There may be an opportunity for further improvements and increased adoption through MY 2032 for many of these technologies included in the HD GHG Phase 2 technology package used to set the existing MY 2027 standards. For example, DRIA Chapter 1.4 provides an update to tractor aerodynamic designs developed by several of the manufacturers as part of the DOE SuperTruck program that demonstrate aerodynamics that are better than those used in the existing MY 2027 standards' HD GHG Phase 2 technology package for high roof sleeper cab tractors in MYs beyond 2027.

The heavy-duty industry has also been developing hybrid powertrains, as described in DRIA Chapter 1.4.1.1. Hybrid powertrains consist of an ICE as well as an electric drivetrain and some designs also incorporate plug-in capability. Hybrid powered vehicles may provide CO_2 emission reductions through the use of downsized engines, recover energy through regenerative braking system that is normally lost while braking, and provide additional engine-off operation during idling and coasting. Hybrid powertrains are available today in a number of heavy-duty vocational vehicles including passenger van/shuttle bus, transit bus, street sweeper, refuse hauler, and delivery truck applications. Heavy-duty hybrid vehicles may include a power takeoff (PTO) system that is used to operate auxiliary equipment, such as the boom/bucket on a utility truck or the water pump on a fire truck.

Furthermore, manufacturers may develop new ICE vehicle technologies through the MY 2032 timeframe. An example of a new technology under development that would reduce GHG emissions from HD vehicles with ICEs is hydrogen-fueled internal combustion engines (H2–ICE). These engines are currently in the prototype stage of innovation [261] for HD vehicles, but have also been demonstrated as technically feasible in the past in the LD fleet. H2–ICE is a technology that produces zero hydrocarbon (HC), carbon monoxide (CO), and CO_2 engine-out emissions.

H2–ICE are similar to existing internal combustion engines and could leverage the technical expertise manufacturers have developed with existing products. H2–ICEs use many of the same components as existing internal combustion engines for many key systems. Similarly, H2–ICE vehicles could be built on the same assembly lines as existing ICE vehicles, by the same workers and with many of the same suppliers.

Though many engine components would be similar between H2–ICE and, for example, a comparable existing diesel-fueled ICE, components such as the cylinder head, piston and piston rings would be unique to H2–ICE as well as intake and exhaust valves and seats to control H2 leakage during combustion. Fuel systems would require changes to fuel injectors and the fuel delivery system. The H2–ICE aftertreatment systems may be simpler than today's comparable diesel-fueled ICEs. They likely would not require the use of a diesel oxidation catalyst (DOC) or a diesel particulate filter (DPF) system. NO_X emissions are still present in the H2–ICE exhaust and therefore a selective catalyst reduction (SCR) system would likely still be required, though smaller in size than an existing comparable diesel-fueled ICE aftertreatment system. The use of lean air-fuel ratios, not exhaust gas recirculation (EGR), would be the most effective way to control NO_X in H2 combustion engines. EGR is less effective with H2 due to the absence of CO_2 in the exhaust gas. Additional information regarding H2–ICE can be found in the DRIA Chapter 1.4.2.

One key significant difference between an existing comparable diesel-fueled ICE and a H2–ICE is the fuel storage tanks. The hydrogen storage tanks that would replace existing ICE fuel tanks are significantly more expensive. The fuel tanks used by H2–ICE would be the same as those used by

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[261] Comment submitted by DTNA to EPA Docket, EPA–HQ–OAR–2017–0055–1168. See *Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards Response to Comments,* EPA–420–R–22–036 December 2022.

a FCEV and may be either compressed storage (350 or 700 Bar) or cryogenic (storage temperatures reaching −253 degrees Celsius). Please refer to Section II.D.3 for the discussion regarding H2 fuel storage tanks. Furthermore, like FCEVs, H2 refueling infrastructure would be required for H2–ICE vehicles.

We request comment on whether we should include additional GHG-reducing technologies and/or higher levels of adoption rates of existing technologies for ICE vehicles in our technology assessment for the final rule.

2. HD Battery Electric Vehicle Technology

The HD BEV market has been growing significantly since MY 2018. DRIA Chapter 1.5 includes BEV vehicle information on over 170 models produced by over 60 manufacturers that cover a broad range of applications, including school buses, transit buses, straight trucks, refuse haulers, vans, tractors, utility trucks, and others, available to the public through MY 2024.

The battery electric propulsion system includes a battery pack that provides the energy to the motor that moves the vehicle. In this section, and in DRIA Chapter 1.5.1 and 2.4, we discuss battery technology that can be found in both BEVs and FCEVs. We request comment on our assessment of heavy-duty battery designs, critical materials, and battery manufacturing.

i. Batteries Design Parameters

Battery design involves considerations related to cost[262] and performance including specific energy[263] and power, energy density,[264] temperature impact, durability, and safety. These parameters typically vary based on the cathode and anode materials, and the conductive electrolyte medium at the cell level. Different battery chemistries have different intrinsic values. Here we provide a brief overview of the different energy and power parameters of batteries and battery chemistries.

a. Battery Energy and Power Parameters

Specific energy and power and energy density are a function of how much energy or power can be stored per unit mass (in Watt-hour per kilogram (Wh/kg) or watt per kilogram (W/kg)) or volume (in Watt-hour per liter (Wh/L)). Therefore, for a given battery weight or mass, the energy (in kilowatt-hour or kWh) can be calculated. For example, a battery with high specific energy and a lower weight may yield the same amount of energy as a chemistry with a lower specific energy and more weight.

Battery packs have a ‘‘nested’’ design where a group of cells are combined to make a battery module and a group of modules are combined to make a battery pack. Therefore, the battery systems can be described on the pack, module, and cell levels. Design choices about the different energy and power capacities to prioritize in a battery can depend on its battery chemistry. Common battery chemistries today include nickel-manganese-cobalt (NMC), nickel-cobalt-aluminum (NCA), and iron-phosphate (LFP) based-chemistries. Nickel-based chemistries typically have higher gravimetric and volumetric energy densities than iron phosphate-based chemistries. Since energy or power is only housed at the chemistry level, any additional mass such as the cell, module, and pack casings will only add to the weight of the battery without increasing the energy of the overall system. Therefore, some pack producers have eliminated the module in favor of a ‘‘cell-to-pack’’ design in recent years.[265]

External factors, especially temperature, can have a strong influence on the performance of the battery. Heavy-duty BEVs today include thermal management systems to keep the battery operating within a desired temperature range, which is commonly referred to as conditioning of the battery. Therefore, while operating a vehicle in cold temperatures, some of the battery energy is used to heat both the battery packs and the vehicle interior.[266] Cold temperatures, in particular, can result in reduced mobility of the lithium ions in the liquid electrolyte inside the battery; for the driver, this may mean lower range. Battery thermal management is also used during hot ambient temperatures to keep the battery from overheating. We consider and account for the energy required for battery thermal management in our analysis, as discussed in Section II.D.5.ii.b.

b. Battery Durability

Another important battery design consideration is the durability of the battery. Durability is frequently associated with cycle life, where cycle life is the number of times a battery can fully charge and discharge before the battery is no longer used for its original purpose. In 2015 the United Nations Economic Commission for Europe (UN ECE) began studying the need for a Global Technical Regulation (GTR) governing battery durability in light-duty vehicles. In 2021 it finalized United Nations Global Technical Regulation No. 22, ‘‘In-Vehicle Battery Durability for Electrified Vehicles,’’[267] or GTR No. 22, which provides a regulatory structure for contracting parties to set standards for battery durability in light-duty BEVs and PHEVs. Likewise, although not finalized, the UN ECE GTR working group began drafting language for HD BEVs and hybrid electric vehicles. Loss of electric range could lead to a loss of utility, meaning electric vehicles could be driven less and therefore displace less distance travelled than might otherwise be driven in conventional vehicles. Furthermore, a loss in utility could also dampen purchaser sentiment.

For batteries that are used in HD BEVs, the state-of-health (SOH) is an important design factor. The environmental performance of electrified vehicles may be affected by excess degradation of the battery system over time. However, the durability of a battery is not limited to the cycling of a battery, there are many phenomena that can impact the duration of usability of a battery. As a battery goes through charge and discharge cycles, the SOH of the battery decreases. Capacity fade, increase in internal resistance, and voltage loss, for example, are other common metrics to measure the SOH of a battery. These parameters together help better understand and define the longevity or durability of the battery. The SOH and, in turn, the cycle life of the battery is determined by both the chemistry of the battery as well as external factors including temperature. The rate at which the battery is discharged as well as the rate at which it is charged will also impact the SOH

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[262] Cost, here, is associated with cost of the battery design produced at scale instead of decrease in cost of batteries from high volume production. This cost may be associated with using more expensive minerals (*e.g.* nickel and cobalt instead of iron phosphate). Alternatively, some battery cell components may be more expensive for the same chemistry. For example, power battery cells are more expensive to manufacture than energy battery cells because these cells require thinner electrodes which are more complex to produce.

[263] Battery specific energy (also referred to as gravimetric energy density) is a measure of battery energy per unit of mass.

[264] Gravimetric energy density (specific energy) is a measure of battery energy per unit of mass. Volumetric energy density (also called energy density) is a measure of battery energy per unit of volume.

[265] BYD ‘‘blade’’ cells are an example of cell-to-pack technology.

[266] *https://www.aaa.com/AAA/common/AAR/files/AAA-Electric-Vehicle-Range-Testing-Report.pdf.*

[267] United Nations Economic Commission for Europe, Addendum 22: United Nations Global Technical Regulation No. 22, United Nations Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles, April 14, 2022. Available at: *https://unece.org/sites/default/files/2022-04/ECE_TRANS_180a22e.pdf.*

of the battery. Lastly, calendar aging, or degradation of the battery while not in use, can also contribute to the deterioration of the battery.

There are a number of ways to improve and prolong the battery life in a vehicle. We took considerations on maintaining the battery temperature while driving by applying additional energy required for conditioning the battery. Furthermore, battery size is increased by 20 percent to accommodate additional energy that may be required resulting from loss of capacity over time.

c. HD BEV Safety Assessment

HD BEV systems must be designed to always maintain safe operation. As with any onroad vehicle, BEVs must be robust while operating in temperature extremes as well as rain and snow. The BEV systems must be designed for reasonable levels of immersion, including immersion in salt water or brackish water. BEV systems must also be designed to be crashworthy and limit damage that compromises safety. If the structure is compromised by a severe impact, the systems must provide first responders with a way to safely conduct their work at an accident scene. The HD BEV systems must be designed to ensure the safety of users, occupants, and the general public in their vicinity.

In DRIA Chapter 1.5.4, we discuss the industry codes and standards used by manufacturers that guide safe design and development of heavy-duty BEVs, including those for developing battery systems and charging systems that protect people and the equipment. These standards have already been developed by the industry and are in place for manufacturers to use today to develop current and future products. The standards guide the design of BEV batteries to allow them to safely accept and deliver power for the life of the vehicle. The standards provide guidance to design batteries that also handle vibration, temperature extremes, temperature cycling, water, and mechanical impact from items such as road debris. For HD BEVs to uphold battery/electrical safety during and after a crash, they are designed to maintain high voltage isolation, prevent leakage of electrolyte and volatile gases, maintain internal battery integrity, and withstand external fire that could come from the BEV or other vehicle(s) involved in a crash. NHTSA continues work on battery safety requirements and extend the applicability of FMVSS No. 305 to HD vehicles and would align with the existing Global Technical Regulation (GTR) No. 20 to include safety requirements during normal operation, charging, and post-crash. We request comment on our assessment that HD BEVs can be designed to maintain safety.

ii. Assessment of Battery Materials and Production

Although the market share of light-duty and heavy-duty ZEVs in the United States is already growing, EPA recognizes that the proposed standards may accelerate this trend. Assessing the feasibility of incremental penetrations of ZEVs that may result from the proposed standards includes consideration of the readiness of the supply chain to provide the required quantities of critical minerals, components, and battery manufacturing capacity. This section provides a general review of how we considered supply chain and manufacturing in this analysis, the sources we considered, and how we used this information in the analysis. It also provides a high-level discussion of the security implications of increased demand for minerals and other commodities used to manufacture ZEVs.

In developing these standards, we considered the ability for global and domestic manufacturing and critical mineral capacity to respond to the projected demand for ZEVs that manufacturers may choose to produce to comply with the proposed standards. As described in this section, we consulted with industry and government agency sources (including DOE, U.S. Geological Survey (USGS), and several analysis firms) to collect information on production capacity, price forecasts, global mineral markets, and related topics, and have considered this information to inform our assumptions about future manufacturing capabilities and costs. We have included consideration of the influence of critical minerals and materials availability as well as vehicle and battery manufacturing capacities on the production of ZEVs.

We believe that the proposed rate of stringency is appropriate in light of this assessment. It is also our assessment that increased vehicle electrification in the United States will not lead to a critical long term dependence on foreign imports of minerals or components, nor that increased demand for these products will become a vulnerability to national security. First, in many cases the reason that these products are often sourced from outside of the United States is not because the products cannot be produced in the U.S., but because other countries have already invested in developing a supply chain for their production. Moreover, the United States will likely develop a domestic supply chain for these products because U.S. manufacturers will need to remain competitive in a global market where electrification is already proceeding rapidly. Second, many vehicle manufacturers, suppliers, startups, and related industries have already recognized the need for increased domestic production capacity as a business opportunity, and are basing business models on building out various aspects of the supply chain. Third, Congress and the Administration have taken significant steps to accelerate this activity by funding, facilitating, and otherwise promoting the rapid growth of U.S. supply chains for these products through the Inflation Reduction Act, the Bipartisan Infrastructure Law, and numerous Executive Branch initiatives. EPA has confidence that these efforts are effectively addressing supply chain concerns. Finally, utilization of critical minerals is different from the utilization of foreign oil, in that oil is consumed as a fuel while minerals become a constituent of manufactured vehicles. Minerals that are imported for vehicle production remain in the vehicle, and can be reclaimed through recycling. Each of these points will be expanded in more detail in the sections below.

We request comment on our assessment and data to support our assessment of battery critical raw materials and battery production for the final rule.

a. Battery Critical Raw Materials

Critical minerals are generally considered to include a large diversity of products, ranging from relatively plentiful materials that are constrained primarily by production capacity and refining, such as aluminum, to those that are both relatively rare and costly to process, such as the rare-earth metals that are used in magnets for permanent-magnet synchronous motors (PMSMs) that are used as the electric motors to power heavy-duty ZEVs and some semiconductor products. Extraction, processing, and recycling of certain critical minerals (such as lithium, cobalt, nickel, magnesium, graphite and rare earth metals) are also an important part of the supply chain supporting the production of battery components.

These minerals are also experiencing increasing demand across many other sectors of the global economy, not just the transportation industry, as the world seeks to reduce carbon emissions. As with any emerging technology, a transition period must take place in which a robust supply chain develops to support production of these products. At the present time, they are commonly sourced from global suppliers and do not yet benefit from a fully developed domestic supply chain.[268] As demand for these materials increases due to increasing production of ZEVs, current mining and processing capacity will expand.

The U.S. Geological Survey lists 50 minerals as ''critical to the U.S. economy and national security.'' [269] [270] The Energy Act of 2020 defines a ''critical mineral'' as a non-fuel mineral or mineral material essential to the economic or national security of the United States and which has a supply chain vulnerable to disruption.[271] Critical minerals are not necessarily short in supply, but are seen as essential to the manufacture of products that are important to the economy or national security. The risk to their availability may stem from geological scarcity, geopolitics, trade policy, or similar factors.[272]

Emission control catalysts for ICE vehicles utilize critical minerals including cerium, palladium, platinum, and rhodium. These are also required for hybrid vehicles due to the presence of the ICE. Critical minerals most relevant to lithium-ion battery production include cobalt, graphite, lithium, manganese, and nickel, which are important constituents of electrode active materials, their presence and relative amounts depending on the chemistry formulation. Aluminum is also used for cathode foils and in some cell chemistries. Rare-earth metals are used in permanent-magnet electric machines, and include several elements such as dysprosium, neodymium, and samarium.

Some of the electrification technologies that use critical minerals have alternatives that use other minerals or eliminate them entirely. For these, vehicle manufacturers in some cases have some flexibility to modify their designs to reduce or avoid use of minerals that are difficult or expensive to procure. For example, in some ZEV battery applications it is feasible and increasingly common to employ an iron phosphate cathode which has lower energy density but does not require cobalt, nickel, or manganese. Similarly, rare earths used in permanent-magnet electric machines have potential alternatives in the form of ferrite or other advanced magnets, or the use of induction machines or advanced externally excited motors, which do not use permanent magnets.

This discussion therefore focuses on minerals that are most critical for battery production, including nickel, cobalt, graphite, and lithium.

Availability of critical minerals for use in battery production depends on two primary considerations: production of raw minerals from mining (or recycling) operations and refining operations that produce purified and processed substances (precursors, electrolyte solutions, and finished electrode powders) made from the raw minerals, that can then be made into battery cells.

As shown in Figure II–1, in 2019 about 50 percent of global nickel production occurred in Indonesia, Philippines, and Russia, with the rest distributed around the world. Nearly 70 percent of cobalt originated from the Democratic Republic of Congo, with some significant production in Russia and Australia, and about 20 percent in the rest of the world. More than 60 percent of graphite production occurred in China, with significant contribution from Mozambique and Brazil for another 20 percent. About half of lithium was mined in Australia, with Chile accounting for another 20 percent and China about 10 percent.

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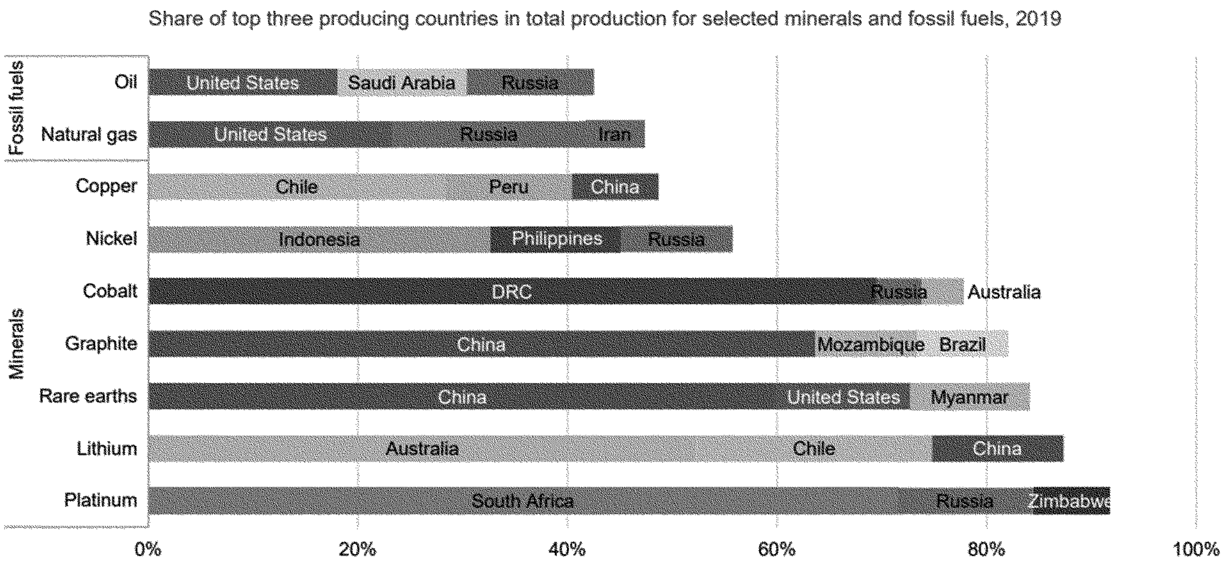

Figure II-1 Share of top three producing countries for critical minerals and fossil fuels in 2019 (IEA).[272]

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[268] As mentioned in Preamble I.C.2.i and in DRIA 1.3.2.2, there are tax credit incentives in the IRA for the production and sale of battery cells and modules of up to $45 per kWh, which includes up to 10 percent of the cost of producing applicable critical materials that meet certain specifications when such components or minerals are produced in the United States.

[269] U.S. Geological Survey, ''U.S. Geological Survey Releases 2022 List of Critical Minerals,'' February 22, 2022. Available at: *https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals.*

[270] The full list includes: Aluminum, antimony, arsenic, barite, beryllium, bismuth, cerium, cesium, chromium, cobalt, dysprosium, erbium, europium, fluorspar, gadolinium, gallium, germanium, graphite, hafnium, holmium, indium, iridium, lanthanum, lithium, lutetium, magnesium, manganese, neodymium, nickel, niobium, palladium, platinum, praseodymium, rhodium, rubidium, ruthenium, samarium, scandium, tantalum, tellurium, terbium, thulium, tin, titanium, tungsten, vanadium, ytterbium, yttrium, zinc, and zirconium.

[271] See 2021 Draft List of Critical Minerals (86 FR 62199–62203).

[272] International Energy Agency, ''The Role of Critical Minerals in Clean Energy Transitions,'' World Energy Outlook Special Report, Revised version. March 2022.

According to the 100-day review under E.O. on America's Supply Chains (E.O. 14017), of the major actors in mineral refining, 60 percent of lithium refining occurred in China, with 30 percent in Chile and 10 percent in Argentina. 72 percent of cobalt refining occurred in China, with another 17 percent distributed among Finland, Canada, and Norway. 21 percent of Class 1 nickel refining occurred in Russia, with 16 percent in China, 15 percent in Japan and 13 percent in Canada.[273] Similar conclusions were reached in an analysis by the International Energy Agency, shown in Figure II–2.

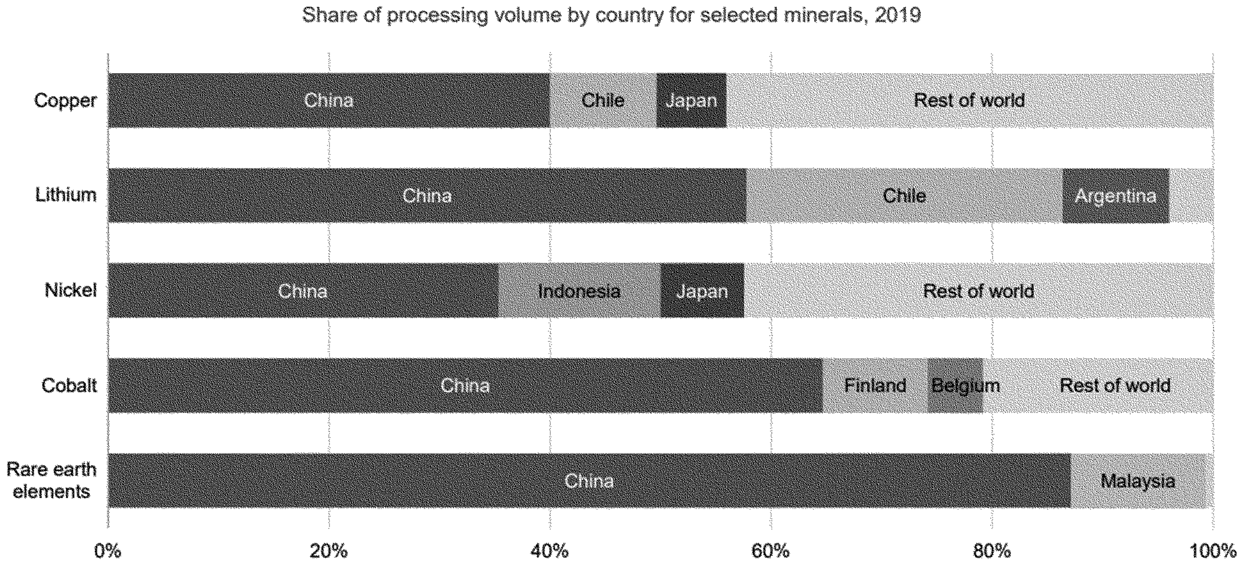

Figure II-2 IEA accounting of share of refining volume of critical minerals by country (IEA).[272]

Currently, the United States is lagging behind much of the rest of the world in critical mineral production. Although the United States has nickel reserves, and opportunity also exists to recover significant nickel from mine waste remediation and similar activities, it is more convenient for U.S. nickel to be imported from other countries, with 68 percent coming from Canada, Norway, Australia, and Finland, countries with which the United States has good trade relations.[274] According to the USGS, ample reserves of nickel exist in the United States and globally, potentially constrained only by processing capacity.[275] The United States has numerous cobalt deposits but few are developed while some have produced cobalt only in the past; about 72 percent of U.S. consumption is imported.[276] Similar observations may be made about graphite and lithium. Significant lithium deposits do exist in the United States in Nevada and California as well as several other locations,[277] [278] and are currently the target of development by suppliers and vehicle manufacturers. U.S. deposits of natural graphite deposits also exist but graphite has not been produced in the United States since the 1950s and significant known resources are largely undeveloped.[279]

Although predicting mineral supply and demand into the future is challenging, it is possible to identify general trends likely to occur in the future. As seen in Figure II–3 and Figure II–4, preliminary projections prepared by Li-Bridge for DOE,[280] and presented to the Federal Consortium for Advanced Batteries (FCAB)[281] in November 2022, indicate that global supplies of cathode active material (CAM) used as a part of the cathode manufacturing process and lithium chemical product are expected to be sufficient through 2035.

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[273] The White House, ''Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth,'' 100-Day Reviews under Executive Order 14017, June 2021.

[274] The White House, ''Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth,'' 100-Day Reviews under Executive Order 14017, June 2021.

[275] The White House, ''Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth,'' 100-Day Reviews under Executive Order 14017, June 2021.

[276] U.S. Geological Survey, ''Cobalt Deposits in the United States,'' June 1, 2020. Available at *https://www.usgs.gov/data/cobalt-deposits-united-states.*

[277] U.S. Geological Survey, ''Mineral Commodity Summaries 2022—Lithium'', January 2022. Available at *https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-lithium.pdf.*

[278] U.S. Geological Survey, ''Lithium Deposits in the United States,'' June 1, 2020. Available at *https://www.usgs.gov/data/lithium-deposits-united-states.*

[279] U.S. Geological Survey, ''USGS Updates Mineral Database with Graphite Deposits in the United States,'' February 28, 2022.

[280] Slides 6 and 7 of presentation by Li-Bridge to Federal Consortium for Advanced Batteries (FCAB), November 17, 2022.

[281] U.S. Department of Energy, Vehicle Technologies Office. ''Federal Consortium for Advanced Batteries (FCAB)''. Available online: *https://www.energy.gov/eere/vehicles/federal-consortium-advanced-batteries-fcab.*

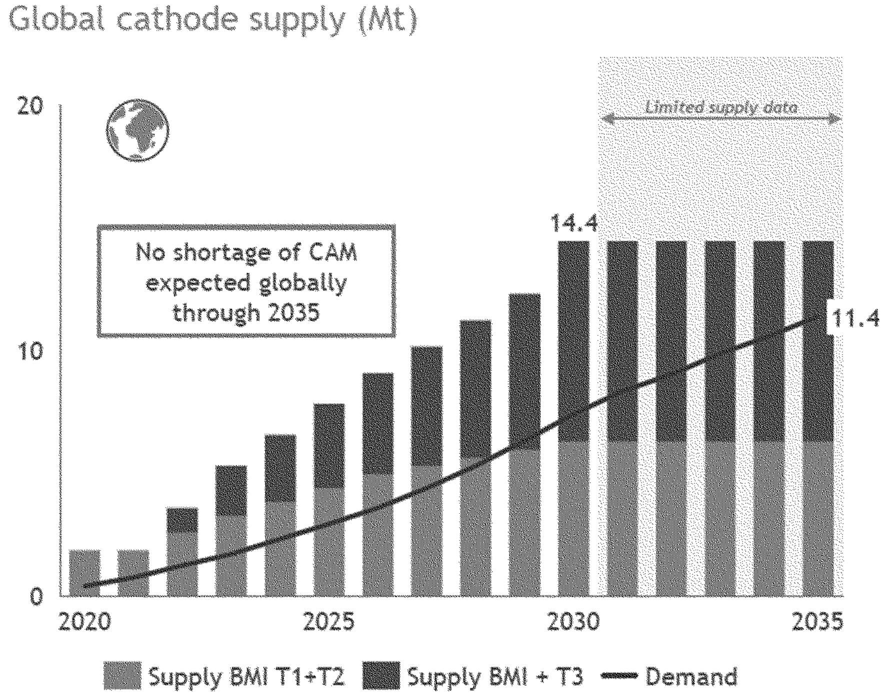

Figure II-3 DOE Li-Bridge assessment of global CAM supply and demand.

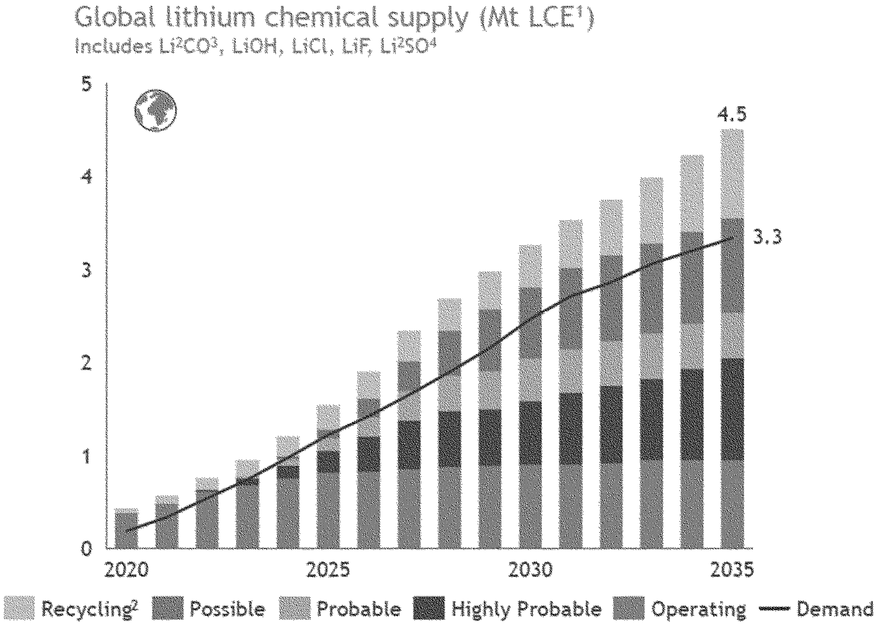

Figure II-4 DOE Li-Bridge assessment of global lithium chemical supply and demand

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The most recent information indicates that the market is responding robustly to demand[282] and lithium supplies are expanding as new resources are characterized, projects continue through engineering economic assessments, and others begin permitting or construction. For example, in October 2022, the IEA projected that global Lithium Carbonate Equivalent (LCE) production from operating mines and those under construction may sufficiently meet primary demand until 2028 under the Stated Policies Scenario.[283] In December 2022, BNEF projected lithium mine production can meet end-use demand

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[282] Bloomberg New Energy Finance, "Lithium-ion Battery Pack Prices Rise for First Time to an Average of $151/kWh," December 6, 2022. Accessed on December 6, 2022 at: *https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/*.

[283] International Energy Agency, "Committed mine production and primary demand for lithium, 2020–2030," October 26, 2022. Accessed on March 9, 2023 at *https://www.iea.org/data-and-statistics/charts/committed-mine-production-and-primary-demand-for-lithium-2020-2030*.

until 2028.[284] [285] Notably, the BNEF data is not exhaustive and includes only three U.S. projects: Silver Peak (phase I and II), Rhyolite Ridge (phase I), and Carolina Lithium (phase I). Additionally, in March 2023 DOE communicated to EPA that DOE and ANL have identified 21 additional lithium production projects in the United States in addition to the three identified in the December 2022 BNEF data. Were they to achieve commercial operations, the 24 U.S. projects would produce an additional 1,000 kilotons per year LCE not accounted for in the December BNEF analysis,[286] and suggests that lithium supplies would meet the BNEF Net-Zero demand projection.

In addition, the European Union is seeking to promote rapid development of Europe’s battery supply chains by considering targeted measures such as accelerating permitting processes and encouraging private investment. To these ends the European Parliament proposed a Critical Raw Materials Act on March 16, 2023, which includes these and other measures to encourage the development of new supplies of critical minerals not currently anticipated in market projections.[287] [288] [289] In DRIA 1.5.1.3 we detail these and many other examples that demonstrate how momentum has picked up in the lithium market since IEA’s May 2022 report. For more discussion, please see DRIA 1.5.1.3.

Despite recent short-term fluctuations in price, the price of lithium is expected to stabilize at or near its historical levels by the mid- to late-2020s.[290] [291] This perspective is also supported by proprietary battery price forecasts by Wood Mackenzie that include the predicted effect of temporarily elevated mineral prices.[292] This is consistent with the BNEF battery price outlook 2022 which expects battery prices to start dropping again in 2024, and BNEF’s 2022 Battery Price Survey which predicts that average pack prices should fall below $100/kWh by 2026.[293] Taken together these outlooks support the perspective that lithium is not likely to encounter a critical shortage as supply responds to meet growing demand.

As described in the following section, the development of mining and processing capacity in the United States is a primary focus of efforts on the part of both industry and the Administration toward building a robust domestic supply chain for electrified vehicle production, and will be greatly facilitated by the provisions of the BIL and the IRA as well as large private business investments that are already underway and continuing.

b. Battery Market and Manufacturing Capacity

Battery systems can be described on the pack, module, and cell levels. A pack typically consists of a group of modules, a module consists of a group of cells, and cells consist of the half-cell electrodes. Cells can be directly supplied to the manufacturer to be assembled into modules and packs; alternatively, cell producers may assemble cells into modules before sending the modules to another supplier to be assembled into a pack, before then sending it to the OEM for final assembly. While there are hundreds of reported automotive battery cell producers, major LD automakers use batteries produced by a handful of battery cell manufacturers. These suppliers include LG Chem, Samsung SDI, SK Innovation, Panasonic/Tesla, Contemporary Amperex Technology Co., Limited (CATL) and BYD. A 2021 report developed by DOE’s Argonne National Lab (ANL) found significant growth in the annual battery supply between 2010 and 2020.[294]

In both the LD and HD industry sectors, there is a meaningful distinction between 1) battery cell suppliers, and 2) battery pack assemblers who refer to themselves as battery producers while using cells produced by a different cell supplier, in understanding how impacts from the increased production volumes of cells and costs of cells in both industries flow to these different types of suppliers. The cost of cells occupies a significant percent of the final pack cost, and cell costs are inversely proportional to cell production volume.[295] [296] In other words, increased cell production volume lowers the cost of battery cells, which in turn lowers the overall pack cost. Thus, though the LD sector demand for automotive batteries is significantly outpacing the demand for vehicle batteries in the HD sector, the battery cell industry for both sectors will likely be significantly influenced by the demand in the LD industry.

Although most global battery manufacturing capacity is currently located outside the U.S., most of the batteries and cells present today in the domestic EV fleet were manufactured in the United States [297] We expect domestic manufacturing of batteries and cells to increase considerably over the coming decade. According to the Department of Energy, at least 13 new battery plants are expected to become operational in the United States within the next four years.[298] Among these 13 new battery plants include the following activities by battery suppliers and vehicle manufacturers. In partnership with SK Innovation, Ford is building three large new battery plants in Kentucky and Tennessee.[299] General

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[284] Sui, Lang. Memorandum to docket EPA–HQ–OAR–2022–0985. Based on subscription data available to BNEF subscribers at *https://www.bnef.com/interactive-datasets/2d5d59acd9000031?tab=DashboardDemand&view=8472b6c7-e8cc-467f-b4a4-fe85468fba3a.*

[285] Sui, Lang. Memorandum to docket EPA–HQ–OAR–2022–0985. Based on subscription data available to BNEF subscribers at *https://www.bnef.com/interactive-datasets/2d5d7ea4a2000001.*

[286] Sui, Lang. Memorandum to docket EPA–HQ–OAR–2022–0985. Department of Energy, communication to EPA titled ‘‘Lithium Supplies—additional datapoints and research,’’ March 8, 2023.

[287] European Union, ‘‘7th High-Level Meeting of the European Battery Alliance: main takeaways by the Chair Maroš Šefčovič and the Council Presidency,’’ March 1, 2023. Accessed on March 9, 2023 at *https://single-market-economy.ec.europa.eu/system/files/2023-03/Main%20takeaways_7th%20High-Level%20Meeting%20of%20EBA.pdf.*

[288] New York Times, ‘‘U.S. Eyes Trade Deals With Allies to Ease Clash Over Electric Car Subsidies,’’ February 24, 2023.

[289] European Parliament, ‘‘Proposal for a regulation of the European Parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials,’’ March 16, 2023. *https://single-market-economy.ec.europa.eu/publications/european-critical-raw-materials-act_en.*

[290] Sun et al., ‘‘Surging lithium price will not impede the electric vehicle boom,’’ Joule, doi:10.1016/j.joule. 2022.06.028 (*https://dx.doi.org/10.1016/j.joule.2022.06.028*).

[291] Green Car Congress, ‘‘Tsinghua researchers conclude surging lithium price will not impede EV boom,’’ July 29, 2022.

[292] Sui, Lang. Memorandum to docket EPA–HQ–OAR–2022–0985. Wood Mackenzie, ‘‘Battery & raw materials—Investment horizon outlook to 2032,’’ accompanying data set, September 2022 (filename: brms-data-q3–2022.xlsx).

[293] Bloomberg New Energy Finance, ‘‘Lithium-ion Battery Pack Prices Rise for First Time to an Average of $151/kWh,’’ December 6, 2022. Accessed on December 6, 2022 at: *https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/.*

[294] Argonne National Laboratory. ‘‘Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010–2020.’’ 2021.

[295] Argonne National Laboratory. ‘‘BatPaC Model Software’’. Available online: *https://www.anl.gov/cse/batpac-model-software.*

[296] BloombergNEF. ‘‘Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite’’. November 30, 2021. Available online: *https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite.*

[297] Argonne National Laboratory, ‘‘Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010–2020,’’ ANL/ESD–21/3, March 2021.

[298] Department of Energy, Fact of the Week #1217, ‘‘Thirteen New Electric Vehicle Battery Plants Are Planned in the U.S. Within the Next Five Years,’’ December 20, 2021.

[299] Dunn, Jason. ‘‘Ford to build battery and assembly plants in Kentucky and Tennessee for

Motors is partnering with LG Energy Solutions to build another three battery cell manufacturing plants in Tennessee, Michigan, and Ohio, and there are discussions about another plant in Indiana.[300] LG Chem has also announced plans for a cathode material production facility in Tennessee, said to be sufficient to supply 1.2 million high-performance electric vehicles per year by 2027.[301] CATL is considering construction of plants in Arizona, Kentucky, and South Carolina.[302] In addition, CATL is partnering with Daimler Truck to expand their global partnership to producm ion batteries for their all electric long haul heavy duty trucks starting 2024 to 2030.[303] Panasonic, already partnering with Tesla for its factories in Texas and Nevada, is planning two new factories in Oklahoma and Kansas.[304] Furthermore, Tesla is also planning a $3.6 billion expansion to their Nevada Gigafactory to mass produce all electric semi trucks.[305] Toyota plans to be operational with a plant in Greensboro, North Carolina in 2025, and Volkswagen in Chattanooga, Tennessee at about the same time.[306] [307] According to S&P Global, announcements such as these could result in a U.S. manufacturing capacity of 382 GWh by 2025,[308] and 580 GWh by 2027,[309] up from roughly 60 GWh [310] [311] today. More recently, the Department of Energy estimates that recent plant announcements for North America to date could enable an estimated 838 GWh of capacity by 2025, 896 GWh by 2027, and 998 GWh by 2030, the vast majority of which is cell manufacturing capacity.[312]

The expected HD battery capacity demand based on this proposed rule would be 17 GWh in MY 2027 and grow to 36 GWh by MY 2032 (as described in DRIA 2.8.3.1), which is well below the expected manufacturing capacity for this time frame. It should be noted that the projected U.S. HD battery demand would be only a fraction of total U.S. battery demand. In comparison, we project in the Light- and Medium-Duty Multipollutant Emissions Standards Proposed Rule that the annual battery production required for the light-duty fleet would be slightly less than 900 GWh in MY 2030, and stabilize at around 1,000 GWh per year for MY 2031 and beyond.[313] Therefore, between the two proposed highway motor vehicle rules, the U.S. market could require 940 GWh of battery capacity by 2030 and 1050 GWh of battery capacity by 2032. DOE estimates plant announcements of ~1,000 GWh by 2030; furthermore, the battery market is an international market where IEA projects 3.7 terrawatt hours (TWh) of battery globally by 2030 in their “Sustainable Development Scenario” [314]

In addition, the IRA and the BIL are providing significant support to accelerate these efforts to build out a U.S. supply chain for mineral, cell, and battery production. The IRA offers sizeable incentives and other support for further development of domestic and North American manufacture of these components. According to the Congressional Budget Office, an estimated $30.6 billion will be realized by manufacturers through the Advanced Manufacturing Production Credit, which includes a tax credit to manufacturers for battery production in the United States. According to one third-party estimate based on information from Benchmark Mineral Intelligence, the recent increase in U.S. battery manufacturing plant announcements could increase this figure to $136 billion or more.[315] Another $6.2 billion or more may be realized through expansion of the Advanced Energy Project Credit, a 30 percent tax credit for investments in projects that reequip, expand, or establish certain energy manufacturing facilities.[316] Together, these provisions create a strong motivation for manufacturers to support the continued development of a North American supply chain and already appear to be proving influential on the plans of manufacturers to procure domestic or North American mineral and component sources and to construct domestic manufacturing facilities to claim the benefits of the act.[317] [318]

In addition, the BIL provides $7.9 billion to support development of the domestic supply chain for battery manufacturing, recycling, and critical minerals.[319] Notably, it supports the

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massive acceleration of EV output”. *Autonomive Logistics.* September 28, 2021. Available online: *https://www.automotivelogistics.media/battery-supply-chain/ford-to-build-battery-and-assembly-plants-in-kentucky-and-tennessee-for-massive-acceleration-of-ev-output/42325.article#*.

[300] Shepardson, David. “GM, LG Energy drop plan for fourth U.S. JV battery plant”. *Reuters.* January 20, 2023. Available online: *https://www.reuters.com/technology/gm-lg-energy-drop-plan-fourth-us-jv-battery-plant-2023-01-20/*.

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[303] Kane, Mark. “Daimler and CATL Expand Global Battery Partnership”. *InsideEVs.* May 23, 2022. Available online: *https://insideevs.com/news/509050/daimler-catl-global-battery-partnership/*.

[304] Alvarez, Simon. “Tesla partner Panasonic looking at potential EV battery plant in Oklahoma: report”. TeslaRati. August 26, 2022. Available online: *https://www.teslarati.com/tesla-panasonic-plans-new-ev-battery-factory-usa/*.

[305] CNBC, “Tesla plans to spend $3.6 billion more on battery and truck manufacturing in Nevada,” January 24, 2023. Accessed on March 21, 2023 at *https://www.cnbc.com/2023/01/24/tesla-plans-to-spend-3point6-billion-more-on-manufacturing-in-nevada.html*.

[306] Toyota. “Toyota Announces $2.5 Billion Expansion of North Carolina Plant with 350 Additional Jobs and BEV Battery Capacity”. August 31, 2022. Available online: *https://pressroom.toyota.com/toyota-announces-2-5-billion-expansion-of-north-carolina-plant-with-350-additional-jobs-and-bev-battery-capacity/*.

[307] Doll, Scooter. “Volkswagen reportedly considering a second US production site plus new battery cell plant”. Available online: *https://electrek.co/2022/04/29/volkswagen-reportedly-considering-a-second-us-production-site-plus-new-battery-cell-plant/*.

[308] S&P Global Market Intelligence, “US ready for a battery factory boom, but now it needs to hold the charge,” October 3, 2022. Accessed on November 22, 2022 at *https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/us-ready-for-a-battery-factory-boom-but-now-it-needs-to-hold-the-charge-72262329*.

[309] S&P Global Mobility, “Growth of Li-ion battery manufacturing capacity in key EV markets,” May 20, 2022. Accessed on November 22, 2022 at *https://www.spglobal.com/mobility/en/research-analysis/growth-of-liion-battery-manufacturing-capacity.html*.

[310] Federal Consortium for Advanced Batteries, “National Blueprint for Lithium Batteries 2021–2030,” June 2021. Available at *https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf*.

[311] S&P Global Mobility, “Growth of Li-ion battery manufacturing capacity in key EV markets,” May 20, 2022. Accessed on November 22, 2022 at *https://www.spglobal.com/mobility/en/research-analysis/growth-of-liion-battery-manufacturing-capacity.html*.

[312] Argonne National Laboratory, “Assessment of Light-Duty Plug-in Electric Vehicles in the United States, 2010–2021,” ANL–22/71, November 2022.

[313] The Light- and Medium-Duty Multipollutant Emissions Standards proposed rule, titled “Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles,” was signed by the Administrator on the same day as this proposal. Available at *https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-multi-pollutant-emissions-standards-model*.

[314] IEA, “Annual EV battery demand projections by region and scenario, 2020–2030”, October 26, 2022. Available at *https://www.iea.org/data-and-statistics/charts/annual-ev-battery-demand-projections-by-region-and-scenario-2020-2030*.

[315] *Axois.com*, “Axios What's Next,” February 1, 2023. Accessed on March 1, 2023 at *https://www.axios.com/newsletters/axios-whats-next-1185bdcc-1b58-4a12-9f15-8ffc8e63b11e.html?chunk=0&utm_term=emshare#story0*.

[316] Congressional Research Service, “Tax Provisions in the Inflation Reduction Act of 2022 (H.R. 5376),” August 10, 2022.

[317] Subramanian, P., “Why Honda's EV battery plant likely wouldn't happen without new climate credits,” Yahoo Finance, August 29, 2022.

[318] LG Chem, “LG Chem to Establish Largest Cathode Plant in US for EV Batteries,” Press Release, November 22, 2022.

[319] Congressional Research Service, “Energy and Minerals Provisions in the Infrastructure

Continued

development and implementation of a $675 million Critical Materials Research, Development, Demonstration, and Commercialization Program administered by the Department of Energy (DOE),[320] and has created numerous other programs in related areas, such as for example, critical minerals data collection by the USGS.[321] Provisions extend across several areas including critical minerals mining and recycling research, USGS energy and minerals research, rare earth elements extraction and separation research and demonstration, and expansion of DOE loan programs in critical minerals and zero-carbon technologies.[322][323] The Department of Energy is working to facilitate and support further development of the supply chain, by identifying weaknesses for prioritization and rapidly funding those areas through numerous programs and funding opportunities.[324][325][326] According to a final report from the Department of Energy's Li-Bridge alliance,[327] ''the U.S. industry can double its value-added share by 2030 (capturing an additional $17 billion in direct value-add annually and 40,000 jobs in 2030 from mining to cell manufacturing), dramatically increase U.S. national and economic security, and position itself on the path to a near-circular economy by 2050.'' [328] The $7.9 billion provided by the BIL for U.S. battery supply chain projects [329] represents a total of about $14 billion when industry cost matching is considered.[330][331] Other recently announced projects will utilize another $40 billion in private funding.[332] According to DOE's Li-Bridge alliance, the total of these commitments already represents more than half of the capital investment that Li-Bridge considers necessary for supply chain investment to 2030.[333]

Further, the DOE Loan Programs Office is administering a major loans program focusing on extraction, processing and recycling of lithium and other critical minerals that will support continued market growth,[334] through the Advanced Technology Vehicles Manufacturing (ATVM) Loan Program and Title 17 Innovative Energy Loan Guarantee Program. This program includes over $20 billion of available loans and loan guarantees to finance critical materials projects.

c. Mineral Security

As stated at the beginning of this Section II.D, it is our assessment that increased electrification in the U.S. transportation sector does not constitute a vulnerability to national security, for several reasons supported by the discussion in this preamble and in DRIA 1.5.1.2.

A domestic supply chain for battery and cell manufacturing is rapidly forming by the actions of stakeholders including vehicle manufacturers and suppliers who wish to take advantage of the business opportunities that this need presents, and by vehicle manufacturers who recognize the need to remain competitive in a global market that is shifting to electrification. It is therefore already a goal of the U.S. manufacturing industry to create a robust supply chain for these products, in order to supply not only the domestic vehicle market, but also all of the other applications for these products in global markets as the world decarbonizes.

Further, the IRA and BIL are proving to be a highly effective means by which Congress and the Administration have provided support for the building of a robust supply chain, and to accelerate this activity to ensure that it forms as rapidly as possible. An example is the work of Li Bridge, a public-private alliance committed to accelerating the development of a robust and secure domestic supply chain for lithium-based batteries. It has set forth a goal that by 2030 the United States should capture 60 percent of the economic value associated with the U.S. domestic demand for lithium batteries. Achieving this target would double the economic value expected in the United States under ''business as usual'' growth.[335] More evidence of recent growth in the supply chain is found in a February 2023 report by Pacific Northwest National Laboratory (PNNL), which documents robust growth in the North American lithium battery industry.[336]

Finally, it is important to note that utilization of critical minerals is different from the utilization of foreign oil, in that oil is consumed as a fuel while minerals become a constituent of manufactured vehicles. That is, mineral security is not a perfect analogy to energy security. Supply disruptions and fluctuating prices are relevant to critical minerals as well, but the impacts of such disruptions are felt differently and by different parties. Disruptions in oil supply or gasoline price has an immediate impact on consumers through higher fuel prices, and thus constrains the ability to travel. In contrast, supply disruptions or price fluctuations of minerals affect only the production and price of new vehicles. In practice, short-term price fluctuations do not always translate to higher production cost as most manufacturers purchase minerals via long-term contracts that insulate them to a degree from changes in spot prices. Moreover, critical minerals are not a single

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Investment and Jobs Act (Pub. L. 117–58)'', February 16, 2022. *https://crsreports.congress.gov/product/pdf/R/R47034*.

[320] Department of Energy, ''DOE Seeks Public Input on Critical Materials Research Program to Strengthen Clean Energy Technology Manufacturing in America,'' August 9, 2022. Available at *https://www.energy.gov/articles/biden-harris-administration-launches-675-million-bipartisan-infrastructure-law-program*.

[321] U.S. Geological Survey, ''Bipartisan Infrastructure Law supports critical-minerals research in central Great Plains,'' October 26, 2022. Available at *https://www.usgs.gov/news/state-news-release/bipartisan-infrastructure-law-supports-critical-minerals-research-central*.

[322] Congressional Research Service, ''Energy and Minerals Provisions in the Infrastructure Investment and Jobs Act (Pub. L. 117–58)'', February 16, 2022. *https://crsreports.congress.gov/product/pdf/R/R47034*.

[323] International Energy Agency, ''Infrastructure and Jobs act: Critical Minerals,'' October 26, 2022. *https://www.iea.org/policies/14995-infrastructure-and-jobs-act-critical-minerals*.

[324] Department of Energy, Li-Bridge, ''Building a Robust and Resilient U.S. Lithium Battery Supply Chain,'' February 2023.

[325] The White House, ''Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth,'' 100-Day Reviews under Executive Order 14017, June 2021.

[326] Federal Consortium for Advanced Batteries, ''National Blueprint for Lithium Batteries 2021–2030,'' June 2021. Available at *https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf*.

[327] Argonne National Laboratory. ''Li-Bridge''. Available online: *https://www.anl.gov/li-bridge*.

[328] Department of Energy, Li-Bridge, '' Building a Robust and Resilient U.S. Lithium Battery Supply Chain,'' February 2023.

[329] Congressional Research Service, ''Energy and Minerals Provisions in the Infrastructure Investment and Jobs Act (Pub. L. 117–58)'', February 16, 2022. *https://crsreports.congress.gov/product/pdf/R/R47034*.

[330] Department of Energy, Li-Bridge, ''Building a Robust and Resilient U.S. Lithium Battery Supply Chain,'' February 2023 (p. 9).

[331] Department of Energy, EERE Funding Opportunity Exchange, EERE Funding Opportunity Announcements. Accessed March 4, 2023 at *https://eere-exchange.energy.gov/Default.aspx#FoaId0596def9-c1cc-478d-aa4f-14b472864eba*.

[332] Federal Reserve Bank of Dallas, ''Automakers' bold plans for electric vehicles spur U.S. battery boom,'' October 11, 2022. Accessed on March 4, 2023 at *https://www.dallasfed.org/research/economics/2022/1011*.

[333] Department of Energy, Li-Bridge, ''Building a Robust and Resilient U.S. Lithium Battery Supply Chain,'' February 2023 (p. 9).

[334] Department of Energy Loan Programs Office, ''Critical Materials Loans & Loan Guarantees,'' *https://www.energy.gov/sites/default/files/2021-06/DOE-LPO_Program_Handout_Critical_Materials_June2021_0.pdf*.

[335] Department of Energy, Li-Bridge, ''Building a Robust and Resilient U.S. Lithium Battery Supply Chain,'' February 2023.

[336] Pacific Northwest National Laboratory, ''North American Lithium Battery Materials V 1.2,'' February 2023. Available at *https://www.pnnl.gov/projects/north-american-lithium-battery-materials-industry-report*.

commodity but a number of distinct commodities, each having its own supply and demand dynamics, and some being capable of substitution by other minerals.[337] Importantly, while oil is consumed as a fuel and thus requires continuous supply, minerals become part of the vehicle and have the potential to be recovered and recycled. Thus even when minerals are imported from other countries, their acquisition adds to the domestic mineral stock that is available for domestic recycling in the future.

Over the long term, battery recycling will be a critical component of the BEV supply chain and will contribute to mineral security and sustainability, effectively acting as a domestically produced mineral source that reduces overall reliance on foreign-sourced products. While the number of end-of-life BEV batteries available for recycling will lag the market penetration of BEVs, it is important to consider the projected growth in development of a battery recycling supply chain during the time frame of the rule and beyond.

By 2050, battery recycling could be capable of meeting 25 to 50 percent of total lithium demand for battery production.[338] [339] To this end, battery recycling is avery active area of research. The Department of Energy coordinates much research in this area through the ReCell Center, described as ‘‘a national collaboration of industry, academia and national laboratories working together to advance recycling technologies along the entire battery life-cycle for current and future battery chemistries.’’ [340] Funding is also being disbursed as directed by the BIL, as discussed in Chapter 1.3.2 of the DRIA.[341] A growing number of private companies are entering the battery recycling market as the rate of recyclable material becoming available from battery production facilities and salvaged vehicles has grown, and manufacturers are already reaching agreements to use these recycled materials for domestic battery manufacturing. For example, Panasonic has contracted with Redwood Materials Inc. to supply domestically processed cathode material, much of which will be sourced from recycled batteries.[342]

Recycling infrastructure is one of the targets of several provisions of the BIL. It includes a Battery Processing and Manufacturing program, which grants significant funds to promote U.S. processing and manufacturing of batteries for automotive and electric grid use, by awarding grants for demonstration projects, new construction, retooling and retrofitting, and facility expansion. It will provide a total of $3 billion for battery material processing, $3 billion for battery manufacturing and recycling, $10 million for a lithium-ion battery recycling prize competition, $60 million for research and development activities in battery recycling, an additional $50 million for state and local programs, and $15 million to develop a collection system for used batteries. In addition, the Electric Drive Vehicle Battery Recycling and Second-Life Application Program will provide $200 million in funds for research, development, and demonstration of battery recycling and second-life applications.[343]

The efforts to fund and build a mid-chain processing supply chain for active materials and related products will also be important to reclaiming minerals through domestic recycling. While domestic recycling can recover minerals and other materials needed for battery cell production, they commonly are recovered in elemental forms that require further midstream processing into precursor substances and active material powders that can be used in cell production. The DOE ReCell Center coordinates extensive research on development of a domestic lithium-ion recycling supply chain, including direct recycling, in which materials can be recycled for direct use in cell production without destroying their chemical structure, and advanced resource recovery which uses chemical conversion to recover raw minerals for processing into new constituents.[344]

Currently, pilot-scale battery recycling research projects and private recycling startups have access to only limited amounts of recycling stock that originate from sources such as manufacturer waste, crashed vehicles, and occasional manufacturer recall/repair events. As ZEVs are currently only a small portion of the U.S. vehicle stock, some time will pass before vehicle scrappage can provide a steady supply of end-of-life batteries to support large-scale battery recycling. During this time, we expect that the midchain processing portion of the supply chain will continue to develop and will be able to capture much of the resources made available by the recycling of used batteries coming in from the fleet.[345]

3. HD Fuel Cell Electric Vehicle Technology

Fuel cell technologies that run on hydrogen have been in existence for decades, though they are just starting to enter the heavy-duty transportation market. Hydrogen FCEVs are similar to BEVs in that they have batteries and use an electric motor instead of an internal combustion engine to power the wheels. Unlike BEVs that need to be plugged in to recharge, FCEVs have fuel cell stacks that use a chemical reaction involving hydrogen to generate electricity. Fuel cells with electric motors are two-to-three times more efficient than ICEs that run on gasoline or diesel, requiring less energy to fuel.[346]

Hydrogen FCEVs do not emit air pollution at the tailpipe—only heat and pure water.[347] With current and near-future technologies, energy can be stored more densely onboard a vehicle as gaseous or liquid hydrogen than it can as electrons in a battery. This allows FCEVs to perform periods of service between fueling events that batteries currently cannot achieve without affecting vehicle weight and limiting payload capacity. Thus, fuel cells are of interest for their potential use in heavy-duty sectors that are difficult to electrify

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[337] For example, manganese can be subsituted by aluminum in the case of nickel-manganese-cobalt (NMC) and nickel-cobalt-aluminum (NCA) batteries. Likewise, a LFP battery uses iron phophaste chemistry without nickel, manganese, cobalt or aluminum. Research has also been conducted to study the replacement of lithium with sodium ions.

[338] Sun et al., ‘‘Surging lithium price will not impede the electric vehicle boom,’’ *Joule,* doi:10.1016/j.joule. 2022.06.028 (*https://dx.doi.org/10.1016/j.joule.2022.06.028*).

[339] Ziemann et al., ‘‘Modeling the potential impact of lithium recycling from EV batteries on lithium demand: a dynamic MFA approach,’’ Resour. Conserv. Recycl. 133, pp. 76–85. *https://doi.org/10.1016/j.resconrec.2018.01.031.*

[340] ReCell Advanced Battery Remanufacturing. *https://recellcenter.org/about/.*

[341] Department of Energy, ‘‘Biden-Harris Administration Announces Nearly $74 Million To Advance Domestic Battery Recycling And Reuse, Strengthen Nation's Battery Supply Chain,’’ Press Release, November 16, 2022.

[342] Randall, T., ‘‘The Battery Supply Chain Is Finally Coming to America,’’ Bloomberg, November 15, 2022.

[343] Environmental Defense Fund and ERM, ‘‘Electric Vehicle Market Update: Manufacturer Commitments and Public Policy Initiatives Supporting Electric Mobility in the U.S. and Worldwide,’’ September 2022.

[344] Department of Energy, ‘‘The ReCell Center for Advanced Battery Recycling FY22 Q4 Report,’’ October 20, 2022. Available at: *https://recellcenter.org/2022/12/15/recell-advanced-battery-recycling-center-fourth-quarter-progress-report-2022/.*

[345] Department of Energy, ‘‘Biden-Harris Administration Announces Nearly $74 Million To Advance Domestic Battery Recycling and Reuse, Strengthen Nation's Battery Supply Chain,’’ Press Release, November 16, 2022.

[346] U.S. Department of Energy, Vehicle Technologies Office. ‘‘Hydrogen Basics’’. Alternative Fuels Data Center. Available online: *https://afdc.energy.gov/fuels/hydrogen_basics.html.*

[347] U.S. Department of Energy, Fuel Cell Technologies Office. ‘‘Fuel Cells’’. November 2015. Available online: *https://www.energy.gov/sites/prod/files/2015/11/f27/fcto_fuel_cells_fact_sheet.pdf.*

using batteries due to range or weight limitations.

In the following sections, and in DRIA Chapter 1.7, we discuss key technology components unique to HD FCEVs. We request comment on our assessment and data to support our assessment of FCEV technology for the final rule.

i. Fuel Cell Stack

A fuel cell system is composed of a fuel cell stack and ''balance of plant'' (BOP) components that support the fuel cell stack (*e.g.,* pumps, sensors, compressors, humidifiers). A fuel cell stack is a module that may contain hundreds of fuel cell units, typically combined in series.[348] A heavy-duty FCEV may have several fuel cell stacks to meet the power needs of a comparable ICE vehicle.

Though there are many types of fuel cell technologies, polymer electrolyte membrane (PEM) fuel cells are typically used in transportation applications because they offer high power density, therefore have low weight and volume, and can operate at relatively low temperatures.[349] PEM fuel cells are built using membrane electrode assemblies (MEA) and supportive hardware. The MEA includes the PEM electrolyte material, catalyst layers (anode and cathode), and gas diffusion layers.[350] Hydrogen fuel and oxygen enter the MEA and chemically react to generate electricity, which is either used to propel the vehicle or is stored in a battery to meet future power needs. The process creates excess water vapor and heat.

Key BOP components include the air supply system that provides oxygen, the hydrogen supply system, and the thermal management system. With the help of compressors and sensors, these components monitor and regulate the pressure and flow of the gases supplied to the fuel cell along with relative humidity and temperature. Similar to ICEs and batteries, PEM fuel cells require thermal management systems to control the operating temperatures. It is necessary to control operating temperatures to maintain stack voltage and the efficiency and performance of the system. There are different strategies to mitigate excess heat that comes from operating a fuel cell. For example, a HD vehicle may include a cooling system the circulates cooling fluid through the stack.[351] Waste heat recovery solutions are also emerging.[352] The excess heat also can be in turn used to heat the cabin, similar to ICE vehicles. Power consumed to operate BOP components can also impact the stack's efficiency.[353] [354] [355]

To improve fuel cell performance, the air and hydrogen fuel that enter the system may be compressed, humidified, and/or filtered.[356] A fuel cell operates best when the air and the hydrogen are free of contaminants, since contaminants can poison and damage the catalyst. PEM fuel cells require hydrogen that is over 99 percent pure, which can add to the fuel production cost.[357] Hydrogen produced from natural gas tends to initially have more impurities (*e.g.,* carbon monoxide and ammonia, associated with the reforming of hydrocarbons) than hydrogen produced from water through electrolysis.[358] There are standards such as ISO 14687 that include hydrogen fuel quality specifications for use in vehicles to minimize impurities.[359]

Fuel cell durability is important in heavy-duty applications, given that vehicle owners and operators often have high expectations for drivetrain lifetimes in terms of years, hours, and miles. Fuel cells can be designed to meet durability needs, or the ability of the stack to maintain its performance over time. Considerations must be included in the design to accommodate operations in less-than-optimized conditions. For example, prolonged operation at high voltage (low power) or when there are multiple transitions between high and low voltage can stress the system. As a fuel cell system ages, a fuel cell's MEA materials can degrade, and performance and maximum power output can decline. The fuel cell can become less efficient, which can cause it to generate more excess heat and consume more fuel.[360] DOE's ultimate long-term technology target for Class 8 HD trucks is a fuel cell lifetime of 30,000 hours, corresponding to an expected vehicle lifetime of 1.2 million miles.[361] A voltage degradation of 10 percent at rated power (*i.e.,* the power level the cell is designed for) by end-of-life is considered by DOE when evaluating targets.[362]

Currently, the fuel cell stack is the most expensive component of a heavy-duty FCEV, primarily due to the technological requirements of manufacturing rather than raw material costs.[363] Larger production volumes are anticipated as global demand increases for fuel cell systems for HD vehicles, which could improve economies of scale.[364] Costs are also anticipated to decline as durability improves, which could extend the life of fuel cells and reduce the need for parts replacement.[365] Fuel cells contain PEM catalysts that typically are made using precious metals from the platinum

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[348] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office. ''Fuel Cell Systems''. Available online: *https://www.energy.gov/eere/fuelcells/fuel-cell-systems.*

[349] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office. ''Types of Fuel Cells''. Available online: *https://www.energy.gov/eere/fuelcells/types-fuel-cells.*

[350] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office. ''Parts of a Fuel Cell''. Available online: *https://www.energy.gov/eere/fuelcells/parts-fuel-cell.*

[351] Hyfindr. ''Fuel Cell Stack''. Available online: *https://hyfindr.com/fuel-cell-stack/.*

[352] Baroutaji, Ahmad, et al. ''Advancements and prospects of thermal management and waste heat recovery of PEMFC''. *Interational Journal of Thermofluids:* 9. February 2021. Available online: *https://www.sciencedirect.com/science/article/pii/S2666202721000021.*

[353] Hoeflinger, Johannes and Peter Hofmann. ''Air mass flow and pressure optimization of a PEM fuel cell range extender system''. *International Journal of Hydrogen Energy.* Volume 45:53. October 02020. Available online: *https://www.sciencedirect.com/science/article/pii/S0360319920327841.*

[354] Pardhi, Shantanu, et al. ''A Review of Fuel Cell Powertrains for Long-Haul Heavy-Duty Vehicles: Technology, Hydrogen, Energy and Thermal Management Systems''. *Energies.* December 2022. Available online: *https://www.mdpi.com/1996-1073/15/24/9557.*

[355] Hyfindr. ''Fuel Cell Stack''. Available online: *https://hyfindr.com/fuel-cell-stack/.*

[356] U.S .Environmental Protection Agency. ''Assessment of Fuel Cell Technologies at Ports''. Prepared for EPA by Eastern Research Group, Inc. July 2022. Available online: *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1015AQX.pdf.*

[357] US Drive. ''Hydrogen Production Tech Team Roadmap''. November 2017. Available online: *https://www.energy.gov/eere/vehicles/articles/us-drive-hydrogen-production-technical-team-roadmap.*

[358] Nhuyen, Huu Linh, et al. ''Review of the Durability of Polymer Electrolyte Membrane Fuel Cell in Long-Term Operation: Main Influencing Parameters and Testing Protocols''. *Energies.* July 2021. Available online: *https://www.mdpi.com/1996-1073/14/13/4048.*

[359] International Organization for Standardization. ''ISO 14687: 2019, Hydrogen fuel quality—Product specification''. November 2019. Available online: *https://www.iso.org/standard/69539.html.*

[360] Nhuyen, Huu Linh, et al. ''Review of the Durability of Polymer Electrolyte Membrane Fuel Cell in Long-Term Operation: Main Influencing Parameters and Testing Protocols''. *Energies.* July 2021. Available online: *https://www.mdpi.com/1996-1073/14/13/4048.*

[361] Marcinkoski, Jason et al. ''DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap—Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks. October 31, 2019. Available online: *https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.*

[362] Marcinkoski, Jason et al. ''DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap—Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks. October 31, 2019. Available online: *https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.*

[363] Deloitte China. ''Fueling the Future of Mobility: Hydrogen and fuel cell solutions for transportation, Volume 1''. 2020. Available online: *https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf.*

[364] *Ibid.*

[365] *Ibid.*

group, which are expensive but efficient and can withstand conditions in a cell. With today's technology, roughly 50 grams of platinum may be required for a 160-kW fuel cell in a vehicle.[366] Platinum group metals are classified as critical minerals in the DOE Critical Minerals and Materials Strategy.[367] Efforts are underway to minimize or eliminate the use of platinum in catalysts.[368]

ii. Fuel Cell and Battery Interaction

The instantaneous power required to move a FCEV can come from either the fuel cell stack, the battery, or a combination of both. Interactions between the fuel cell stacks and batteries of a FCEV can be complex and may vary based on application. Each manufacturer likely would employ a unique strategy to optimize the durability of these components and manage costs. The strategy selected would impact the size of the fuel cell stack and the size of the battery.

The fuel cell stack can be used to charge the battery that in turn powers the wheels (*i.e.,* series hybrid or range-extending), or it can work with the battery to provide power (*i.e.,* parallel hybrid or primary power) to the wheels. In the emerging HD FCEV market, when used to extend range, the fuel cell tends to have a lower peak power potential and may be sized to match the average power needed during a typical use cycle, including steady highway driving. At idle, the fuel cell may run at minimal power or turn off based on state of charge of the battery. The battery is used during prolonged high-power operations such as grade climbing and is typically in charge-sustaining mode, which means the average state of charge is maintained above a certain level while driving. When providing primary power, the fuel cell tends to have a larger peak power potential, sized to match all power needs of a typical duty cycle and to meet instantaneous power needs. The battery is mainly used to capture energy from regenerative braking and to help with acceleration and other transient power demands.[369]

Based on how the fuel cell stacks and batteries are managed, manufacturers may use different types of batteries in HD FCEVs. Energy battery cells are typically used to store energy for applications with distance needs, so may be used more with range-extending fuel cells in vehicles with a relatively large battery. Power battery cells are typically used to provide additional high power for applications with high power needs in primary power fuel cell-dominant vehicles.[370]

iii. Onboard Hydrogen Storage Tanks

Fuel cell vehicles carry hydrogen fuel onboard using large tanks. Hydrogen has extremely low density, so it must be compressed or liquified for use. There are various techniques for storing hydrogen onboard a vehicle, depending on how much fuel is needed to meet range requirements. Most transportation applications today use Type IV tanks,[371] which typically include a plastic liner wrapped with a composite material such as carbon fiber that can withstand high pressures with minimal weight.[372] [373] High-strength carbon fiber is expensive, accounting for over 50 percent of the cost of onboard storage at production volumes of over 100,000 tanks per year.[374]

Some existing fuel cell buses use compressed hydrogen gas at 350 bars (~5,000 pounds per square inch, or psi) of pressure, but other applications are using tanks with increased compressed hydrogen gas pressure at 700 bar (~10,000 psi) for extended driving range.[375] A Heavy-Duty Vehicle Industry Group was formed in 2019 to standardize 700 bar high-flow fueling hardware components globally that meet fueling speed requirements (*i.e.,* so that fill times are similar to comparable HD ICE vehicles, as identified in DOE technical targets for Class 8 long-haul tractor-trailers).[376] High-flow refueling rates for heavy-duty vehicles of 60–80 kg hydrogen in under 10 minutes were recently demonstrated in a DOE lab setting.[377] [378] [379]

Based on our review of the literature, we believe that most HD vehicles likely have sufficient physical space to package hydrogen storage tanks onboard.[380] Geometry and packing challenges may constrain the amount of gaseous hydrogen that can be stored onboard and, thus, the maximum range of trucks that travel longer distances without a stop for fuel.[381] Liquid hydrogen is emerging as a cost-effective onboard storage option for long-haul operations; however, the technology readiness of liquid storage and refueling technologies is relatively low compared to compressed gas technologies.[382]

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[366] James, Brian D., et al. ''Fuel Cell Truck System Cost Analysis''. Strategic Analysis Inc. July 2018. Available online: *https://www.energy.gov/sites/prod/files/2018/08/f54/fcto-truck-workshop-2018-10-james.pdf.*

[367] U.S. Department of Energy, Advanced Manufacturing & Industrial Decarbonization Office. ''Critical Minerals & Materials''. Available online: *https://www.energy.gov/eere/amo/critical-minerals-materials.*

[368] Berkeley Lab. ''Strategies for Reducing Platinum Waste in Fuel Cells. November 2021. Available online: *https://als.lbl.gov/strategies-for-reducing-platinum-waste-in-fuel-cells/.*

[369] Islam, Ehsan Sabri, Ram Vijayagopal, Aymeric Rousseau. ''A Comprehensive Simulation Study to Evaluate Future Vehicle Energy and Cost Reduction Potential'', *Report to the U.S. Department of Energy, Contract ANL/ESD-22/6.* October 2022. See Full report. Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

[370] Sharpe, Ben and Hussein Basma. ''A Meta-Study of Purchase Costs for Zero-Emission Trucks''. The International Council on Clean Transportation. February 2022. Available online: *https://theicct.org/publication/purchase-cost-ze-trucks-feb22/.*

[371] Type I–III tanks are not typically used in transportation for reasons related to low hydrogen density, metal embrittlement, weight, or cost.

[372] Langmi, Henrietta et. al. ''Hydrogen storage''. Electrochemical Power Sources: Fundamentals, Systems, and Applications. 2022. Portion available online: *https://www.sciencedirect.com/topics/engineering/compressed-hydrogen-storage.*

[373] U.S. Department of Energy, Fuel Cell Technologies Office. ''Hydrogen Storage''. March 2017. Available online: *https://www.energy.gov/sites/prod/files/2017/03/f34/fcto-h2-storage-fact-sheet.pdf.*

[374] Houchins, Cassidy and Brian D. James. ''2019 DOE Hydrogen and Fuel Cell Program Review: Hydrogen Storage Cost Analysis''. Strategic Analysis. May 2019. Available online: *https://www.hydrogen.energy.gov/pdfs/review19/st100_james_2019_o.pdf.*

[375] Basma, Hussein and Felipe Rodriquez. ''Fuel cell electric tractor-trailers: Technology overview and fuel economy''. Working Paper 2022–23. The International Council on Clean Transportation. July 2022. Available online: *https://theicct.org/wp-content/uploads/2022/07/fuel-cell-tractor-trailer-tech-fuel-jul22.pdf.*

[376] NextEnergy. ''Hydrogen Heavy Duty Vehicle Industry Group''. Available online: *https://nextenergy.org/hydrogen-heavy-duty-vehicle-industry-group/.*

[377] DOE suggests that 60 kg of H2 will be required to achieve a 750-mile range in a Class 8 tractor-trailer truck, assuming a fuel economy of 12.4 miles per kilogram. In the DOE lab, one fill (61.5 kg) was demonstrated from the fueling station into seven type-IV tanks of a HD vehicle simulator, and the second fill (75.9 kg) was demonstrated from the station into nine tanks.

[378] Marcinkoski, Jason et. al. ''DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap—Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks. October 31, 2019. Available online: *https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.*

[379] Martineau, Rebecca. ''Fast Flow Future for Heavy-Duty Hydrogen Trucks: Expanded Capabilities at NREL Demonstration High-Flow-Rate Hydrogen Fueling for Heavy-Duty Applications''. National Renewable Energy Lab. June 2022. Available online: *https://www.nrel.gov/news/program/2022/fast-flow-future-heavy-duty-hydrogen-trucks.html.*

[380] Kast, James et. al. ''Designing hydrogen fuel cell electric trucks in a diverse medium and heavy duty market''. *Research in Transportation Economics:* Volume 70. October 2018. Available online: *https://www.sciencedirect.com/science/article/pii/S0739885916301639.*

[381] Basma, Hussein and Felipe Rodriquez. ''Fuel cell electric tractor-trailers: Technology overview and fuel economy''. Working Paper 2022–23. The International Council on Clean Transportation. July 2022. Available online: *https://theicct.org/wp-content/uploads/2022/07/fuel-cell-tractor-trailer-tech-fuel-jul22.pdf.*

[382] Basma, Hussein and Felipe Rodriquez. ''Fuel cell electric tractor-trailers: Technology overview and fuel economy''. Working Paper 2022–23. The

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Nonetheless, companies like Daimler and Hyzon are pursuing onboard liquid hydrogen to minimize potential payload impacts and maintain the flexibility to drive up to 1,000 miles between refueling, comparable to today's diesel ICE vehicle refueling ranges.[383] [384] Therefore given our assessment of technology readiness, liquid storage tanks were not included as part of the technology packages that support the feasibility and appropriateness of our proposed standards. We request comment and data related to packaging space availability associated with FCEVs and projections for the development and application of liquid hydrogen in the HD transportation sector over the next decade.

iv. HD FCEV Safety Assessment

FCEVs have two potential risk factors that can be mitigated through proper design, process, and training: hydrogen and electricity. Electricity risks are identical to those of BEVs and, thus, are discussed in Section II.D.2 and DRIA Chapter 1.5.2. Hydrogen risks can occur throughout the process of fueling a vehicle. FCEVs must be designed such that hydrogen can safely be delivered to a vehicle and then transferred into a vehicle's onboard storage tanks and fuel cell stacks. Hydrogen has been handled, used, stored, and moved in industrial settings for more than 50 years, and there are many established methods for doing so safely.[385] There is also federal oversight and regulation throughout the hydrogen supply chain system.[386] Safety training and education are key for maintaining reasonable risk while handling and using hydrogen. For example, hydrogen-related fuel cell vehicle risks can be mitigated by following various SAE and OSHA standards, as discussed in DRIA Chapter 1.7.4. We request comment on our assessment that HD FCEVs can be designed to maintain safety.

4. Summary of Technology Assessment

In prior HD GHG rulemakings, EPA promulgated standards that could feasibly be met through technological improvements in many areas of the vehicle. For example, the HD GHG Phase 2 CO_2 emission standards were premised on technologies such as engine waste heat recovery, advanced aerodynamics (like those developed for DOE's SuperTruck programs), and, in some cases, hybrid powertrains. We evaluated each technology's effectiveness as demonstrated over the regulatory duty cycles using EPA's GEM and estimated the appropriate adoption rate of each technology.[387] We then developed a technology package for each of the regulatory subcategories. We are following a similar approach in this Phase 3 NPRM.

In the HD GHG Phase 2 final rule, we included ZEV technologies in our assessment of the suite of technologies for HD vocational vehicles and tractors. However, in 2016, when the HD GHG Phase 2 rule was being developed, we stated that "adoption rates for these advanced technologies in heavy-duty vehicles are essentially non-existent today and seem unlikely to grow significantly within the next decade without additional incentives." [388] Thus, at that time, instead of including ZEV technologies in the technology packages for setting the Phase 2 standards, we provided advanced technology credit multipliers to help incentivize the development of ZEV technologies.

Since the 2016 promulgation of the HD GHG Phase 2 final rule, as discussed in Section I.C, a number of important factors have contributed to changes in the HD landscape. Therefore, as detailed in this Section II and DRIA Chapter 2, we now are proposing that BEV technologies and FCEV technologies will be technically feasible for HD vehicles and suitable for most applications, as assessed by vehicle type and each Phase 3 MY. As further detailed in this Section II and DRIA Chapter 2, we are also proposing that BEV and FCEV technologies are feasible at the adoption rates included in the technology packages, which vary depending on the respective vehicle type and Phase 3 MY, and thus that the proposed revised standards for MY 2027 and proposed new standards for MYs 2028 through 2032 are feasible and appropriate. Similar to Phase 1 and Phase 2, the technology packages used to support the standards in this proposal include a mix of technologies applied to HD vehicles, and development of those technology packages included an assessment of the projected feasibility of the development and application of BEV, FCEV, and other technologies that reduce GHG emissions from HD vehicles. While our analysis in this Section II.D focuses on certain technologies in the technology packages to demonstrate the feasibility of the proposed HD vehicle GHG emission standards, there are other technologies as described in DRIA Chapter 1 that can reduce CO2 emissions. Under the proposed rule, manufacturers may choose to produce the technologies that work best for their business case and the operator's needs in meeting the proposed standards, as the proposed standards are performance-based and do not mandate any specific technology for any manufacturer or any vehicle subcategory.

EPA developed a bottom-up approach to estimate the operational characteristics and costs of ZEV technologies for this proposal. This approach takes into consideration concerns received on the HD2027 NPRM concerning the proposed revised MY 2027 GHG vehicle standards' analysis presented in the HD2027 NPRM. We developed a new technology assessment tool, Heavy-Duty Technology Resource Use Case Scenario (HD TRUCS), to evaluate the design features needed to meet the power and energy demands of various HD vehicles when using ZEV technologies, as well as costs related to manufacturing, purchasing and operating ICE and ZEV technologies. HD TRUCS is described in more detail in Section II.D.5 and DRIA Chapter 2 but we briefly summarize the approach here.

To build technology packages using HD TRUCS, we created 101 representative HD vehicles that cover the full range of weight classes within the scope of this rulemaking (Class 2b through 8 vocational vehicles and tractors). The representative vehicles cover many aspects of work performed by the industry. This work was translated into energy and power demands per vehicle type based on everyday use of HD vehicles, ranging from moving goods and people to mixing cement. We then identified the technical properties required for a BEV

International Council on Clean Transportation. July 2022. Available online: *https://theicct.org/wp-content/uploads/2022/07/fuel-cell-tractor-trailer-tech-fuel-jul22.pdf*.

[383] Daimler Truck. "Development milestone: Daimler Truck tests fuel-cell truck with liquid hydrogen". June 2022. Available online: *https://media.daimlertruck.com/marsMediaSite/en/instance/ko/Development-milestone-Daimler-Truck-tests-fuel-cell-truck-with-liquid-hydrogen.xhtml?oid=51975637*.

[384] Hyzon. "Hyzon Motors, Chart Industries to Develop Liquid Hydrogen Fuel Cell-Powered Truck, Targeting 1000-Mile Range". July 2021. Available online: *https://www.hyzonmotors.com/in-the-news/hyzon-motors-chart-industries-to-develop-liquid-hydrogen-fuel-cell-powered-truck-targeting-1000-mile-range*.

[385] Hydrogen Tools. "Best Practices Overview". Pacific Northwest National Laboratory. Available online: *https://h2tools.org/bestpractices/best-practices-overview*.

[386] Baird, Austin R. et. al. "Federal Oversight of Hydrogen Systems". Sandia National Laboratories. March 2021. Available online: *https://energy.sandia.gov/wp-content/uploads/2021/03/H2-Regulatory-Map-Report_SAND2021-2955.pdf*.

[387] GEM is an EPA vehicle simulation tool used to certify HD vehicles. A detailed description of GEM can be found in the RIA for the HD GHG Phase 2 rulemaking, available at *https://nepis.epa.gov/Exe/ZyPDF.cgi/P100P7NS.PDF?Dockey=P100P7NS.PDF*.

[388] 81 FR 73498 (October 25, 2016).

or FCEV to meet the operational needs of a comparable ICE HD vehicle.[389]

Since batteries can add weight and volume to a vehicle,[390] we evaluated battery mass and physical volume required to package a battery pack. If the performance needs of a BEV resulted in a battery that was too large or heavy, then we did not consider the BEV for that application in our technology package because of, for example, the impact on payload and, thus, potential work accomplished relative to a comparable ICE vehicle.[391]

To evaluate costs, including costs of compliance for manufacturers as well as user costs related to purchasing and operating ZEVs, we sized vehicle components that are unique to ZEVs to meet the work demands of each representative vehicle. We applied cost estimates to each vehicle component based on sizing to assess the difference in total powertrain costs between the ICE and ZEV powertrains. We accounted for the IRA battery tax credit and vehicle tax credit, as discussed in Section II.E.4. We also compared operating costs due to fuel consumption as well as vehicle maintenance and repair, and we included the cost to procure and install depot charging infrastructure for BEVs. For FCEVs, similar to ICE vehicles' infrastructure and fuel costs, we assumed hydrogen infrastructure costs were embedded in the cost of hydrogen fuel.

We relied on research and findings discussed in DRIA Chapters 1 and 2 to conduct this analysis. For MYs 2027 through 2029, we focused primarily on BEV technology. Consistent with our analysis, research shows that BEV technologies can become cost-competitive in terms of total cost of ownership for many HD vehicles by the late 2020s, but it would take longer for FCEVs.[392] [393] [394] Given that there are more BEV models available today compared to FCEV models (see, *e.g.,* DRIA Chapters 1.7.5 and 1.7.6), we inferred that BEV adoption is likely to happen sooner than the adoption of FCEV technology.

Starting in MY 2030, we also considered FCEV technology for select applications. BEV technology is more energy efficient than FCEV technology but may not be suitable for all applications, such as when the performance needs result in additional battery mass that affects payload. FCEVs are more energy efficient than diesel vehicles and can have shorter refueling times than BEVs with large batteries.[395] [396] We considered FCEVs in the technology packages for applications that travel longer distances and/or carry heavier loads (*i.e.,* for those that may be sensitive to refueling times or payload impacts). This included coach buses, heavy-haul tractors, sleeper cab tractors, and day cab tractors.

Though fuel cell technology is still emerging in HD vehicle applications, FCEVs are a viable ZEV technology for heavy-duty transportation [397] [398] [399] and will be available in the 2030 timeframe (see DRIA Chapter 1.7.5).[400] [401] [402] [403] Inclusion of FCEVs in the technology packages starting in MY 2030 takes into consideration additional lead time to allow manufacturers to design, develop, and manufacture HD FCEV models. Fuel cell technology in other sectors has been in existence for decades [404] and has been demonstrated to be technically feasible in heavy-duty transportation.[405] Interim research and development (R&D) technical targets and projects (see DRIA Chapter 1.7.7) are in place to facilitate necessary improvements in the performance, durability, and costs of hydrogen-fueled long-haul HD tractors in 2030.[406] With substantial federal investment in low-GHG hydrogen production (see DRIA Chapter 1.3.2), we project that the price of hydrogen fuel will drop enough by 2030 to make HD FCEVs cost-competitive with comparable ICE vehicles for some duty cycles. Hydrogen infrastructure is expected to need the additional time prior to MY 2030 to further develop, as discussed in greater detail in DRIA Chapter 1.8,[407] [408] but we expect the

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[389] Heavy-duty vehicles are typically powered by a diesel-fueled compression-ignition (CI) engine, though the heavy-duty market includes vehicles powered by gasoline-fueled spark-ignition (SI) engines and alternative-fueled ICEs. We selected diesel-powered ICE vehicles as the baseline vehicle for the assessment in HD TRUCS in our analysis because a diesel-fueled CI engine is broadly available for all of the 101 vehicle types.

[390] Smith, David et. al. ''Medium- and Heavy-Duty Vehicle Electrification: An Assessment of Technology and Knowledge Gaps''. U.S. Department of Energy: Oak Ridge National Laboratory and National Renewable Energy Laboratory. December 2019. Available online: *https://info.ornl.gov/sites/publications/Files/Pub136575.pdf.*

[391] This does not necessarily mean that a BEV with a large battery weight and volume would not be technically feasible for a given HD vehicle use, but rather this is an acknowledgement that we considered impacts of increased battery size on feasibility considerations like payload capacity as well as cost and payback within the selection of HD vehicle technologies for the technology packages.

[392] Ledna et. al. ''Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis''. U.S. Department of Energy, National Renewable Energy Laboratory. March 2022. Available online: *https://www.nrel.gov/docs/fy22osti/82081.pdf.*

[393] Hall, Dale and Nic Lutsey. ''Estimating the Infrastructure Needs and Costs for the Launch of Zero-Emission Trucks''. White Paper: The International Council on Clean Transportation. August 2019. Available online: *https://theicct.org/wp-content/uploads/2021/06/ICCT_EV_HDVs_Infrastructure_20190809.pdf.*

[394] Robo, Ellen and Dave Seamonds. Technical Memo to Environmental Defense Fund: Investment Reduction Act Supplemental Assessment: Analysis of Alternative Medium- and Heavy-Duty Zero-Emission Vehicle Business-As-Usual Scenarios. ERM. August 19, 2022. Available online: *https://www.erm.com/contentassets/154d08e0d0674752925cd82c66b3e2b1/edf-zev-baseline-technical-memo-addendum.pdf.*

[395] A technology is more energy efficient if it uses less energy to do the same amount of work. Energy can be lost as it moves through the vehicle's components due to heat and friction.

[396] Cunanan, Carlo et. al. ''A Review of Heavy-Duty Vehicle Powertrain Technologies: Diesel Engine Vehicles, Battery Electric Vehicles, and Hydrogen Fuel Cell Electric Vehicles''. Clean Technol. Available online: *https://www.mdpi.com/2571-8797/3/2/28.*

[397] Mihelic, Rick et. al. ''Making Sense of Heavy-Duty Hydrogen Fuel Cell Tractors''. North American Council for Freight Efficiency. December 16, 2020. Available online: *https://nacfe.org/research/electric-trucks/making-sense-of-heavy-duty-hydrogen-fuel-cell-tractors/.*

[398] Cunanan, Carlo et. al. ''A Review of Heavy-Duty Vehicle Powertrain Technologies: Diesel Engine Vehicles, Battery Electric Vehicles, and Hydrogen Fuel Cell Electric Vehicles''. *Clean Technol.* Available online: *https://www.mdpi.com/2571-8797/3/2/28.*

[399] Cullen et. al. ''New roads and challenges for fuel cells in heavy-duty transportation.'' Nature Energy. March 25, 2021. Available online: *https://www.nature.com/articles/s41560-021-00775-z.*

[400] For example, California's Advanced Clean Fleets Regulation requires that 10 percent of sleeper cab tractors and specialty vehicles must be zero-emission by 2030. We note that although our technology package consider FCEVs for specific HD applications, a diverse range of technologies may be used to comply with the proposed performance-based standards.

[401] California Air Resources Board. ''Advanced Clean Fleets Regulation Summary''. October 27, 2022. Available online: *https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary* (ACF 2030 goals).

[402] Adler, Alan. ''Hyundai's Xcient positioned for instant US fuel cell truck leadership''. *FreightWaves.* November 29, 2022. Available online: *https://www.freightwaves.com/news/hyundais-xcient-positioned-for-instant-us-fuel-cell-truck-leadership.*

[403] GNA. ''State of Sustainable Fleet: 2022 Market Brief—Fuel Cell Electric Miniguide''. 2022. Available online: *https://www.stateofsustainablefleets.com/.*

[404] U.S. Energy Information Administration. ''Hydrogen explained: Use of hydrogen''. Last updated January 20, 2022. Available online: *https://www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php.*

[405] Toyota. ''Toyota, Kenworth Prove Fuel Cell Electric Truck Capabilities with Successful Completion of Truck Operations for ZANZEFF Project''. September 22, 2022. Available online: *https://pressroom.toyota.com/toyota-kenworth-prove-fuel-cell-electric-truck-capabilities-with-successful-completion-of-truck-operations-for-zanzeff-project/.*

[406] Marcinkoski, Jason et. al. ''DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap—Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks. October 31, 2019. Available online: *https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.*

[407] U.S. Department of Energy. ''Pathways to Commercial Liftoff: Clean Hydrogen''. March 2023.

Continued

refueling needs can be met by MY 2030.[409] We also recognize that regulations, like this proposed rule, can further incentivize technology and refueling infrastructure development and deployment. Therefore, we included FCEVs in our technology assessment beginning in MY 2030, which is our best projection after considering the IRA incentives related to hydrogen as a transportation fuel and FCEVs, DOE's hydrogen assessments, and other information discussed here in Section II and in DRIA Chapter 1.

After considering operational characteristics and costs in 2021 dollars, we determined the payback period, which is the number of years it would take to offset any incremental cost increase of a ZEV over a comparable ICE vehicle. Lastly, technology adoption rates for BEVs or FCEVs for the technology packages were selected based on the payback period. We request comment on this approach and any supporting data on the potential for these and additional technologies to be available in the HD market in the MY 2027 through MY 2032 timeframe.

5. EPA's HD TRUCS Analysis Tool

For this proposal, EPA developed an analysis tool, HD TRUCS, to evaluate the design features needed to meet the energy and power demands of various HD vehicle types when using ZEV technologies. The overarching design and functionality of HD TRUCS is premised on ensuring each of the 101 ZEV types could perform the same work as its ICE counterpart. We did this by sizing the BEV and FCEV components such that they could meet the driving demands based on the 90th percentile daily VMT for each application, while also accounting for the HVAC and battery thermal conditioning load requirements in hot and cold weather and any PTO demands for the vehicle. Furthermore, we accounted for the fact that the usable battery capacity is less than 100 percent and that batteries deteriorate over time. We also sized the ZEV powertrains to ensure that the vehicles would meet an acceptable level of acceleration from a stop and be able to maintain a cruise speed while going up a hill at six-percent grade. In this subsection, we discuss the primary inputs used in HD TRUCS. Additional details on HD TRUCS can be found in DRIA Chapter 2. We welcome comment on all aspects of HD TRUCS.

i. Vehicles Analyzed

We developed inputs for 101 different vehicle types for our assessment in HD TRUCS. This encompasses 22 different applications in the HD vehicle market, as shown in Table II–3. These vehicles applications are further differentiated by weight class, duty cycle, and daily vehicle miles traveled (VMT) for each of these vehicle applications into 101 vehicle types. These 101 vehicle types cover all 33 of the heavy-duty regulatory subcategories, as shown in DRIA Chapter 2.8.3.1. The initial list of HD TRUCS vehicles contained 87 vehicle types and was based on work the Truck and Engine Manufacturers Association (EMA) and California Air Resources Board (CARB) conducted for CARB's ACT rule.[410] We consolidated the list; eliminated some of the more unique vehicles with small populations like mobile laboratories; and assigned operational characteristics that correspond to the Urban, Multi-Purpose, and Regional duty cycles used in GEM. We also added additional vehicle types to reflect vehicle applications that were represented in EPA's certification data. Chapter 2.1 of the DRIA summarizes the 101 unique vehicle types represented in HD TRUCS and how they are categorized, each with a vehicle identifier, vehicle application, vehicle weight class, MOtor Vehicle Emission Simulator (MOVES) SourceTypeID and RegClassID,[411] and GEM duty cycle category. We request comment on our approach, including our categorization of vehicle types and applications in the data, and whether there are additional specific vehicle types we should include in our assessment.

TABLE II–3—HD VEHICLE APPLICATIONS INCLUDED IN HD TRUCS

Ambulance.
Box Truck.
Cement Mixer.
Coach Bus.
Dump Truck.
Fire Truck.
Flatbed/Stake Truck.
Port Drayage Tracto.
Refuse Truck.
RV.
School Bus.
Shuttle bus.
Snow Plow.
Step Van.
Street Sweeper.
Tanker Truck.
Tow Truck.
Tractor, Day Cab.
Tractor, Sleeper Cab.
Transit Bus.
Utility Truck.
Yard Tractor.

Heavy-duty vehicles are typically powered by a diesel-fueled compression-ignition (CI) engine, though the heavy-duty market also includes vehicles powered by gasoline-fueled spark-ignition (SI) engines and alternative-fueled ICE. We selected diesel-powered ICE vehicles as the baseline vehicle for the assessment in HD TRUCS in our analysis because a diesel-fueled CI engine is broadly available for all of the 101 vehicle types and are more efficient than SI engines. Chapter 2.2 of the DRIA includes the details we developed for each of the baseline vehicles, including the size of the engine and the transmission type. This information was used to determine the weight and the cost of the ICE powertrains.

In the analysis, for MYs 2027 through 2029, we focused primarily on BEV technology. Starting in MY 2030, we also considered FCEV technology for select applications that travel longer distances and/or carry heavier loads. This included coach buses, heavy-haul tractors, sleeper cab tractors, and day cab tractors that are designed to travel longer distances. We request comment on our approach that focuses primarily on BEVs, which currently are more prevalent in the HD vehicle market, and whether there are additional vehicle types that should be evaluated as FCEVs along with BEVs.

ii. Vehicle Energy Demand

Vehicles require energy to perform the work required of the vehicle. This work includes driving, idling, and providing heating and cooling; in addition, some vehicles require energy to operate equipment. Vehicles with regenerative braking systems have the opportunity to recover some of the kinetic energy that would otherwise be lost during braking. There are a wide variety of energy demands across the heavy-duty sector, depending on the vehicle's application. For example, some vehicles, such as long-haul tractors, spend the vast

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Available online: *https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf.*

[408] The proposed rule projects that hydrogen consumption from FCEVs will be a small proportion of total low-GHG hydrogen production expected in 2030: from 1.3% in 2030 to 8.3% in 2032.

[409] U.S. Department of Energy. "DOE National Clean Hydrogen Strategy and Roadmap". Draft September 2022. Available online: *https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf.*

[410] California Air Resources Board, Appendix E: Zero Emission Truck Market Assessment (2019), *available at https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/appe.pdf* (last accessed on Sept. 26, 2022).

[411] MOVES homepage: *https://www.epa.gov/moves* (last accessed October 2022).

majority of the time driving, a fraction of the time idling, and require heating and cooling of the cabin, but do not require operation of additional equipment. A transit bus typically operates at low speeds, so it requires less energy for driving than a long-haul tractor, but requires more energy for heating or cooling due to its large amount of interior cabin volume. Unlike ICE vehicles where the cabin heating is often provided by excess heat from the main ICE, BEVs do not have excess heat from an ICE to utilize in this manner and thus require more energy than ICE vehicles to heat the cabin and additional energy to manage the temperature of the batteries. As another example of the wide variety of energy demands for HD vehicles, a utility truck, also known as a bucket truck, may only drive a few miles to a worksite while idling for the majority of the day and using energy to move the bucket up and down. The power to run the separate equipment on ICE vehicles is typically provided by a PTO from the main engine. In HD TRUCS, we determined the daily energy demand for each of the 101 vehicle types by estimating both the baseline energy demands that are similar regardless of the powertrain configuration and the energy demands that vary by powertrain. The baseline energy includes energy at the axle to move the vehicle, energy recovered from regenerative braking energy, and PTO energy. Powertrain-specific energy includes energy required to condition the battery and heat or cool the cabin using a heating, ventilation, and air conditioning (HVAC) system. We discuss each of these in the following subsections.

a. Baseline Energy

The amount of energy needed at the axle to move the vehicle down the road is determined by a combination of the type of drive cycle (such as urban or freeway driving) and the number of miles traveled over a period of time. For each HD TRUCS vehicle type, we determined the baseline energy consumption requirement that would be needed for each of the ZEV applications. To do this, we used the drive cycles and cycle weightings adopted for HD GHG Phase 2 for our assessment of the energy required per mile for each vehicle type. EPA's GEM model simulates road load power requirements for various duty cycles to estimate the energy required per mile for HD vehicles. To understand the existing heavy-duty industry, we performed an analysis on current heavy-duty vehicles in the market in order to determine typical power requirements and rates of energy consumption at the axle. These values represent the energy required to propel a vehicle of a given weight, frontal area, and tire rolling resistance to complete the specified duty cycle on a per-mile basis, independent of the powertrain. In DRIA Chapter 2.2.2, we describe the GEM inputs and results used to estimate the propulsion energy and power requirements at the axle for ICE vehicles on a per-mile basis. We also used these inputs, along with some simple electric vehicle assumptions, to develop a model for electric vehicles to calculate weighted percent of energy recovery due to regenerative braking. Additional detail can be found in DRIA Chapter 2.2.2.1.3. We request comment on our approach, including other data we should consider in our assessment of energy consumption.

Some vocational vehicles have attachments that perform work, typically by powering a hydraulic pump, which are powered by PTOs. Information on in-use PTO energy demand cycles is limited. NREL published two papers describing investigative work into PTO usage and fuel consumption.[412] [413] These studies, however, were limited to electric utility vehicles, such as bucket trucks and material handlers. To account for PTO usage in HD TRUCS, we chose to rely on a table described in California's Diesel Tax Fuel Regulations, specifically in Regulation 1432, “Other Nontaxable Uses of Diesel Fuel in a Motor Vehicle,” [414] that covers a wider range of vehicles beyond the electric utility vehicles in the referenced NREL studies. This table contains “safe-harbor” percentages that are presumed amounts of diesel fuel used for “auxiliary equipment” operated from the same fuel tank as the motor vehicle. We used this source to estimate PTO energy use as a function of total fuel consumed by vehicle type, as discussed in DRIA Chapter 2.2.2.1.4. We request additional data that could be considered in our assessment of PTO loads in our final rulemaking assessment.

Within HD TRUCS, we calculated the total energy needed daily based on a daily VMT for each vehicle type. We used multiple sources to develop the VMT for each vehicle. Daily VMT for each vehicle came from one of five **Sources:** the NREL FleetDNA database, a University of California-Riverside (UCR) database, the 2002 Vehicle Inventory and Use Survey (VIUS), the CARB Large Entity Report, or an independent source specific to an application, as discussed in DRIA Chapter 2.2.1.2.[415] Each vehicle type was assigned a 50th percentile or average daily VMT [416] that was used to estimate operational costs, such as average annual fuel, hydrogen, or electricity costs, and maintenance and repair costs (see DRIA Chapters 2.3.4, 2.4.4, and 2.5.3). We also account for the change in use of the vehicle over the course of its ownership and operation in HD TRUCS by applying a MOVES-based VMT ratio based on vehicle age to the 50th percentile VMT to arrive at a 10 year average VMT, as described in more detail in DRIA Chapter 2.2.1.2.2. We also developed a 90th percentile daily VMT and used it in HD TRUCS to size ZEV components, such as batteries, and estimate the size requirements for EVSE. We selected the 90th percentile daily VMT data because we project that manufacturers will design their BEVs to meet most daily VMT needs, but not the most extreme operations. BEVs designed for all daily VMT needs would be unnecessarily heavy and expensive for most operations, which would limit their appeal in the broad market. Please see DRIA Chapter 2.2.1.2 for the complete list of VMT for each of the 101 vehicle types. We request comment, including comment with data, on our VMT assessments.

b. Powertrain-Specific Energy

Heating, ventilation, and air conditioning (HVAC) requirements vary by vehicle type, location, and duty cycle. The HVAC energy required to heat and cool interior cabins is considered separately from the baseline energy in HD TRUCS, since these energy loads are not required year-round or in

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[412] NREL, Characterization of PTO and Idle Behavior for Utility Vehicles, Sept 2017. Available online: *https://www.nrel.gov/docs/fy17osti/66747.pdf.*

[413] NREL, Fuel and Emissions Reduction in Electric Power Take-Off Equipped Utility Vehicles, June 2016. Available online: *https://www.nrel.gov/docs/fy17osti/66737.pdf.*

[414] *See* Cal. Code Regs. tit. 18, § 1432, “Other Nontaxable Uses of Diesel Fuel in a Motor Vehicle,” *available at https://www.cdtfa.ca.gov/lawguides/vol3/dftr/dftr-reg1432.html.*

[415] NREL and EPA. Heavy-Duty Vehicle Activity for EPA MOVES. Available at *https://data.nrel.gov/submissions/168,* last accessed on October 15, 2022, which includes an assessment of both the NREL and UC-Riverside databases; U.S. Census Bureau. 2002 Vehicle Inventory and Use Survey. *https://www.census.gov/library/publications/2002/econ/census/vehicle-inventory-and-use-survey.html,* last accessed on October 15, 2022. CARB. Large Entity Reporting. Available at *https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks/large-entity-reporting.*

[416] We used the 50th percentile as a proxy for average VMT from the NREL FleetDNA database and the UC-Riverside database. The NREL and UC-Riverside databases each contained a selection of vehicles that we used to calculate 50th and 90th percentile daily VMT. When each database had a VMT value, the values were averaged to get VMT for a specific market segment. See DRIA Chapter 2.2.1.2 for further details.

all regions of the country. Nearly all commercial vehicles are equipped with heat and basic ventilation and most vehicles are equipped with air conditioning (A/C). In ICE vehicles, traditional cabin heating uses excess thermal energy produced by the main ICE. This is the only source of cabin heating for many vehicle types. Additionally, on ICE vehicles, cabin A/C uses a mechanical refrigerant compressor that is engine belt-driven.

For BEVs, the energy required for thermal management is different than for ICE vehicles. First, the loads for HVAC are different because the vehicle is not able to be heated from excess heat from the engine. In this analysis, we project HD BEVs would be equipped with either a positive temperature coefficient (PTC) electric resistance heater with traditional A/C, or a full heat pump system, as described in DRIA Chapter 1. The vehicle's battery is used to power either system, but heat pumps are many times more efficient than PTC heaters. Given the success and increasing adoption of heat pumps in light-duty EVs, we believe that heat pumps will be the more commonly used technology and thus assume the use of heat pumps in HD TRUCS.

To estimate HVAC energy consumption of BEVs in HD TRUCS, we performed a literature and market review. Even though there are limited real-world studies, we agreed with the HVAC modeling-based approach described in Basma et. al.[417] This physics-based cabin thermal model considers four vehicle characteristics: the cabin interior, walls, materials, and number of passengers. The authors modeled a Class 8 electric transit bus with an HVAC system consisting of two 20-kW reversible heat pumps, an air circulation system, and a battery thermal management system. We used their estimated HVAC power demand values as a function of temperature, resembling a parabolic curve, where hotter and colder temperatures require more power with the lowest power demand between 59 to 77 °F.

The power required for HVAC in HD TRUCS is based on a Basma et. al study that determined the HVAC power demand across a range of ambient temperatures.[418] We created three separate ambient temperature bins: one for heating (less than 55 °F), one for cooling (greater than 80 °F), and one for a temperature range that requires only ventilation (55–80 °F). In HD TRUCS, we already accounted for the energy loads due to ventilation in the axle loads, so no additional energy consumption is applied here for the ventilation-only operation. We then weighted the power demands by the percent HD VMT traveled at a specific temperature range. The results of the VMT-weighted HVAC power demand for a Class 8 Transit Bus are shown in Table II–4. We request comment on and data to support other approaches to quantify the HVAC energy demand in BEVs, including the ambient temperature ranges where heating and cooling are utilized.

TABLE II–4—HD TRUCS VMT-WEIGHTED HVAC POWER DEMAND OF A CLASS 8 TRANSIT BUS

	Temperature (°F)	Consumption (kW)
Heating	<55	5.06
Ventilation	55–80	0.00
Cooling	>80	3.32

Lastly, HVAC load is dependent on cabin size—the larger the size of the cabin, the greater the HVAC demand. The values for HVAC power demand shown in Table II–4 represent the power demand to heat or cool the interior of a Class 8 Transit bus. However, HD vehicles have a range of cabin sizes; therefore, we developed scaling ratios relative to the cabin size of a Class 8 bus. Each vehicle's scaling factor is based on the surface area of the vehicle compared to the surface area of the Class 8 bus. For example, a Class 4–5 shuttle bus has a cabin size ratio of 0.6, in this case, the heating demand for the vehicle will be 3.04 kW and the cooling demand would be 1.99 kW. The adjustment ratio for buses and ambulances are between 0.3–0.6, while the cabin size for remaining HDVs have a similar cabin to a mid-size light duty vehicle and therefore, a single average scaling factor of 0.2 was applied to all remaining vehicle types.[419] We welcome data to support these or other cabin size scaling factors.

Fuel cell stacks produce excess heat during the conversion of hydrogen to electricity, similar to an ICE during combustion. This excess heat can be used to heat the interior cabin of the vehicle. In HD TRUCS, we already accounted for the energy loads due to ventilation in the axle loads, so no additional energy consumption is applied to FCEV for heating operation. Therefore, for FCEV energy consumption in HD TRUCS, we only include additional energy requirements for air conditioning (*i.e.* not for heating).[420] As described in DRIA Chapter 2.4.1.1.1, we assigned a power demand of 3.32 kW for powering the air conditioner on a Class 8 bus. The A/C loads are then scaled by the cabin volume for other vehicle applications in HD TRUCS and applied to the VMT fraction that requires cooling, just as we did for BEVs.

BEVs have thermal management systems to maintain battery core temperatures within an optimal range of approximately 68 to 95 degrees Fahrenheit (F).[421] In HD TRUCS, we accounted for the battery thermal management energy demands as a function of ambient temperature based on a Basma et. al study.[422] As described in DRIA Chapter 2.4.1.1.3, we determined the amount of energy consumed to heat the battery with cabin air when it is cold outside (less than 55 °F) and energy consumed to cool the battery when it is hot outside (greater than 80 °F) with refrigerant cooling. For the ambient temperatures between these two regimes, we agreed with Basma, et. al that only ambient air cooling is required for the batteries, which requires no additional load. We first determined a single VMT-weighted power consumption value for battery heating and a value for battery cooling based on the MOVES HD VMT distribution, based on the same method used for HVAC. Then, we determined the energy required for battery conditioning required for eight hours of daily operation and expressed it in terms of percent of total battery size. Table II–5 shows the energy consumption for battery conditioning for both hot and cold ambient temperatures, expressed as a percentage of battery capacity, used in HD TRUCS. We request additional data on the battery thermal management loads for HD BEVs.

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[417] Basma, Hussein, Charbel Mansour, Marc Haddad, Maroun Nemer, Pascal Stabat. ''Comprehensive energy modeling methodology for battery electric buses''. Energy: Volume 207, 15 September 2020, 118241. Available online: *https://www.sciencedirect.com/science/article/pii/S0360544220313487.*

[418] It should be noted that Basma model has discrete values in Celsius and MOVES data has discrete values in Fahrenheit. The Basma discrete values in the Basma model is fitted to a parabolic curve and converted into Fahrenheit to best fit the VMT distribution that is available in MOVES.

[419] The interior cabin where the driver and passengers sit are heated while where the cargo is stored is not heated.

[420] FCEVs use waste heat from the fuel cell for heating, and that ventilation operates the same as it does for an ICE vehicle.

[421] Basma, Hussein, Charbel Mansour, Marc Haddad, Maroun Nemer, Pascal Stabat. ''Comprehensive energy modeling methodology for battery electric buses''. Energy: Volume 207, 15 September 2020, 118241. Available online: *https://www.sciencedirect.com/science/article/pii/S0360544220313487.*

[422] Ibid.

TABLE II–5—BATTERY CONDITIONING ENERGY CONSUMPTION

	Ambient temperature (°F)	Energy consumption (%)
Battery Heating	<55	1.9
Battery Cooling	>80	4.2

iii. BEV Component Sizing and Weight

We used HD TRUCS to determine the size of two of the major components in a BEV—the battery and the motor. The size of these components is determined by the energy needs of the specific vehicle to meet its daily operating requirements. In this subsection, we also discuss our method to evaluate the payload and packaging impact of the battery.

a. Battery

First, in HD TRUCS, we based the size of the battery on the daily demands on the vehicle to perform a day's work, based on the 90th percentile VMT (sizing VMT). As described in the Vehicle Energy Demand subsection, this daily energy consumption is a function of miles the vehicle is driven and the energy it consumes because of: (1) moving the vehicle per unit mile, including the impact of regenerative braking, and PTO energy requirements and (2) battery conditioning and HVAC energy requirements. Then we also accounted for the battery efficiency, depth of discharge, and deterioration in sizing of the batteries for BEVs in HD TRUCS.

The daily energy consumption of each BEV in HD TRUCS is determined by applying efficiency losses to energy consumption at the axle, as described in DRIA Chapter 2.4.1.1.3. We have accounted for these losses in the battery, inverter, and e-motor before the remaining energy arrives at the axle, as shown in Table II–6. We request comment, including data, on our approach and the results for our assessment of system efficiencies for HD BEV components.

TABLE II–6—BEV COMPONENT EFFICIENCIES USED IN HD TRUCS

Component	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 (%)
Battery	95	95	95	95	95	95
Inverter	97.0	97.0	97.0	97.5	97.5	97.5
E-Motor	94.5	94.5	94.5	95.0	95.0	95.0
Total System Efficiency	*87*	*87*	*87*	*88*	*88*	*88*

Next, we oversized the battery to account separately for the typical usable amount of battery and for battery deterioration over time. We sized the battery limiting the battery to a maximum depth of discharge of 80 percent, recognizing that manufacturers and users likely would not allow the battery capacity to be depleted beyond 80 percent of original capacity. We also accounted for deterioration of the battery capacity over time by oversizing the battery by 20 percent, assuming only 80 percent of the battery storage is available throughout its life. Therefore, the battery sizes we used in our assessment are conservative because they could meet 100 percent of the daily operating requirement using the 90th percentile VMT at the battery end of life. This is described in greater detail in DRIA Chapter 2.4.1.1 and 2.7.5.4. We request comment on approach and results for the useable battery range and battery deterioration for HD BEVs that we could consider for our final rule analysis.

b. Motor

We determined the size of the motor for each BEV based on the peak power of the transient cycle and highway cruise cycles, the vehicle's ability to meet minimum performance targets in terms of acceleration rate of the vehicle, and the ability of the vehicle to maintain speed going up a hill. As described in DRIA Chapter 2.4.1.2, we estimated a BEV motor's peak power needs to size the e-motor, after considering the peak power required during the ARB transient cycle [423] and performance targets included in ANL's Autonomie model [424] and in Islam et al.,[425] as indicated in Table II–7. We assigned the target maximum time to accelerate a vehicle from stop to 30 mph and 60 mph based on weight class of each vehicle. We also used the criteria that the vehicle must be able to maintain a specified cruise speed while traveling up a road with a 6 percent grade, as shown in Table II–7. In the case of cruising at 6 percent grade, the road load calculation is set at a constant speed for each weight class bin on a hill with a 6 percent incline. We determined the required power rating of the motor as the greatest power required to drive the vehicle over the ARB transient test cycle, at 55 mph and 65 mph constant cruise speeds, or at constant speed at 6 percent grade, and then applied losses from the e-motor. We request comment on our approach using these performance targets.

TABLE II–7—ANL PERFORMANCE TARGETS

	Vocational				Tractors	
Weight Class Bin	2b–3	4–5	6–7	8	7	8
0–30 mph Time (s)	7	8	16	20	18	20
0–60 mph Time (s)	25	25	50	100	60	100

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[423] EPA uses three representative duty cycles for calculating CO_2 emissions in GEM: transient cycle and two highway cruise cycles. The transient duty cycle was developed by the California Air Resources Board (CARB) and includes no grade—just stops and starts. The highway cruise duty cycles represent 55-mph and 65-mph vehicle speeds on a representative highway. They use the same road load profile but at different vehicle speeds, along with a percent grade ranging from −5 percent to 5 percent.

[424] Islam, Ehsan Sabri. Ram Vijayagopal, Ayman Moawad, Namdoo Kim, Benjamin Dupont, Daniela Nieto Prada, Aymeric Rousseau, "A Detailed Vehicle Modeling & Simulation Study Quantifying Energy Consumption and Cost Reduction of Advanced Vehicle Technologies Through 2050," *Report to the U.S. Department of Energy, Contract ANL/ESD–21/10,* October 2021. See previous reports and analysis: 2021. Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

[425] Islam, Ehsan Sabri, Ram Vijayagopal, Aymeric Rousseau. "A Comprehensive Simulation Study to Evaluate Future Vehicle Energy and Cost Reduction Potential", Report to the U.S. Department of Energy, Contract ANL/ESD–22/6, October 2022. Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

TABLE II–7—ANL PERFORMANCE TARGETS—Continued

Cruise Speed (mph) @ 6% grade	65	55	45	25	30	30

c. Battery Weight and Volume

Performance needs of a BEV can result in a battery that is so large or heavy that it impacts payload and, thus, potential work accomplished relative to a comparable ICE vehicle. We determined the battery weight and physical volume for each vehicle application in HD TRUCS using the specific energy and energy density of the battery for each battery capacity. As described in DRIA Chapter 2.4.2, to determine the weight impact, we used battery specific energy, which measures battery energy per unit of mass. While battery technologies have made tremendous advancements in recent years, it is well known that current automotive batteries add mass to the vehicle. Our values for the specific energy of battery packs with lithium-ion cell chemistries are based on Autonomie.[426] The values we used in HD TRUCS are shown in Table II–8.

TABLE II–8—BATTERY PACK-LEVEL SPECIFIC ENERGY IN HD TRUCS (WH/KG)

Model year	2027	2028	2029	2030	2031	2032
Specific Energy (Wh/kg)	199	203	208	213	218	223

To evaluate battery volume and determine the packaging space required for each HD vehicle type, we used battery energy density. We also estimated the battery's width using the wheelbase and frame depths.

Battery energy density (also referred to as volumetric energy density) measures battery energy per unit of volume. This value was not available as a part of the Autonomie; however, the overall trend of energy density shows a linear correlation with specific energy. In this analysis, we determined the energy density is 2.5 times that of specific energy, as shown in Table II–9.

TABLE II–9—BATTERY PACK LEVEL ENERGY DENSITY IN HD TRUCS (WH/L)

Model year	2027	2028	2029	2030	2031	2032
Specific Energy (Wh/L)	496	508	521	533	545	557

We request comment on our approach and results as well as comment and data on current and projected levels of battery-specific energy and battery-specific density values for HD vehicles.

Heavy-duty vehicles are used to perform work, such as moving cargo or carrying passengers. Consequently, heavy-duty vehicles are sensitive to increases in vehicle weight and carrying volume. To take this into account, we also evaluated BEVs in terms of the overall impact on payload-carrying ability and battery packaging space. The results of this analysis can be found in DRIA Chapters 2.4.2 and 2.8.1. We found that the extra weight of the batteries for applications such as coach buses and tractors that travel long distances could have an impact on operations of these vehicles as BEVs. Therefore, for applications where our analysis showed that BEVs impacted the payload capacity by over 30 percent, we assessed fuel cell technology. In this proposal we are using a single technology package that supports the feasibility of the proposed standards, but we recognize the potential of BEVs in the applications where we evaluate FCEVs, as demonstrated by the development of a long-haul battery electric tractor by Tesla.

iv. Charging Infrastructure for BEVs

Charging infrastructure represents a key element required for HD BEV operation. More charging infrastructure will be needed to support the growing fleet of HD BEVs. This will likely consist of a combination of (1) depot charging—with infrastructure installed in parking depots, warehouses, and other private locations where vehicles are parked off-shift (when not in use), and (2) en-route charging, which provides additional electricity for vehicles during their operating hours.

In draft RIA Chapters 2.6 and 2.7.7 we describe how we accounted for charging infrastructure in our analysis of HD BEV technology feasibility and adoption rates for MYs 2027–2032. For this analysis, we estimate infrastructure costs associated with depot charging to fulfill each BEV's daily charging needs off-shift with the appropriately sized electrical vehicle supply equipment.[427] This approach reflects our expectation that many heavy-duty BEV owners will opt to purchase and install EVSE at depots; accordingly, we explicitly account for all of these upfront costs in our analysis. By contrast, we do not estimate upfront hardware and installation costs for public and other en-route electric charging infrastructure because the BEV charging needs are met with depot charging in our analysis. Discussion of private sector infrastructure investments and charging deployment projects is included in DRIA Chapter 1.6.2. We request comment on this analytical approach.

Vehicle owners with return-to-base operations who choose to install depot charging equipment have many options from which to select. This includes AC

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[426] Islam, Ehsan Sabri. Ram Vijayagopal, Ayman Moawad, Namdoo Kim, Benjamin Dupont, Daniela Nieto Prada, Aymeric Rousseau, ''A Detailed Vehicle Modeling & Simulation Study Quantifying Energy Consumption and Cost Reduction of Advanced Vehicle Technologies Through 2050,'' *Report to the U.S. Department of Energy, Contract ANL/ESD–21/10,* October 2021. See previous reports and analysis: 2021. Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

[427] We sized EVSE to meet vehicles' daily electricity consumption (kWh/day) based on the 90th percentile VMT.

or DC charging, power level, as well as the number of ports and connectors per charging unit, connector type(s), communications protocols, and additional features such as vehicle-to-grid capability (which allows the vehicle to supply energy back to the grid). Many of these selections will impact EVSE hardware and installation costs, with power level as one of the most significant drivers of cost. While specific cost estimates vary across the literature, higher-power charging equipment is typically more expensive than lower-power units. For this reason, we have chosen to evaluate infrastructure costs separately for four different, common charging types in our depot charging analysis: AC Level 2 (19.2 kW) and 50 kW, 150 kW, and 350 kW DC fast charging (DCFC).

How long a vehicle is off-shift and parked at a depot, warehouse, or other home base each day is a key factor for determining which charging type(s) could meet its needs. The amount of time available at the depot for charging (dwell time) will depend on a vehicle's duty cycle. For example, a school bus or refuse truck may be parked at a depot in the afternoon and remain there until the following morning whereas a transit bus may continue to operate throughout the evening. Even for a specific vehicle, off-shift dwell times may vary between weekends and weekdays, by season, or due to other factors that impact its operation. The 101 vehicle types in our analysis span a wide range of vehicle applications and duty cycles, and we expect their off-shift dwell times at depots to vary accordingly. As described in DRIA Chapter 2.6.4.1, in order to better understand what an average depot dwell time might look like, we examined a dataset with engine start and off times for 564 commercial vehicles. We used the longest time the vehicle engine was off each day as a rough proxy for depot dwell time, finding the average across all 564 vehicles to be over 14 hours, with proxy dwell times for most of the seven vehicle categories examined rounding to 12 hours or longer. However, assigning specific dwell times for each of the 101 vehicle types in our analysis is challenging due a lack of comprehensive datasets on parking times and locations, and, as further detailed in DRIA Chapter 2.6.4.1, we acknowledge limitations in the approach and dataset we examined. Given these uncertainties, we used an off-shift dwell time for all vehicle types of 12 hours for the purpose of selecting charging equipment at depots in our analysis.

v. FCEV Component Sizing

To compare diesel-fueled HD ICE vehicles and HD FCEV technology costs and performance in HD TRUCS, this section explains how we define HD FCEVs based on the performance and use criteria in DRIA Chapter 2.2 (that we also used for HD BEVs, as explained in Section D.5.ii). We determined the e-motor, fuel cell stack, and battery pack sizes to meet the power requirements for each of the eight FCEVs represented in HD TRUCS. We also estimated the size of the onboard fuel tank needed to store the energy, in the form of hydrogen, required to meet typical range and duty cycle needs. See DRIA Chapter 2.5 for further details. We request comment, including data, on our approach and results from our assessment of HD FCEV component sizing.

a. E-Motor

As discussed in DRIA Chapter 2.4.1.2, the electric motor (e-motor) is part of the electric drive system that converts the electric power from the battery or fuel cell into mechanical power to move the wheels of the vehicle. In HD TRUCS, the e-motor was sized for a FCEV like it was sized for a BEV—to meet peak power needs of a vehicle, which is the maximum power to drive the ARB transient cycle, meet the maximum time to accelerate from 0 to 30 mph, meet the maximum time to accelerate from 0 to 60 mph, and maintain a set speed up a six-percent grade. Additional power was added to account for e-motor efficiency losses using the same e-motor efficiency losses calculated and applied for BEVs, as discussed in DRIA Chapter 2.4.1.1.3.

b. Fuel Cell Stack

Vehicle power in a FCEV comes from a combination of the fuel cell (FC) stack and the battery pack. The FC stack behaves like the internal combustion engine of a hybrid vehicle, converting chemical energy stored in the hydrogen fuel into useful work. The battery is charged by power derived from regenerative braking, as well as excess power from the FC stack. Some FCEVs are designed to primarily rely on the fuel cell stack to produce the necessary power, with the battery exclusively used to capture energy from regenerative braking. Other FCEVs are designed to store more energy in a battery to meet demand during situations of high-power need.[428] [429]

While much of FCEV design is dependent on the use case of the vehicle, manufacturers also balance the cost of components such as the FC stack, the battery, and the hydrogen fuel storage tanks. For the purposes of this HD TRUCS analysis, we focused on proton-exchange membrane (PEM) fuel cells that use energy battery cells, where the fuel cell and the battery were sized based on the demands of the vehicle. In HD TRUCS, the fuel cell stack was sized either to reach the 90th percentile of power required for driving the ARB transient cycle or to maintain a constant highway speed of 75 mph. The 90th percentile power requirement was used to size the fuel cells of vocational vehicles. For sleeper and day cabs, the fuel cell was sized using the power required to drive at 75 mph with 80,000-pound gross combined vehicle weight (GCVW).

To avoid undersizing the fuel cell stack, we applied efficiency values to account for losses that take place before the remaining energy arrives at the axle. The same battery and inverter efficiencies from Table II–10 were used for the FCEV calculations. Fuel cell stack efficiency losses are due to the conversion of onboard hydrogen to electricity. The DOE technical targets for Class 8 long-haul tractor-trailers are to reach 68 percent peak efficiency by around 2030 (this is the interim target; the ultimate target is to reach 72 percent efficiency).[430] [431] Table II–10 shows the fuel cell efficiency values that we used for MYs 2027–2032 in HD TRUCS, which are slightly more conservative yet include expected improvements over time. We averaged the high-tech peak efficiency estimates with low-tech peak efficiency estimates from ANL's 2022 Autonomie [432] for 2025, 2030, and 2035

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[428] Note that ANL's analysis defines a fuel cell hybrid EV as a battery-dominant vehicle with a large energy battery pack and a small fuel cell, and a fuel cell EV as a fuel cell-dominant vehicle with a large fuel cell and a smaller power battery. Ours is a slightly different approach because we consider a fuel cell-dominant vehicle with a battery with energy cells. We took this approach because energy cell batteries are less expensive to manufacture than power cell batteries.

[429] Islam, Ehsan Sabri, Ram Vijayagopal, Aymeric Rousseau. ''A Comprehensive Simulation Study to Evaluate Future Vehicle Energy and Cost Reduction Potential'', *Report to the U.S. Department of Energy, Contract ANL/ESD–22.6.* October 2022. See Full report. Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

[430] According to DOE, ultimate targets are ''based on 2050 simple cost of ownership assumptions and reflects anticipated timeframe for market penetration''.

[431] Marcinkoski, Jason et. al. ''DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap—Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks. October 31, 2019. Available online: *https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.*

[432] Islam, Ehsan Sabri, Ram Vijayagopal, Aymeric Rousseau. ''A Comprehensive Simulation Study to Evaluate Future Vehicle Energy and Cost Reduction Potential'', *Report to the U.S. Department of Energy,*

Continued

for available vehicle types. We then linearly interpolated these averaged values to calculate values for each year.

linearly interpolated these averaged values to calculate values for each year.

TABLE II–10—FCEV FUEL CELL EFFICIENCIES FOR MY 2027–2032

Component	2027 (%)	2028 (%)	2029 (%)	2030 (%)	2031 (%)	2032 (%)
Fuel Cell	64.5	64.5	64.5	66.0	66.0	66.0

c. Battery Pack

As described in DRIA Chapter 2.5.1.1.3, in HD TRUCS, the battery power accounts for the difference between the power demand of the e-motor at any moment and the maximum power output of the fuel cell stack. We sized the battery to meet these power needs in excess of the fuel cell stack's capability only when the fuel cell cannot provide sufficient power. In our analysis, the remaining power needs are sustained for a duration of 10 minutes (*e.g.,* to assist with a climb up a steep hill).

d. Onboard Hydrogen Storage Tank

A FCEV is re-fueled like a gasoline or diesel-fueled vehicle. We determined the capacity of the onboard hydrogen energy storage system using an approach like the BEV methodology for battery pack sizing in DRIA Chapter 2.4.1.1, but we based the amount of hydrogen needed on the daily energy consumption needs of a FCEV.

As described in DRIA Chapter 2.5.1.2, we converted FCEV energy consumption (kWh) into hydrogen weight using an energy content of 33.33 kWh per kg of hydrogen. In our analysis, 95 percent of the hydrogen in the tank (''usable H2'') can be accessed. This is based on targets for light-duty vehicles, where a 700-bar hydrogen fuel tank with a capacity of 5.9 kg has 5.6 kg of usable hydrogen.[433] Furthermore, we added an additional 10 percent to the tank size in HD TRUCS to avoid complete depletion of hydrogen from the tank.

E. Technology, Charging Infrastructure, and Operating Costs

In the following subsections, we first discuss BEV technology (Section II.E.1) and associated EVSE technology costs (Section II.E.2) and FCEV technology costs (Section II.E.3). DRIA Chapter 2.4.3. (for BEVs) and DRIA Chapter 2.5.2 (for FCEVs) includes the cost estimates for each of the 101 applications. We then discuss the Inflation Reduction Act tax credits we quantified in our analysis in Section II.E.4. Our assessment of operating costs including the fuel or electricity costs, along with the maintenance and repair costs, are presented in Section II.E.5. This subsection concludes with the overall payback analysis in Section II.E.6. DRIA Chapter 2.8.2 includes the vehicle technology costs, EVSE costs, operating costs, and payback results for each of the 101 HD applications. The technology costs aggregated into MOVES categories are also described in detail in DRIA Chapter 3.1.

1. BEV Technology Costs

The incremental cost of a BEV powertrain system is calculated as the cost difference from the comparable vehicle powertrain with an ICE. The ICE vehicle powertrain cost is a sum of the costs of the engine (including the projected cost of the HD2027 standards), alternator, gearbox (transmission), starter, torque converter, and final drive system.

Heavy-duty BEV powertrain costs consist of the battery, electric motor, inverter, converter, onboard charger, power electronics controller, transmission or gearbox, final drive, and any electrical accessories. DRIA Chapter 2.4.3 contains additional detail on our cost projections for each of these components. We request comment, including additional data, on our analysis for consideration in the final rule regarding current and projected BEV component costs.

Battery costs are widely discussed in the literature because they are a key driver of the cost of a HD electric vehicle. The per unit cost of the battery, in terms of $/kWh, is the most common metric in determining the cost of the battery as the final size of the battery may vary significantly between different applications. The total battery pack cost is a function of the per unit kWh cost and the size (in terms of kWh) of the pack.

There are numerous projections for battery costs and battery pricing in the literature that cover a range of estimates. Sources do not always clearly define what is included in their cost or price projections, nor whether the projections reflect direct manufacturing costs incurred by the manufacturer or the prices seen by the end-consumer. Except as noted, the values in the literature we used were developed prior to enactment of the Inflation Reduction Act. For example, BloombergNEF presents battery prices that would reach $100 per kWh in 2026.[434] In 2021, ANL developed cost projections for heavy-duty vehicle battery packs in their benefit analysis (BEAN) model, that ranged from $225 per kWh to $175 per kWh in 2027 and drop to $150 per kWh to $115 per kWh in 2035.[435] In a recent update to BEAN, released after the IRA was passed, ANL now projects heavy-duty battery pack costs in the range of $95 per kWh to $128 per kWh in 2025 and a drop to between $70 per kWh and $90 per kWh in 2035.[436] The direct manufacturing battery cost for MY 2027 used in HD TRUCS is based on a literature review of costs of zero-emission truck components conducted by the International Council on Clean Transportation (ICCT).[437] As described in detail in DRIA Chapter 2.4.3.1, we considered this source to be a comprehensive review of the literature at the time of the HD TRUCS analysis for the cost of battery packs in the

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Contract ANL/ESD–22.6. October 2022. See Medium- and heavy-duty vehicles (assumptions). Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

[433] U.S. Department of Energy, US Drive. ''Target Explanation Document: Onboard Hydrogen Storage for Light-Duty Fuel Cell Vehicles''. 2017. Available online: *https://www.energy.gov/sites/prod/files/2017/05/f34/fcto_targets_onboard_hydro_storage_explanation.pdf.*

[434] Bloomberg NEF. ''Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite.'' November 30, 2021. *https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite/.*

[435] Argonne National Lab, Vehicle & Mobility Systems Group, BEAN, found at: *https://vms.taps.anl.gov/tools/bean/* (accessed August 2022).

[436] Argonne National Lab, Vehicle & Mobility Systems Group, BEAN, found at: *https://vms.taps.anl.gov/tools/bean/* (accessed December 2022).

[437] Sharpe, Ben and Hussein Basma. ''A meta-study of purchase costs for zero-emission trucks''. The International Council on Clean Transportation, Working Paper 2022–09 (February 2022). Available online: *https://theicct.org/publication/purchase-cost-ze-trucks-feb22/.*

absence of the IRA, which may mean that it presents higher costs than will be realized with the incentives in the IRA, even when accounting for the battery tax credit described in Section II.E.4. In 2025, the average cost is estimated to be $163.50/kWh (2019$) and, in 2030, the average cost is projected to fall to $100 (2019$). We applied a linear interpolation of these values that yields an estimated cost of $138/kWh (2019$) for MY 2027. We then projected the costs to MY 2032 by using an EPA estimate of market learning related to battery production and the respective reduction in battery costs over this period of time, as shown in Table II–11. We request comment, including data, on our approach and projections for battery pack costs for the heavy-duty sector, including values that specifically incorporate the potential impacts of the IRA.

TABLE II–11—DIRECT MANUFACTURING PACK-LEVEL BATTERY COSTS IN HD TRUCS

[2021$]

Model year	2027	2028	2029	2030	2031	2032
Battery Cost ($/kWh)	145	134	126	120	115	111

Batteries are the most significant cost component for BEVs and the IRA section 13502, ''Advanced Manufacturing Production Credit,'' has the potential to significantly reduce the cost of BEVs whose batteries are produced in the United States. As discussed in Section II.E.4, we thus then also accounted for the IRA Advanced Manufacturing Production Credit, which provides up to $45 per kWh tax credits (with specified phase-out in calendar years (CYs) 2030–2033) for the production and sale of battery cells and modules, and additional tax credits for producing critical minerals such as those found in batteries, when such components or minerals are produced in the United States and other criteria are met.

An electric drive (e-drive)—another major component of an electric vehicle—includes the electric motor, an inverter, a converter, and optionally, a transmission system or gearbox. The electric energy in the form of direct current (DC) is provided from the battery; an inverter is used to change the DC into alternating current (AC) for use by the motor. The motor then converts the electric power into mechanical or motive power to move the vehicle. Conversely, the motor also receives AC from the regenerative braking, whereby the converter changes it to DC to be stored in the battery. The transmission reduces the speed of the motor through a set of gears to an appropriate speed at the axle. An emerging trend is to replace the transmission and driveline with an e-axle, which is an electric motor integrated into the axle, e-axles are not explicitly covered in our cost analysis.[438] We request data on e-axle costs that we could consider for the final rule.

Similar to the battery cost, there is a range of electric drive cost projections available in the literature. One reason for the disparity is differences across the literature is what is included in each for the ''electric drive''; some cost estimates include only the electric motor and others present a more integrated model of e-motor/inverter/gearbox combination. As described in detail in DRIA Chapter 2.4.3.2.1, EPA's MY 2027 e-drive cost, shown in Table II–12, comes from ANL's 2022 BEAN model and is a linear interpolation of the average of the high- and low-tech scenarios for 2025 and 2030, adjusted to 2021$.[439] We then calculated MY 2028–2032 values, also shown in Table II–12, using an EPA estimate of market learning shown in DRIA Chapter 3.2.1. We welcome comment, including data, on our assessment of e-drive costs.

TABLE II–12—E-DRIVE DIRECT MANUFACTURING COSTS IN HD TRUCS

[$/kW] [2021$]

Model year	2027	2028	2029	2030	2031	2032
E-Drive Cost ($/kW)	20	18	17	16	16	15

Gearbox and final drive units are used to reduce the speed of the motor and transmit torque to the axle of the vehicle. In HD TRUCS, the final drive unit direct manufacturing cost is $1,500 per unit, based on the ''Power Converter'' average cost in ANL's BEAN model.[440] The cost of the gearbox varies depending on the vehicle weight class and duty cycle. In our assessment, all light heavy-duty BEVs would be direct drive and have no transmission and therefore no cost, consistent with ANL's BEAN model. We then mapped BEAN gearbox costs for BEVs to the appropriate medium heavy-duty and heavy heavy-duty vehicles in HD TRUCS. Gearbox and final drive costs for BEVs are in DRIA Chapter 2.4.3.2.

Power electronics are another electrification component (along with batteries and motors) where a DC–DC converter transitions high battery voltage to a common 12V level for auxiliary uses. EPA's power electronics and electric accessories costs of $6,000 per unit came from ANL's BEAN model.[441] See DRIA Chapter 2.4.3.2.2 for further details.

When using a Level 2 charging plug, an on-board charger converts AC power from the grid to usable DC power via an AC–DC converter. When using a DC fast charger (DCFC), any AC–DC converter is bypassed, and the high-voltage battery is charged directly. As further discussed in DRIA Chapter 2.4.3.3, EPA's on-board charger costs, as shown in Table II–13, come from ANL's BEAN model and we averaged the low-tech and high-tech values for 2025 and 2030, and then MY

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[438] E-axles are an emerging technology that have potential to realize efficiency gains because they have fewer moving parts.

[439] Argonne National Lab, Vehicle & Mobility Systems Group, BEAN, found at: *https://vms.taps.anl.gov/tools/bean/* (accessed December 2022).

[440] *Ibid.*

[441] Argonne National Lab, Vehicle & Mobility Systems Group, BEAN, found at: *https://vms.taps.anl.gov/tools/bean/* (accessed August 2022).

2027 was linearly interpolated and adjusted to 2021$.[442] We then calculated the MY 2028–2032 costs using the learning curve shown in DRIA Chapter 3.2.1.

TABLE II–13—ON-BOARD CHARGER DIRECT MANUFACTURING COSTS IN HD TRUCS

[2021$]

Model year	2027	2028	2029	2030	2031	2032
On-Board Charger Cost ($/unit)	38	35	33	31	30	29

The total upfront BEV direct manufacturing cost is the summation of the per-unit cost of the battery, motor, power electronics, on-board charger, gearbox, final drive, and accessories. The total direct manufacturing technology costs for BEVs for each of the 101 vehicle types in HD TRUCS can be found in DRIA Chapter 2.4.3.5 for MY 2027 and MY 2032.

2. Charging Infrastructure Costs

In our analysis of depot charging infrastructure costs, we account for the cost to purchasers to procure both EVSE (which we refer to as the hardware costs) as well as costs to install the equipment. These installation costs typically include labor and supplies, permitting, taxes, and any upgrades or modifications to the on-site electrical service. We developed our EVSE cost estimates from the available literature, as discussed in DRIA Chapter 2.6.

Both hardware and installation costs could vary over time. For example, hardware costs could decrease due to manufacturing learning and economies of scale. Recent studies by ICCT assumed a 3 percent reduction in hardware costs for EVSE per year to 2030.[443] [444] By contrast, installation costs could increase due to growth in labor or material costs. Installation costs are also highly dependent on the specifics of the site including whether sufficient electric capacity exists to add charging infrastructure and how much trenching or other construction is required. If fleet owners choose to install charging stations at easier, and therefore, lower cost sites first, then installation costs could rise over time as stations are developed at more challenging sites. One of the ICCT studies found that these and other countervailing factors could result in the average cost of a 150 kW EVSE port in 2030 being similar (~3 percent lower) to that in 2021.[445] After considering the uncertainty on how costs may change over time, we keep the combined hardware and installation costs per EVSE port constant. We request comment on this approach.

Our infrastructure analysis centered around four charging types for heavy-duty depot charging. As shown in Table II–14, the EVSE costs we used in our analysis range from about $10,000 for a Level 2 port to over $160,000 for a 350 kW DCFC port. As described in Chapter 2.6, in our analysis, we allow up to two vehicles to share one DCFC port if there is sufficient depot dwell time for both vehicles to meet their daily charging needs.[446] In those cases, the EVSE costs per vehicle are halved. We request comment, including data, on our approach and assessment of current and future costs for charging equipment and installation.

TABLE II–14—COMBINED HARDWARE AND INSTALLATION EVSE COSTS, PER VEHICLE

[2021$]

Charging type	Cost	Cost
	(1 Vehicle per port)	(2 Vehicles per port)
Level 2 (19.2 kW)	$10,541	Not Applicable
DCFC–50 kW	31,623	$15,811
DCFC–150 kW	99,086	49,543
DCFC–350 kW	162,333	81,166

EPA acknowledges that there may be additional infrastructure needs and costs beyond those associated with charging equipment itself. While planning for additional electricity demand is a standard practice for utilities and not specific to BEV charging, the buildout of public and private charging stations (particularly those with multiple high-powered DC fast charging units) could in some cases require upgrades to local distribution systems. For example, a recent study found power needs as low as 200 kW could trigger a requirement to install a distribution transformer.[447] The use of onsite battery storage and renewables may be able to reduce the need for some distribution upgrades; station operators may also opt to install these to mitigate demand charges associated with peak

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[442] Argonne National Lab, Vehicle & Mobility Systems Group, BEAN, found at: *https://vms.taps.anl.gov/tools/bean/* (accessed August 2022).

[443] Minjares, Ray, Felipe Rodriguez, Arijit Sen, and Caleb Braun. ‘‘Infrastructure to support a 100% zero-emission tractor-trailer fleet in the United States by 2040’’. ICCT, September 2021. Available online: *https://theicct.org/sites/default/files/publications/ze-tractor-trailer-fleet-us-hdvs-sept21.pdf.*

[444] Bauer, Gordon, Chih-Wei Hsu, Mike Nicholas, and Nic Lutsey. ‘‘Charging Up America: Assessing the Growing Need for U.S. Charging Infrastructure Through 2030’’. The International Council on Clean Transportation, July 2021. Available online: *https://theicct.org/wp-content/uploads/2021/12/charging-up-america-jul2021.pdf.*

[445] *Ibid.*

[446] We note that for some of the vehicle types we evaluated, more than two vehicles could share a DCFC port and still meet their daily electricity consumption needs. However, we choose to limit sharing to two vehicles pending market developments and more robust depot dwell time estimates.

[447] Borlaug, B., Muratori, M., Gilleran, M. et al, ‘‘Heavy-duty truck electrification and the impacts of depot charging on electricity distribution systems,’’ Nat Energy 6, 673–682 (2021). Accessed on January 11, 2023, at *https://doi.org/10.1038/s41560-021-00855-0.*

power.[448] However, there is considerable uncertainty associated with future distribution upgrade needs, and in many cases, some costs may be borne by utilities rather than directly incurred by BEV or fleet owners. Therefore, we do not model them directly as part of our infrastructure cost analysis. We welcome comments on this and other aspects of our cost analysis.

As discussed in Section V, we model changes to power generation due to the increased electricity demand anticipated in the proposal as part of our upstream analysis. We project the additional generation needed to meet the demand of the heavy-duty BEVs in the proposal to be relatively modest (as shown in DRIA Chapter 6.5). As the proposal is estimated to increase electric power end use by heavy-duty electric vehicles by 0.1 percent in 2027 and increasing to 2.8 percent in 2055. The U.S. electricity end use between the years 1992 and 2021, a similar number of years included in our proposal analysis, increased by around 25 percent[449] without any adverse effects on electric grid reliability or electricity generation capacity shortages. Grid reliability is not expected to be adversely affected by the modest increase in electricity demand associated with HD BEV charging.

A GAO report noted that the private sector and the government share responsibility for the reliability of the U.S. electric power grid. The report stated, ''Most of the electricity grid—the commercial electric power transmission and distribution system comprising power lines and other infrastructure—is owned and operated by private industry. However, Federal, state, local, Tribal, and territorial governments also have significant roles in enhancing the resilience of the electricity grid.''[450] For instance, at the Federal level, the Department of Homeland Security (DHS) coordinates Federal efforts to promote the security and reliability of the nation's energy sector; the Department of Energy (DOE) leads Federal efforts including research and technology development; and the Federal Energy Regulatory Commission (FERC) regulates the interstate electricity transmission and is responsible for reviewing and approving mandatory electric Reliability Standards, which are developed by the North American Electric Reliability Corporation (NERC).[451] NERC is the federally designated U.S. electric reliability organization which ''develops and enforces Reliability Standards; annually assesses seasonal and long-term reliability; monitors the bulk power system through system awareness; and educates, trains, and certifies industry personnel.''[452] These efforts help to keep the U.S. electric power grid is reliable. We also consulted with FERC and EPRI staff on bulk power system reliability and related issues.

U.S. electric power utilities routinely upgrade the nation's electric power system to improve grid reliability and to meet new electric power demands. For example, when confronted with rapid adoption of air conditioners in the 1960s and 1970s, U.S. electric power utilities successfully met the new demand for electricity by planning and building upgrades to the electric power distribution system. Likewise, U.S. electric power utilities planned and built distribution system upgrades required to service the rapid growth of power-intensive data centers and server farms over the past two decades. U.S. electric power utilities have already successfully designed and built the distribution system infrastructure required for 1.4 million battery electric vehicles.[453] Utilities have also successfully integrated 46.1 GW of new utility-scale electric generating capacity into the grid.[454]

When taking into consideration ongoing upgrades to the U.S. electric power grid, and that the U.S. electric power utilities generally have more capacity to produce electricity than is consumed,[455] the expected increase in electric power demand attributable to vehicle electrification is not expected to adversely affect grid reliability due to the modest increase in electricity demand associated with electric vehicle charging. The additional electricity demand from HD BEVs will depend on the time of day that charging occurs, the type or power level of charging, and the use of onsite storage and vehicle-to-grid (V2G) or other vehicle-grid-integration (VGI) technology, among other considerations, as discussed in DRIA Chapter 1.6.4. As noted by Lipman et al.,[456] a wide variety of organizations are engaged in VGI research, including the California Energy Commission,[457] California Public Utilities Commission,[458] California Independent System Operator,[459] the Electric Power Research Institute, as well as charging providers, utilities (*e.g.,* SCE, PG&E, SDG&E), and automakers. Electric Island, a truck charging station deployed by Daimler Trucks North America and Portland General Electric which is planned to eventually include megawatt-level charging, will offer an opportunity to test energy management and VGI with heavy-duty BEVs. Future plans for Electric Island also include the use of onsite solar generation and battery storage.[460]

Finally, we note that DOE is engaged in multiple efforts to modernize the grid and improve resilience and reliability. For example, in November 2022, DOE announced $13 billion in funding opportunities under the BIL to support transmission and distribution infrastructure. This includes $3 billion for smart grid grants with a focus on PEV integration among other topics.[461]

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[448] Matt Alexander, Noel Crisostomo, Wendell Krell, Jeffrey Lu, Raja Ramesh,'' Assembly Bill 2127: Electric Vehicle Charging Infrastructure Assessment,'' July 2021, California Energy Commission. Accessed March 9, 2023, at *https://www.energy.ca.gov/programs-and-topics/programs/electric-vehicle-charging-infrastructure-assessment-ab-2127.*

[449] Annual Energy Outlook 2022, U.S. Energy Information Administration, March 3, 2022 (*https://www.eia.gov/outlooks/aeo/narrative/introduction/sub-topic-01.php*).

[450] Federal Efforts to Enhance Grid Resilience. General Accounting Office, GAO–17–153, 1/25/2017. *https://www.gao.gov/assets/gao-17-153.pdf.*

[451] Electricity Grid Resilience. General Accounting Office, GAO–21–105403, 9/20/2021, *https://www.gao.gov/assets/gao-21-105403.pdf.*

[452] North American Electric Reliability Corporation. ''About NERC''. Available online: *https://www.nerc.com/AboutNERC/Pages/default.aspx.*

[453] U.S. DOE Alternative Fuels Data Center, Maps and Data—Electric Vehicle Registrations by State, *https://afdc.energy.gov/data/.*

[454] EIA, ''Electric Power Annual 2021'', November 2022. Available online: *https://www.eia.gov/electricity/annual/html/epa_01_01.html.*

[455] EIA, ''Electric Power Annual 2021'', November 2022. Available online: *https://www.eia.gov/electricity/annual/html/epa_01_01.html.*

[456] Lipman, Timothy, Alissa Harrington, and Adam Langton. 2021. ''Total Charge Management of Electric Vehicles.'' California Energy Commission.'' Publication Number: CEC–500–2021–055. Available online: *https://www.energy.ca.gov/sites/default/files/2021-12/CEC-500-2021-055.pdf.*

[457] Chhaya, S., et al., ''Distribution System Constrained Vehicle-to-Grid Services for Improved Grid Stability and Reliability,'' Publication Number: CEC–500–2019–027, 2019. Available online: *https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2019-027.pdf.*

[458] Order Instituting Rulemaking to Continue the Development of Rates and Infrastructure for Vehicle Electrification. California Public Utilities Commission, Rulemaking 18–12–006, 12/21/2020.

[459] California Independent System Operator (CAISO), ''California Vehicle-Grid Integration (VGI) Roadmap: Enabling vehicle-based grid services,'' February 2014.

[460] PGE, ''Daimler Trucks North America, Portland General Electric open first-of-its-kind heavy-duty electric truck charging site,'' April 21, 2021. Available online: *https://portlandgeneral.com/news/2021-04-21-daimler-portland-general-electric-open-electric-charging-site.*

[461] DOE, ''Biden-Harris Administration Announces $13 Billion to Modernize and Expand America's Power Grid,'' November 18, 2022. Available online: *https://www.energy.gov/articles/biden-harris-administration-announces-13-billion-modernize-and-expand-americas-power-grid.*

3. FCEV Technology Costs

FCEVs and BEVs include many of the same components such as a battery pack, e-motor, power electronics, gearbox unit, final drive, and electrical accessories. Therefore we used the same costs for these components across vehicles used for the same applications; for detailed descriptions of these components, see DRIA Chapter 2.4.3. In this subsection and DRIA Chapter 2.5.2, we present the costs for components for FCEVs that are different from a BEV. These components include the fuel cell stack and hydrogen fuel tank. The same energy cell battery costs used for BEVs are used for fuel cell vehicles, but the battery size of a comparable FCEV is smaller. We request comment, including data, on our approach and cost projections for FCEV components.

i. Fuel Cell Stack Costs

The fuel cell stack is the most expensive component of a heavy-duty FCEV. Fuel cells for the heavy-duty sector are expected to be more expensive than fuel cells for the light-duty sector because they operate at higher average continuous power over their lifespan, which requires a larger fuel cell stack size, and because they have longer durability needs (*i.e.,* technology targets are for 25,000 to 30,000 hours for a truck versus 8,000 hours for cars).[462]

Projected costs vary widely in the literature. They are expected to decrease as manufacturing matures. Larger production volumes are anticipated as global demand increases for fuel cell systems for HD vehicles, which could improve economies of scale.[463] Costs are also anticipated to decline as durability improves, which could extend the life of fuel cells and reduce the need for parts replacement.[464] Burke et al. compared estimates from the literature and chose values of $240 per kW in 2025 for a high case in their analysis, based on 1,000 heavy-duty fuel cell units produced per year, and $145 per kW for both a low case in 2025 and a high case in 2030, based on 3,000 units produced per year.[465]

The interim DOE cost target for Class 8 tractor-trailer fuel stacks is $80 per kW by 2030. Their ultimate target is $60 per kW in 2050, set to ensure that costs are comparable to those of advanced diesel engines and other factors. These targets are based on 100,000 units per year production volume. They pointed to analysis that suggests that 2019 costs at a manufacturing volume of 1,000 units per year were around $190 per kW.[466] In BEAN model updates, ANL estimated a range based on vehicle type of between $156 per kW and $174 per kW in 2025, and from $65 per kW to $99 per kW by 2035.[467]

A Sharpe and Basma meta-study of other reports found 2025 costs ranging from $750 per kW to $50 per kW. The authors stated that they expect fuel cell costs to drop by about 30 percent between 2025 and 2030 due to manufacturer learning, improved materials and performance, and economies of scale.[468] Like the approach we took for BEV battery costs, we averaged the 2025 cost values from the Sharpe and Basma meta-study, averaged the 2030 values, and then linearly interpolated to get MY 2027 values and adjusted to 2021$; we then applied the learning curve shown in DRIA Chapter 3.2.1 to calculate MY 2028–2032 values. The resulting fuel cell stack direct manufacturing costs are shown in Table II–15.[469]

TABLE II–15—HD FUEL CELL STACK DIRECT MANUFACTURING COSTS

[2021$]

Model year	2027	2028	2029	2030	2031	2032
$/kW	242	223	210	200	192	185

ii. Hydrogen Fuel Tank Costs

Hydrogen storage cost projections also vary widely in the literature. Sharpe and Basma reported costs ranging from as high as $1,289 per kg to $375 per kg of usable hydrogen in 2025. They expect hydrogen tank costs to drop by 21 percent between 2025 and 2030 due to lighter weight and lower cost carbon fiber-reinforced materials, technology improvements, and economies of scale.[470]

The interim DOE target for Class 8 tractor-trailers is $300 per kg of hydrogen by 2030. Their ultimate target is $266 per kg (2016$) by 2050. They include all components necessary to support the tank and are based on a production volume of 100,000 tanks per year. They point to analysis that suggests that 2019 costs for 700-bar tanks at a manufacturing volume of 1,000 tanks per year were roughly $1,200 per kg.[471] For reference, the Kenworth ''beta'' fuel cell truck holds

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[462] Marcinkoski, Jason et. al. ''DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap—Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks. October 31, 2019. Available online: *https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.*

[463] Deloitte China. ''Fueling the Future of Mobility: Hydrogen and fuel cell solutions for transportation, Volume 1''. 2020. Available online: *https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf.*

[464] Deloitte China. ''Fueling the Future of Mobility: Hydrogen and fuel cell solutions for transportation, Volume 1''. 2020. Available online: *https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf.*

[465] U.S. Department of Energy. ''DOE National Clean Hydrogen Strategy and Roadmap''. Draft September 2022. Available online: *https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf.*

[466] Marcinkoski, Jason et. al. ''DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap—Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks. October 31, 2019. Available online: *https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf. https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.*

[467] Argonne National Lab, Vehicle & Mobility Systems Group, BEAN, found at: *https://vms.taps.anl.gov/tools/bean/* (accessed December 2022).

[468] Sharpe, Ben and Hussein Basma. ''A meta-study of purchase costs for zero-emission trucks''. The International Council on Clean Transportation, Working Paper 2022–09 (February 2022). Available online: *https://theicct.org/publication/purchase-cost-ze-trucks-feb22/.*

[469] IRA section 13502 provides tax credits for 10 percent of the cost of producing applicable critical materials, including those found in fuel cells (providing that the minerals meet certain specifications), when such components or minerals are produced in the U.S. We did not include a detailed cost breakdown of fuel cells quantitatively in our analysis, but the potential impact of the tax credit on fuel cells may be significant because platinum (an applicable critical mineral commonly used in fuel cells) is a major contributor to the cost of fuel cells.

[470] Sharpe, Ben and Hussein Basma. ''A meta-study of purchase costs for zero-emission trucks''. The International Council on Clean Transportation, Working Paper 2022–09 (February 2022). Available online: *https://theicct.org/publication/purchase-cost-ze-trucks-feb22/.*

[471] Marcinkoski, Jason et al. ''DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap—Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks. October 31, 2019. Available online: *https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.*

six 10-kg hydrogen storage tanks at 700 bar.[472]

Like the approach we took for battery and fuel cell stack costs, we averaged all of the 2025 cost values in the Sharpe and Basma meta-study, averaged all of the 2030 values, and then linearly interpolated to determine the MY 2027 value, adjusted to 2021 dollars. We applied the learning curve shown in DRIA Chapter 3.2.1 to calculate MY 2028–2032 values. The hydrogen fuel tank direct manufacturing costs are shown in Table II–16.

TABLE II–16—HYDROGEN FUEL TANK DIRECT MANUFACTURING COSTS

[2021$]

	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032
$/kg H_2	801	738	694	660	634	612

4. Inflation Reduction Act Tax Credits

The IRA,[473] which was signed into law on August 16, 2022, includes a number of provisions relevant to vehicle electrification. There are two provisions of the IRA we included within our quantitative analysis in HD TRUCS. First, Section 13502, ''Advanced Manufacturing Production Credit,'' provides up to $45 per kWh tax credits for the production and sale of battery cells and modules when such components are produced in the United States and other qualifications are met. Second, Section 13403, ''Qualified Commercial Clean Vehicles,'' provides for a vehicle tax credit applicable to HD vehicles if certain qualifications are met. Beyond these two tax credits described in sections 13403 and 13502 of the IRA, there are numerous provisions in the IRA and the BIL[474] that may impact HD vehicles and increase adoption of HD ZEV technologies. These range from tax credits across the supply chain, to grants which may help direct ZEVs to communities most burdened by air pollution, to funding for programs to build out electric vehicle charging infrastructure, as described in Section I of this preamble and DRIA Chapter 1.3.2. We welcome comment on our assessment of how the IRA will impact the heavy-duty industry, and how EPA could consider reflecting those impacts in our assessment for establishing the HD GHG standards under this proposal, including comment on methods to appropriately account for these provisions in our assessment.

Regarding the first of the two provisions, IRA section 13502, ''Advanced Manufacturing Production Credit,'' provides up to $45 per kWh tax credits for the production and sale of battery cells (up to $35 per kWh) and modules (up to $10 per kWh) and 10 percent of the cost of producing critical minerals such as those found in batteries, when such components or minerals are produced in the United States and other qualifications are met. These credits begin in CY 2023 and phase down starting in CY 2030, ending after CY 2032. As further discussed in DRIA Chapter 2.4.3.1, we recognize that there are currently few manufacturing plants for HD vehicle batteries in the United States. We expect that the industry will respond to this tax credit incentive by building more domestic battery manufacturing capacity in the coming years, in part due to the BIL and IRA. For example, Proterra recently announced its first heavy-duty battery manufacturing plant in the United States,[475] Tesla is expanding its facilities in Nevada to produce its Semi BEV tractor and battery cells,[476] and Cummins has entered into an agreement with Arizona-based Sion Power to design and supply battery cells for commercial electric vehicle applications.[477] In addition, DOE is funding through the BIL battery materials processing and manufacturing projects to ''support new and expanded commercial-scale domestic facilities to process lithium, graphite and other battery materials, manufacture components, and demonstrate new approaches, including manufacturing components from recycled materials.'' [478] Thus, we model this tax credit in HD TRUCS such that HD BEV and FCEV manufacturers fully utilize the battery module tax credit and gradually increase their utilization of the cell tax credit for MY 2027–2029 until MY 2030 and beyond, when they earn 100 percent of the available cell and module tax credits. The battery pack costs and battery tax credits used in our analysis are shown in Table II–17. We request comment on our approach to modeling this tax credit, including our projection that the full value of the tax credit earned by the manufacturer is passed through to the purchaser because market competition would drive manufacturers to minimize their prices.

TABLE II–17—PACK-LEVEL BATTERY DIRECT MANUFACTURING COSTS AND IRA TAX CREDITS IN HD TRUCS

[2021$]

Model year	2027	2028	2029	2030	2031	2032
Battery Pack Cost ($/kWh)	145	134	126	120	115	111

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[472] *https://www.kenworth.com/media/voffdzok/ata-fuel-cell-flyer-08-25-2021-v2.pdf* and *https://www.greencarreports.com/news/1120765_toyota-and-kenworth-to-build-10-fuel-cell-semis-for-la-port-duty*.

[473] Inflation Reduction Act of 2022, Public Law 117–169, 136 Stat. 1818 (2022) (''Inflation Reduction Act'' or ''IRA''), available at *https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf*.

[474] United States, Congress. Public Law 117–58. Infrastructure Investment and Jobs Act of 2021. *Congress.gov, www.congress.gov/bill/117th-congress/house-bill/3684/text*. 117th Congress, House Resolution 3684, passed 15 Nov. 2021.

[475] Proterra. ''First Proterra Powered commercial EV battery produced at new Powered 1 battery factory''. January 12, 2023. Available online: *https://www.proterra.com/press-release/first-battery-at-powered1-factory/*.

[476] Sriram, Akash, Aditya Soni, and Hyunjoo Jin. ''Tesla plans $3.6 bln Nevada expansion to make Semi truck, battery cells.'' Reuters. January 25, 2023. Last accessed on March 31, 2023 at *https://www.reuters.com/markets/deals/tesla-invest-over-36-bln-nevada-build-two-new-factories-2023-01-24/*.

[477] Sion Power. ''Cummins Invests in Sion Power to Develop Licerion® Lithium Metal Battery Technology for Commercial Electric Vehicle Applications''. November 30, 2021. Available online: *https://sionpower.com/2021/cummins-invests-in-sion-power-to-develop-licerion-lithium-metal-battery-technology-for-commercial-electric-vehicle-applications/*.

[478] U.S. Department of Energy. ''Bipartisan Infrastructure Law: Battery Materials Processing and Battery Manufacturing & Recycling Funding Opportunity Announcement—Factsheets''. October 19, 2022. Available online: *https://www.energy.gov/sites/default/files/2022-10/DOE%20BIL%20Battery%20FOA-2678%20Selectee%20Fact%20Sheets%20-%201_2.pdf*.

TABLE II–17—PACK-LEVEL BATTERY DIRECT MANUFACTURING COSTS AND IRA TAX CREDITS IN HD TRUCS—Continued

[2021$]

Model year	2027	2028	2029	2030	2031	2032
IRA Cell Credit ($/kWh)	8.75	17.50	26.25	26.25	17.50	8.75
IRA Module Credit ($/kWh)	10.00	10.00	10.00	7.50	5.00	2.50
IRA Total Battery Credit ($/kWh)	18.75	27.50	36.25	33.75	22.50	11.25
Battery Pack Cost Less IRA Total Battery Credit ($/kWh)	126.25	106.50	89.75	86.25	92.50	99.75

Regarding the second of the two provisions, IRA section 13403 creates a tax credit applicable to each purchase of a qualified commercial clean vehicle. These vehicles must be on-road vehicles (or mobile machinery) that are propelled to a significant extent by a battery-powered electric motor. The battery must have a capacity of at least 15 kWh (or 7 kWh if it is Class 3 or below) and must be rechargeable from an external source of electricity. This limits the qualified vehicles to BEVs and plug-in hybrid electric vehicles (PHEVs). Additionally, fuel cell electric vehicles (FCEVs) are eligible. The credit is available from calendar year (CY) 2023 through 2032, which overlaps with the model years for which we are proposing standards (MYs 2027 through 2032), so we included the tax credit in our calculations for each of those years in HD TRUCS.

For BEVs and FCEVs, the tax credit is equal to the lesser of: (A) 30 percent of the BEV or FCEV cost, or (B) the incremental cost of a BEV or FCEV when compared to a comparable ICE vehicle. The limit of this tax credit is $40,000 for Class 4–8 commercial vehicles and $7,500 for commercial vehicles Class 3 and below. For example, if a BEV costs $350,000 and a comparable ICE vehicle costs $150,000,[479] the tax credit would be the lesser of: (A) $0.30 \times \$350{,}000 = \$105{,}000$ or (B) $\$350{,}000 - \$150{,}000 = \$200{,}000$. In this example, (A) is less than (B), but (A) exceeds the limit of $40,000, so the tax credit would be $40,000.

We included this tax credit in HD TRUCS by decreasing the incremental upfront cost a vehicle purchaser must pay for a ZEV compared to a comparable ICE vehicle following the process explained in the previous paragraph. The calculation for this tax credit was done after applying a retail price equivalent to our direct manufacturing costs. We did not calculate the full cost of vehicles in our analysis, instead we determined that all Class 4–8 ZEVs could be eligible for the full $40,000 (or $7,500 for ZEVs Class 3 and below) if the incremental cost calculated compared to a comparable ICE vehicle was greater than that amount. In order for this determination to be true, all Class 4–8 ZEVs must cost more than $133,333 such that 30 percent of the cost is at least $40,000 (or $25,000 and $7,500, respectively, for ZEVs Class 3 and below), which seems reasonable based on our assessment of the literature.[480] As in the calculation described in the previous paragraph, both (A) and (B) are greater than the tax credit limit and the vehicle purchaser may receive the full tax credit. The incremental cost of a ZEV taking into account the tax credits for each vehicle segment in MY 2027 and MY 2032 are included in DRIA Chapter 2.8.2. We welcome comment on how we included the IRA tax credits for HD vehicles in our assessment.

5. Operating Costs

Operating costs for HD vehicles encompass a variety of costs, such as labor, insurance, registration fees, fueling, maintenance and repair (M&R), and other costs. For this analysis, we are primarily interested in costs that would differ for a comparable diesel-powered ICE vehicle and a ZEV.[481] These operational cost differences are used to calculate an estimated payback period in HD TRUCS. We expect fueling costs and M&R costs to be different for ZEVs than for comparable diesel-fueled ICE vehicles, but we do not anticipate other operating costs, such as labor and insurance, to differ significantly, so the following subsections focus on M&R and fueling costs. Operating costs are averaged over a 10-year time period of the annual M&R cost and annual fuel cost.

i. Maintenance and Repair Costs

M&R costs contribute to the overall operating costs for HD vehicles. To establish a baseline cost for maintenance and repair of diesel-fueled ICE vehicles, we relied on the research compiled by Burnham et al. and used equations found in the ANL's BEAN model.[482] [483] Burnham et al. used data from Utilimarc and the American Transportation Research Institute (ATRI) to estimate maintenance and repair costs per mile for multiple heavy-duty vehicle categories over time. We selected the box truck curve to represent vocational vehicles and short-haul tractors, and the semi-tractor curve to represent long-haul tractors.[484] Additional details regarding this analysis can be found in DRIA Chapter 2.3.4.2. Averaging the M&R costs for years 0–9 yields about 67 cents per mile for vocational vehicles and short-haul tractors and about 25 cents per mile for long-haul tractors, after adjusting to 2021$. We welcome comment, including additional data, on our approach and assessment of HD ICE vehicle M&R costs.

Data on real-world M&R costs for HD ZEVs is limited due to limited HD ZEV technology adoption today. We expect the overall maintenance costs to be lower for ZEVs compared to a comparable ICE vehicles for several reasons. First, an electric powertrain has fewer moving parts that accrue wear or need regular adjustments. Second, ZEVs do not require fluids such as engine oil or diesel exhaust fluid (DEF), nor do they require exhaust filters to reduce

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[479] Sharpe, B., Basma, H. ''A meta-study of purchase costs for zero-emission trucks''. International Council on Clean Transportation. February 17, 2022. Available online: *https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf*.

[480] Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M.A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., Boloor, M. ''Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains''. Argonne National Laboratory. April 1, 2021. Available at *https://publications.anl.gov/anlpubs/2021/05/167399.pdf*.

[481] For diesel-fueled ICE vehicles, we also estimated the cost of the diesel exhaust fluid (DEF) required for the selective catalytic reduction aftertreatment system. See DRIA Chapter 2.3.4.1 for DEF costs.

[482] Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M.A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., Boloor, M. ''Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains''. Argonne National Laboratory. Chapter 3.5.5. April 1, 2021. Available at *https://publications.anl.gov/anlpubs/2021/05/167399.pdf*.

[483] Argonne National Lab, Vehicle & Mobility Systems Group, BEAN, found at: *https://vms.taps.anl.gov/tools/bean/* (accessed August 2022).

[484] Short haul tractors and vocational vehicles are represented by the same M&R equation because they have duty cycles and annual VMT that are similar.

particulate matter or other pollutants. Third, the per-mile rate of brake wear is expected to be lower for ZEVs due to regenerative braking systems. Several literature sources propose applying a scaling factor to diesel vehicle maintenance costs to estimate ZEV maintenance costs.[485] [486] [487] We followed this approach and applied a maintenance and repair cost scaling factor of 0.71 for BEVs and 0.75 for FCEVs to the maintenance and repair costs of diesel-fueled ICE vehicles. The scaling factors are based on an analysis from Wang et al. that estimates a future BEV heavy-duty truck would have a 29 percent reduction, and a future FCEV heavy-duty vehicle would have a 25 percent reduction, compared to a diesel-powered heavy-duty vehicle.[488] [489] We welcome comment on our approach and these projections.

In our payback analysis in HD TRUCS, we did not account for potential diesel engine rebuild costs for ICE vehicles, potential replacement battery costs for BEVs, or potential replacement fuel cell stack costs for FCEVs because our payback analysis typically covers a shorter period of time than the expected life of these components. Typical battery warranties being offered by HD BEV manufacturers range between 8 and 15 years today.[490] A BEV battery replacement may be practically necessary over the life of a vehicle if the battery deteriorates to a point where the vehicle range no longer meets the vehicle's operational needs. We believe that proper vehicle and battery maintenance and management can extend battery life. For example, manufacturers will utilize battery management system to maintain the temperature of the battery[491] as well active battery balancing to extend the life of the battery.[492] [493] Likewise, pre-conditioning has also shown to extend the life of the battery as well.[494] Furthermore, research suggests that battery life is expected to improve with new batteries over time as battery chemistry and battery charging strategies improve, such that newer MY BEVs will have longer battery life. We request comment on this approach for both ICE vehicles and ZEVs, in addition to data on battery and fuel stack replacement costs, engine rebuild costs, and expected component lifetime periods.

ii. Fuel, Electricity, and Hydrogen Costs

The annual fuel cost for operating a diesel-fueled ICE vehicle is a function of its yearly fuel consumption and the cost of diesel fuel. The yearly fuel consumption is described in DRIA Chapter 2.3.4.3. We used the DOE Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2022 transportation sector reference case projection for diesel fuel for on-road use for diesel prices.[495] This value includes Federal and State taxes but excludes county and local taxes. The average annual fuel cost is averaged over a 10-year period.

The annual electricity cost for operating a HD electric vehicle is a function of the electricity price, daily energy consumption of the vehicle, and number of operating days in a year. In HD TRUCS, we used the DOE EIA AEO 2022 reference case commercial electricity end-use rate projection.[496] We selected this value instead of the transportation end use prices in AEO because those are similar to the prices for the residential sector, which implies they may be more relevant to light-duty vehicle charging than commercial truck charging.

For the purposes of the HD TRUCS analysis, rather than focusing on depot hydrogen fueling infrastructure costs that would be incurred upfront, we included infrastructure costs in our per-kilogram retail price of hydrogen. The retail price of hydrogen is the total price of hydrogen when it becomes available to the end user, including the costs of production, distribution, storage, and dispensing at a fueling station. This price per kilogram of hydrogen includes the amortization of the station capital costs. This approach is consistent with the method we use in HD TRUCS for ICE vehicles, where the equivalent diesel fuel costs are included in the diesel fuel price instead of accounting for the costs of fuel stations separately.

We acknowledge that this market is still emerging and that hydrogen fuel providers will likely pursue a diverse range of business models. For example, some businesses may sell hydrogen to fleets through a negotiated contract rather than at a flat market rate on a given day. Others may offer to absorb the infrastructure development risk for the consumer, in exchange for the ability to sell excess hydrogen to other customers and more quickly amortize the cost of building a fueling station. FCEV manufacturers may offer a ''turnkey'' solution to fleets, where they provide a vehicle with fuel as a package deal. These uncertainties are not reflected in our hydrogen price estimates presented in the DRIA.

As discussed in DRIA Chapter 1.3.2 and 1.8, large incentives are in place to reduce the price of hydrogen production, particularly from electrolytic sources. In June 2021, DOE launched a Hydrogen Shot goal to reduce the cost of renewable hydrogen

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[485] Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M.A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., Boloor, M. ''Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains''. Argonne National Laboratory. April 1, 2021. Available online: *https://publications.anl.gov/anlpubs/2021/05/167399.pdf*.

[486] Hunter, Chad, Michael Penev, Evan Reznicek, Jason Lustbader, Alicia Birkby, and Chen Zhang. ''Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks''. National Renewable Energy Lab. September 2021. Available online: *https://www.nrel.gov/docs/fy21osti/71796.pdf*.

[487] Burke, Andrew, Marshall Miller, Anish Sinha, et. al. ''Evaluation of the Economics of Battery-Electric and Fuel Cell Trucks and Buses: Methods, Issues, and Results''. August 1, 2022. Available online: *https://escholarship.org/uc/item/1g89p8dn*.

[488] Wang, G., Miller, M., and Fulton, L.'' Estimating Maintenance and Repair Costs for Battery Electric and Fuel Cell Heavy Duty Trucks, 2022. Available online: *https://escholarship.org/content/qt36c08395/qt36c08395_noSplash_589098e470b036b3010eae00f3b7b618.pdf?t=r6zwjb*.

[489] Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M.A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., Boloor, M. ''Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains''. Argonne National Laboratory. April 1, 2021. Available online: *https://publications.anl.gov/anlpubs/2021/05/167399.pdf*.

[490] Type C BEV school bus battery warranty range five to fifteen years according to *https://www.nyapt.org/resources/Documents/WRI_ESB-Buyers-Guide_US-Market_2022.pdf*. The Freightliner electric walk-in van includes an eight year battery warranty according to *https://www.electricwalkinvan.com/wp-content/uploads/2022/05/MT50e-specifications-2022.pdf*.

[491] Basma, Hussein, Charbel Mansour, Marc Haddad, Maroun Nemer, Pascal Stabat. ''Comprehensive energy modeling methodology for battery electric buses''. Energy: Volume 207, 15 September 2020, 118241. Available online: *https://www.sciencedirect.com/science/article/pii/S0360544220313487*.

[492] Bae, SH., Park, J.W., Lee, S.H. ''Optimal SOC Reference Based Active Cell Balancing on a Common Energy Bus of Battery'' Available online: *http://koreascience.or.kr/article/JAKO201709641401357.pdf*.

[493] Azad, F.S., Ahasan Habib, A.K.M., Rahman, A., Ahmed I. ''Active cell balancing of Li-Ion batteries using single capacitor and single LC series resonant circuit.'' *https://beei.org/index.php/EEI/article/viewFile/1944/1491*.

[494] ''How to Improve EV Battery Performance in Cold Weather'' Accessed on March 31, 2023. *https://www.worktruckonline.com/10176367/how-to-improve-ev-battery-performance-in-cold-weather*.

[495] U.S. Energy Information Administration. Annual Energy Outlook 2022. Last accessed on 9/28/2022 at *https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2022&cases=ref2022~highmacro~lowmacro~highprice~lowprice~highogs~lowogs~hirencst~lorencst~aeo2019ref&sourcekey=0*.

[496] U.S. Department of Energy, Energy Information Administration. Annual Energy Outlook 2022, Table 8: Electricity Supply, Disposition, Prices, and Emissions. September 21, 2022. Available online: *https://www.eia.gov/outlooks/aeo/data/browser/#/?id=8-AEO2022&cases=ref2022&sourcekey=0*.

production by 80 percent to $1 per kilogram in one decade.[497] The BIL and IRA included funding for several hydrogen programs to accelerate progress towards the Hydrogen Shot and jumpstart the hydrogen market in the U.S.

For example, the BIL requires development of a National Clean Hydrogen Strategy and Roadmap. In September 2022, DOE released a draft of a holistic plan that shows how low-GHG hydrogen can help reduce emissions throughout the country by about 10 percent by 2050 relative to 2005 levels.[498] DRIA Chapter 2.5.3.1 further discusses DOE's National Clean Hydrogen Strategy and Roadmap.

Recent analysis from ANL using BEAN includes a hydrogen price of $4.37 per gallon diesel equivalent (gde) in 2030,[499] which equates to roughly $3.92 per kg hydrogen.[500] [501] This analysis was published after the IRA was passed, and reflects a lower H2 price in 2030 than was in the previous year's analysis.[502] This price is at the low end of the range published in DOE's ''Pathways to Commercial Liftoff'' report on Clean Hydrogen (''Liftoff Report''), which projects that heavy-duty road transport can expect to pay a retail price of between $4 and $5 per kg of hydrogen in 2030 if advances in distribution and storage are commercialized.[503] This price incorporates BIL and IRA incentives for hydrogen.[504] Other DOE estimates prior to the IRA ranged from $6-$7 per kg in 2030, inclusive of production, delivery, and dispensing, with the range representing uncertainty in the assumed rate of technological progress.[505] [506] [507]

Other available estimates explore clean hydrogen production costs alone. For example, Rhodium Group found a hydrogen producer price of $0.39–1.92 per kg, including the IRA hydrogen production tax credit and assuming the use of utility-scale solar to produce hydrogen.[508] McKinsey projected green hydrogen costs of roughly $1.30–2.30 per kg in 2030, produced using alkaline electrolyzers. Their analysis did not mention the IRA. It showed lower costs for blue and grey hydrogen in 2030 before green hydrogen out-competes both by around 2040.[509] An ICCT estimate of average hydrogen production costs in 2030 is closer to $3.10 per kg, but their analysis did not consider IRA impacts.[510]

According to the Hydrogen Council, increasing the scale and rate of use of hydrogen across sectors could substantially reduce the costs of local distribution. As trucking capacity increases and the use, size, and density of refueling stations increases, equipment manufacturing costs could decline. For example, they suggest that 2020 distribution costs of about $5–6 per kg could decline by approximately 80 percent to get to $1–1.50 per kg in 2030.[511] A 2018 DOE document details similar opportunities to reach $2 per kg in distribution and dispensing costs. In addition to learning and economies of scale associated with scaled use, they suggest that potential research and development advancements related to the efficiency and reliability of components could help meet related DOE price targets.[512]

As further explained in DRIA Chapter 2.5.3.1, for use in HD TRUCS, we projected the future hydrogen prices shown in Table II–18 for 2027–2030 and beyond. These values are based on ANL BEAN values and are in line with price projections in DOE's Liftoff Report that consider the impacts of BIL and IRA. We converted the $/kg estimates for 2025 and 2030 included in BEAN to dollar per kg by using the conversion factor of 1 gallon of diesel is equivalent to 1.116 kg of hydrogen, based on its lower heating value. We rounded up to the nearest $0.50 increment given the uncertainty of projections, and then interpolated for 2027 to 2029. Prices for 2030 and beyond are held constant in BEAN and in HD TRUCS.

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[497] Satyapal, Sunita. ''2022 AMR Plenary Session''. U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office. June 6, 2022. Available online: *https://www.energy.gov/sites/default/files/2022-06/hfto-amr-plenary-satyapal-2022-1.pdf.*

[498] U.S. Department of Energy. ''DOE National Clean Hydrogen Strategy and Roadmap''. Draft September 2022. Available online: *https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf.*

[499] Islam, Ehsan Sabri, Ram Vijayagopal, Aymeric Rousseau. ''A Comprehensive Simulation Study to Evaluate Future Vehicle Energy and Cost Reduction Potential'', *Report to the U.S. Department of Energy, Contract ANL/ESD–22/6,* October 2022. See Medium- and heavy-duty vehicles (techno-economic analysis with BEAN). Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

[500] The conversion used was 1 gallon of diesel is equivalent to 1.116 kg of hydrogen, based on a lower heating value.

[501] Hydrogen Tools ''Energy Equivalency of Fuels (LHV)''. U.S. Department of Energy: Pacific Northwest National Laboratory. Available online: *https://h2tools.org/hyarc/hydrogen-data/energy-equivalency-fuels-lhv.*

[502] Islam, Ehsan Sabri. Ram Vijayagopal, Ayman Moawad, Namdoo Kim, Benjamin Dupont, Daniela Nieto Prada, Aymeric Rousseau, ''A Detailed Vehicle Modeling & Simulation Study Quantifying Energy Consumption and Cost Reduction of Advanced Vehicle Technologies Through 2050,'' *Report to the U.S. Department of Energy, Contract ANL/ESD–21/10,* October 2021. See previous reports and analysis: 2021. Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

[503] U.S. Department of Energy. ''Pathways to Commercial Liftoff: Clean Hydrogen''. March 2023. Available online: *https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf.*

[504] The Liftoff Report and draft National Strategy say that fuel cell trucks and buses can be one of the first new sectors to adopt hydrogen because of a higher ''willingness to pay'' for fuel (*i.e.,* a threshold price at which they can remain competitive) compared to other hard-to-decarbonize sectors like chemicals and steel.

[505] Islam, Ehsan Sabri., Ram Vijayagopal, Ayman Moawad, Namdoo Kim, Benjamin Dupont, Daniela Nieto Prada, Aymeric Rousseau, ''A Detailed Vehicle Modeling & Simulation Study Quantifying Energy Consumption and Cost Reduction of Advanced Vehicle Technologies Through 2050,'' *Report to the U.S. Department of Energy, Contract ANL/ESD–21/10,* October 2021. See previous reports and analysis: 2021. Available online: *https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.*

[506] Hunter, Chad, Michael Penev, Evan Reznicek, Jason Lustbader, Alicia Birkby, and Chen Zhang. ''Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks''. National Renewable Energy Lab. September 2021. Available online: *https://www.nrel.gov/docs/fy21osti/71796.pdf.*

[507] Ledna et al. ''Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis''. U.S. Department of Energy, National Renewable Energy Laboratory. March 2022. Available online: *https://www.nrel.gov/docs/fy22osti/82081.pdf.*

[508] Larsen, John et al. ''Assessing the Climate and Clean Energy Provisions in the Inflation Reduction Act''. Rhodium Group. August 12, 2022. Available online: *https://rhg.com/research/climate-clean-energy-inflation-reduction-act/.*

[509] Heid, Bernd et al. ''Five charts on hydrogen's role in a net-zero future''. McKinsey Sustainability. October 25, 2022. Available online: *https://www.mckinsey.com/capabilities/sustainability/our-insights/five-charts-on-hydrogens-role-in-a-net-zero-future.*

[510] Zhou, Yuanrong, et al. ''Current and future cost of e-kerosene in the United States and Europe''. Working Paper 2022–14: The International Council on Clean Transportation. March 2022. Available online: *https://theicct.org/wp-content/uploads/2022/02/fuels-us-europe-current-future-cost-ekerosene-us-europe-mar22.pdf.*

[511] Hydrogen Council. ''Path to hydrogen competitiveness: A cost perspective''. January 20, 2020. Available online: *https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf.*

[512] Rustagi, Neha et al. Record 18003: ''Current Status of Hydrogen Delivery and Dispensing Costs and Pathways to Future Cost Reductions''. U.S. Department of Energy. December 17, 2018. Available online: *https://www.hydrogen.energy.gov/pdfs/18003_current_status_hydrogen_delivery_dispensing_costs.pdf.*

TABLE II–18—PRICE OF HYDROGEN FOR CYS 2027–2030+

[2021$]

	2027	2028	2029	2030 and beyond
$/kg H2	6.10	5.40	4.70	4.00

We request comment on our approach and assessment of future fuel, electricity, and hydrogen prices for the transportation sector.

6. Payback

After assessing the suitability of the technology and costs associated with ZEVs, a payback calculation was performed on each of the 101 HD TRUCS vehicles for the BEV technology and FCEV technology that we were considering for the technology packages for each use case for each MY in the MY 2027–2032 timeframe. The payback period was calculated by determining the number of years that it would take for the annual operational savings of a ZEV to offset the incremental upfront purchase price of a BEV or FCEV (after accounting for the IRA section 13502 battery tax credit and IRA section 13403 vehicle tax credit as described in DRIA Chapters 2.4.3.1 and 2.4.3.5, respectively) and charging infrastructure costs (for BEVs) when compared to purchasing a comparable ICE vehicle. The ICE vehicle and ZEV costs calculated include the retail price equivalent (RPE) multiplier of 1.42 to include both direct and indirect manufacturing costs, as discussed further in DRIA Chapter 3. The operating costs include the diesel, hydrogen or electricity costs, DEF costs, and the maintenance and repair costs. The payback results are shown in Table 2–75 and Table 2–76 for BEVs for MY 2027 and MY 2032, and in Table 2–77 for FCEVs for MY 2032 of DRIA Chapter 2.

F. Proposed Standards

Similar to the approach we used to support the feasibility of the HD GHG Phase 2 vehicle CO_2 emission standards, we developed technology packages that, on average, would meet each of the proposed standards for each regulatory subcategory of vocational vehicles and tractors after considering the various factors described in this section, including technology costs for manufacturers and costs to purchasers. We applied these technology packages to nationwide production volumes to support the proposed Phase 3 GHG vehicle standards. The technology packages utilize the averaging portion of the longstanding ABT program, and we project manufacturers would produce a mix of HD vehicles that utilize ICE-powered vehicle technologies and ZEV technologies, with specific adoption rates for each regulatory subcategory of vocational vehicles and tractors for each MY. Note that we have analyzed a technology pathway to support the feasibility and appropriateness of each proposed level of stringency for each proposed standard, but manufacturers would be able to use a combination of HD engine or vehicle GHG-reducing technologies, including zero-emission and ICE technologies, to meet the standards.

The proposed standards are shown in Table II–19 and Table II–20 for vocational vehicles and Table II–21and Table II–22 for tractors. We request comment and data on our proposal as well as comment and data supporting more or less stringent HD vehicle GHG standards than those proposed, as specified in Section II.H. We also request comment on setting additional new HD vehicle GHG standards in MYs 2033 through 2035 that are more progressively stringent than the MY 2032 standards and that either continue the approach and trajectory of the proposed standards or utilize a different approach and trajectory that we solicited comment on in this proposal.

The approach we used to select the proposed standards, described in this Section II, does not specifically include accounting for ZEV adoption rates that would result from compliance with the California ACT program. The approach we used developed ZEV technology adoption rates on a nationwide basis. EPA granted the California ACT waiver request on March 30, 2023, which did not allow sufficient time for us to consider an alternative approach for this proposal. With the granting of the California ACT waiver, we intend to consider for the final rule how vehicles sold to meet the ACT requirement in California and other states that may adopt it under CAA section 177 would impact or be accounted for in the standard setting approach described in this Section II. For example, we may adjust our reference case to reflect the ZEV levels projected from ACT in California and other states. We also may consider increasing the technology adoption rates in the technology packages and correspondingly increase the stringency of the proposed Phase 3 emission standards to account for the incremental difference in the projected ZEV adoption levels from the proposed Phase 3 emission standards and the adoption levels projected from ACT in those states. We welcome comment on how to consider this ACT in our proposed approach or in other approaches.

TABLE II–19—PROPOSED MY 2027 THROUGH 2032+ VOCATIONAL VEHICLE CO_2 EMISSION STANDARDS

[Grams/ton-mile]

Model year	Subcategory	CI light heavy	CI medium heavy	CI heavy heavy	SI light heavy	SI medium heavy
2027	Urban	294	213	232	340	252
	Multi-Purpose	257	190	193	299	223
	Regional	218	173	152	246	202
2028	Urban	275	209	228	321	248
	Multi-Purpose	238	186	189	280	219
	Regional	199	169	148	227	198
2029	Urban	255	202	225	301	241
	Multi-Purpose	218	179	186	260	212

TABLE II–19—PROPOSED MY 2027 THROUGH 2032+ VOCATIONAL VEHICLE CO_2 EMISSION STANDARDS—Continued

[Grams/ton-mile]

Model year	Subcategory	CI light heavy	CI medium heavy	CI heavy heavy	SI light heavy	SI medium heavy
	Regional	179	162	145	207	191
2030	Urban	238	195	200	284	234
	Multi-Purpose	201	172	161	243	205
	Regional	162	155	120	190	184
2031	Urban	219	188	193	265	227
	Multi-Purpose	182	165	154	224	198
	Regional	143	148	113	171	177
2032 and later	Urban	179	176	177	225	215
	Multi-Purpose	142	153	138	184	186
	Regional	103	136	97	131	165

TABLE II–20—PROPOSED MY 2027 THROUGH 2032+ OPTIONAL CUSTOM CHASSIS VOCATIONAL VEHICLE CO_2 EMISSION STANDARDS

[Grams/ton-mile]

Optional custom chassis vehicle category	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032 and later
School Bus	190	182	176	168	163	149
Other Bus	286	269	255	237	220	189
Coach Bus	205	205	205	185	164	154
Refuse Hauler	253	241	232	221	212	191
Concrete Mixer	259	250	240	231	224	205
Motor home	226	226	226	226	226	226
Mixed-use vehicle	316	316	316	316	316	316
Emergency vehicle	319	319	319	319	319	319

TABLE II–21—PROPOSED MY 2027 THROUGH MY 2032+ TRACTOR CO_2 EMISSION STANDARDS

[Grams/ton-mile]

Model year	Roof height	Class 7 all cab styles	Class 8 day cab	Class 8 sleeper cab
2027	Low Roof	86.6	66.1	64.1
	Mid Roof	93.1	70.2	69.6
	High Roof	90.0	68.1	64.3
2028	Low Roof	84.7	64.6	64.1
	Mid Roof	91.0	68.6	69.6
	High Roof	88.0	66.6	64.3
2029	Low Roof	81.8	62.4	64.1
	Mid Roof	87.9	66.3	69.6
	High Roof	85.0	64.3	64.3
2030	Low Roof	77.0	58.7	57.7
	Mid Roof	82.7	62.4	62.6
	High Roof	80.0	60.6	57.9
2031	Low Roof	67.3	51.4	51.3
	Mid Roof	72.4	54.6	55.7
	High Roof	70.0	53.0	51.4
2032 and Later	Low Roof	63.5	48.4	48.1
	Mid Roof	68.2	51.5	52.2
	High Roof	66.0	50.0	48.2

TABLE II–22—PROPOSED MY 2027 THROUGH MY 2032+ HEAVY-HAUL TRACTOR CO_2 EMISSION STANDARDS

[Grams/ton-mile]

Model year	CO_2 emission standards
2027	48.3
2028	48.3
2029	48.3
2030	43.0
2031	42.5
2032 and Later	41.1

We are proposing new CO_2 emission standards using the regulatory subcategories we adopted in HD GHG Phase 2, as discussed in Section II.C. As we discuss later in this subsection, the fraction of ZEVs and fraction of ICE vehicles in the technology packages varies across the 101 HD TRUCS vehicle types and thus in the regulatory subcategories. We recognize there may be different regulatory structures that could be used to reduce GHG emissions from the HD vehicles.

During the development of this proposed action, EPA has heard requests from several stakeholders that EPA consider establishing CO_2 standards for specific vehicle applications (*e.g.,* school buses, urban buses, pick-up and delivery vehicles, drayage trucks, etc.), as a complement to CO_2 emission standards that utilize the existing HD GHG Phase 2 program structure. There are several reasons stakeholders have explained for asking EPA to consider this approach. One reason is to target specific applications which may be the most suited for more stringent CO_2 standards at a more rapid pace than a broader regulatory subcategory. For example, a pick-up and delivery application may be more suitable for faster adoption of BEV technology than the broader subcategory of medium heavy-duty vocational vehicles. This approach could further support the industry and marketplace focusing resources on specific applications in the near term in response to more stringent EPA standards, rather than potentially spreading those resources across a broader range of products. Another reason some stakeholders suggested EPA consider an application-specific approach would be to accelerate the deployment of ZEVs that are concentrated in frontline communities to reduce air pollution more quickly in those communities.

We note the current HD GHG Phase 2 program structure includes standards at broad vehicle subcategory levels (*e.g.,* light heavy-duty vocational vehicles, medium heavy-duty vocational vehicles, etc.) as well as optional CO_2 emission standards for seven specific custom chassis applications (*e.g.,* emergency vehicles, motor homes, cement mixers, school buses). It is important to note the suggestions from stakeholders for EPA to establish application-specific standards for some heavy-duty vehicles to accelerate emission reductions in the Phase 3 program are much different than the reasons EPA established the HD GHG Phase 2 optional custom chassis standards. EPA established the optional custom chassis program for a number of reasons, including: a recognition there are manufacturers who produce specialized heavy-duty vocational vehicles where some of the technologies EPA used for the primary program standards would be unsuited for use, concern that the primary program drive cycles are either unrepresentative or unsuitable for certain specialized heavy-duty vocational vehicles, concern that some manufacturers of these specialized vocational vehicles have limited product offerings such that the primary program's emissions averaging is not of practical value as a compliance flexibility, and also concern regarding the appropriateness of the primary program's vocational vehicle standards as applied to certain specialized/custom vocational vehicles (See 81 FR 73531 and 81 FR 73686, October 25, 2016).

Potential challenges EPA recognizes with an application-specific, more stringent CO_2 standard approach include determining what criteria EPA would use to establish application-specific standards, how such standards would fit in the overall Phase 3 program structure, and the difficulty in defining some applications. For example, a drayage truck in general can be any Class 8 tractor (both sleeper cab and day cab) that is used to move shipping containers to and from ports from other locations, including rail yards, shipping terminals, or other destinations. A drayage tractor is not a unique application nor do these tractors contain unique design features to differentiate them from other tractors—nearly any tractor can be used for drayage operation. Nevertheless, in consideration of potentially targeting specific applications most suited for more stringent CO_2 standards at a more rapid pace than a broader regulatory subcategory, EPA requests comment on a standards structure for Phase 3 which would establish unique, mandatory, application-specific standards for some subset of heavy-duty vehicle applications. EPA requests comment on what data, what program structure, what applications, and what criteria EPA should consider for designing application-specific standards. EPA also requests comment on how the application-specific CO_2 standards would interact with the broader Phase 3 program structure EPA has included in this proposal, including the CO_2 emissions averaging, banking, and trading program. For example, if EPA were to separate these applications and apply more stringent standards, EPA requests comment on whether emission credits should be allowed to be averaged across the primary Phase 3 program and the application specific standards, and if yes, what limits if any should apply to those standards. Under this example, EPA may consider that allowing credits to flow into an application-specific category could undermine the reasons for establishing such a category (to accelerate the application of technology and accelerate emission reductions), while allowing credits generated within an application specific category to flow into the primary program may provide incentive for even greater reductions from the application-specific category.

To support that the proposed standards are achievable through the technology pathway projected in the technology packages, the proposed CO_2 standards for each subcategory were determined in two steps giving consideration to costs, lead time, and other factors, as described in this section and Section II.G. First, we determined the technology packages that include ZEVs and ICE vehicles with GHG-reducing technologies for each of the vocational vehicle and tractor subcategories as discussed in Section II.F.1. Then we determined the numeric level of the proposed standards as discussed in Sections II.F.2 and II.F.3.

1. Technology Adoption Rates in the Technology Packages

We based the proposed standards on technology packages that include both ICE vehicle and ZEV technologies. In our analysis, the ICE vehicles include a suite of technologies that represent a vehicle that meets the existing MY 2027 Phase 2 CO_2 emission standards. These technologies exist today and continue to evolve to improve the efficiency of the engine, transmission, drivetrain, aerodynamics, and tire rolling resistance in HD vehicles and therefore reduce their CO_2 emissions. There also may be opportunity for further adoption of these Phase 2 ICE technologies beyond the adoption rates used in the HD GHG Phase 2 rule. In addition, the heavy-duty industry continues to develop CO_2-reducing technologies such as hybrid powertrains and H2–ICE powered vehicles.

In the transportation sector, new technology adoption rates often follow an S-shape. As discussed in the preamble to the HD GHG Phase 2 final rule, the adoption rates for a specific technology are initially slow, followed by a rapid adoption period, then leveling off as the market saturates, and not always at 100 percent.[513] For this proposal, we developed a method to project adoption rates of BEVs and FCEVs in the HD vehicle market after considering methods in the literature. Our adoption function, and methods considered and explored in the formulation of the method used in this proposal, are described in DRIA Chapter 2.7.9. As stated there, given information currently available and our experience with the HD vehicle industry, when purchasing a new vehicle, we believe that the payback period is the most

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[513] 81 FR 73558, Oct 25, 2016.

relevant metric to determine adoption rates in the HD vehicle industry.

The ZEV adoption rate schedule, shown in Table II–23, shows that when the payback is immediate, we project up to 80 percent of a manufacturer's fleet to be ZEV, with diminishing adoption as the payback period increases.[514] The schedule was used to assign ZEV adoption rates to each of the 101 HD TRUCS vehicle types based on its payback period for MYs 2027 and 2032.

We phased in the proposed standards gradually between MYs 2027 and 2032 to address potential lead time concerns associated with feasibility for manufacturers to deploy ZEV technologies that include consideration of time necessary to ramp up battery production, including the need to increase the availability of critical raw materials and expand battery production facilities, as discussed in Section II.D.2.ii. We also phased in the proposed standards recognizing that it will take time for installation of EVSE by the BEV purchasers. We project BEV adoption as early as MY 2027, and we project adoption of FCEVs in the technology packages starting in MY 2030 for select applications that travel longer distances and/or carry heavier loads (*i.e.,* coach buses, heavy-haul tractors, sleeper cab tractors, and day cab tractors). There has been only limited development of FCEVs for the HD market to date, therefore our assessment is that it would be appropriate to provide manufacturers with additional lead time to design, develop, and manufacture FCEV models, but that it would be feasible by MY 2030. With substantial Federal investment in low-GHG hydrogen production (see DRIA Chapter 1.8.2), we anticipate that the price of hydrogen fuel could drop enough by 2030 to make HD FCEVs cost-competitive with comparable ICE vehicles for some duty cycles. We also note that the hydrogen infrastructure is expected to need additional time to further develop, as discussed in greater detail in DRIA Chapter 1.8, but we expect the refueling needs can be met by MY 2030. We also recognize the impact regulations can have on technology and recharging/refueling infrastructure development and deployment. Thus we request comment and data on our proposed adoption rate, including schedule and methods. We also request comment and data to support other adoption rate schedules; see also Section II.H.

TABLE II–23—ADOPTION RATE SCHEDULE IN HD TRUCS

Payback (yr)	MY 2027 adoption rates for BEVs (%)	MY 2032 adoption rates for BEVs and FCEVs (%)
<0	80	80
0–1	55	55
1–2	32	45
2–4	18	35
4–7	13	25
7–10	10	20
10–15	5	15
>15	0	5

We applied an additional constraint within HD TRUCS that limited the maximum penetration rate to 80 percent for any given vehicle type. This conservative limit was developed after consideration of the actual needs of the purchasers related to two primary areas of our analysis. First, this 80 percent volume limit takes into account that we sized the batteries, power electronics, e-motors, and infrastructure for each vehicle type based on the 90th percentile of the average VMT. We utilize this technical assessment approach because we do not expect heavy-duty OEMs to design ZEV models for the 100th percentile VMT daily use case for vehicle applications, as this could significantly increase the ZEV powertrain size, weight, and costs for a ZEV application for all users, when only a relatively small part of the market would need such capabilities. Therefore, the ZEVs we analyzed and have used for the feasibility and cost projections for this proposal are likely not appropriate for 100 percent of the vehicle applications in the real-world. Our second consideration for including an 80 percent volume limit for ZEVs is that we recognize there is a wide variety of real-world operation even for the same type of vehicle. For example, some owners may not have the ability to install charging infrastructure at their facility, or some vehicles may need to be operational 24 hours a day. Under our proposed standards, ICE vehicles would continue to be available to address these specific vehicle applications. We request comment, data, and analysis on both of these considerations and our use of an 80 percent volume limit. Our request for comment includes a request for data to inform an assessment of the distribution of daily miles traveled and the distribution of the number of hours available daily to charge for each of the vehicle types that we could use to update a constraint like this in the final rulemaking analysis.

After the technology assessment, as described in Section II.D.4 and DRIA Chapter 2, and payback analysis, as described in Section II.E.6 and DRIA Chapter 2.8.2, EPA determined the ICE vehicle and ZEV adoption rates for each regulatory subcategory. We first determined the ZEV adoption rates projected for each of the 101 vehicle types for MYs 2027 and 2032, which can be found in DRIA Chapter 2.8.3.1. We then aggregated the projected ZEV adoption rates for the specific vehicle types into their respective regulatory subcategories relative to the vehicle's sales weighting, as described in DRIA Chapter 2.9.1. The resulting projected ZEV adoption rates (shown in Table II–24) and projected ICE vehicle adoption rates that achieve a level of CO_2 emissions performance equal to the existing MY 2027 emission standards (shown in Table II–21) were built into our technology packages. We request comment and data on our projected adoption rates in the technology packages as well as data supporting higher or lower adoption rates than the projected levels. We also request comment on projecting adoption rates out through MY 2035.

TABLE II–24—PROJECTED ZEV ADOPTION RATES FOR MYS 2027–2032 TECHNOLOGY PACKAGES

Regulatory subcategory	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 (%)
LHD Vocational	22	28	34	39	45	57
MHD Vocational	19	21	24	27	30	35
HHD Vocational	16	18	19	30	33	40
MHD All Cab and HHD Day Cab Tractors	10	12	15	20	30	34
Sleeper Cab Tractors	0	0	0	10	20	25
Heavy Haul Tractors	0	0	0	11	12	15

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[514] See DRIA Chapter 2.7.9 for additional information on the development of the adoption rate schedule for the technology packages for the proposed standards.

TABLE II–24—PROJECTED ZEV ADOPTION RATES FOR MYS 2027–2032 TECHNOLOGY PACKAGES—Continued

Regulatory subcategory	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 (%)
Optional Custom Chassis: School Bus	30	33	35	38	40	45
Optional Custom Chassis: Other Bus	0	6	11	17	23	34
Optional Custom Chassis: Coach Bus [515]	0	0	0	10	20	25
Optional Custom Chassis: Refuse Hauler	15	19	22	26	29	36
Optional Custom Chassis: Concrete Mixer	18	21	24	27	29	35
Optional Custom Chassis: Emergency Vehicles	0	0	0	0	0	0
Optional Custom Chassis: Recreational Vehicles	0	0	0	0	0	0
Optional Custom Chassis: Mixed Use	0	0	0	0	0	0

TABLE II–25—PROJECTED ADOPTION RATES FOR MYS 2027–2032 ICE VEHICLES WITH CO_2-REDUCING TECHNOLOGIES IN THE TECHNOLOGY PACKAGES

Regulatory subcategory	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 (%)
LHD Vocational	78	72	66	61	55	43
MHD Vocational	81	79	76	73	70	65
HHD Vocational	84	82	81	70	67	60
MHD All Cab and HHD Day Cab Tractors	90	88	85	80	70	66
Sleeper Cab Tractors	100	100	100	90	80	75
Heavy Haul Tractors	100	100	100	89	88	85
Optional Custom Chassis: School Bus	70	67	65	62	60	55
Optional Custom Chassis: Other Bus	100	94	89	83	77	66
Optional Custom Chassis: Coach Bus [516]	100	100	100	90	80	75
Optional Custom Chassis: Refuse Hauler	85	81	78	74	71	64
Optional Custom Chassis: Concrete Mixer	82	79	76	73	71	65
Optional Custom Chassis: Emergency Vehicles	100	100	100	100	100	100
Optional Custom Chassis: Recreational Vehicles	100	100	100	100	100	100
Optional Custom Chassis: Mixed Use	100	100	100	100	100	100

2. Calculation of the Proposed Tractor Standards

The proposed CO_2 emission standards for the tractor subcategories are calculated by determining the CO_2 emissions from a technology package that consists of both ICE-powered vehicles and ZEVs. The projected fraction of ZEVs that emit zero grams CO_2/ton-mile at the tailpipe are shown in Table II–24. The remaining fraction of vehicles in the technology package are ICE-powered vehicles that include the technologies listed in Table II–1 (reflecting the GEM inputs for the individual technologies that make up the technology packages that meets the existing MY 2027 CO_2 tractor emission standards). Thus, in the technology packages, the ICE-powered vehicles emit at the applicable existing MY 2027 CO_2 emission standards, as shown in Table II–26. We request comment on ICE vehicle technologies that could support more stringent standards than those proposed.

The proposed CO_2 emission standards for each model year are calculated by multiplying the fraction of ICE-powered vehicles in each technology package by the applicable existing MY 2027 CO_2 emission standards. The proposed standards are presented in Section II.F.

TABLE II–26—EXISTING MY 2027 AND LATER TRACTOR CO_2 EMISSION STANDARDS

[Grams/ton-mile]

	Class 7 All cab styles	Class 8 Day cab	Class 8 Sleeper cab	Heavy-haul
Low Roof	96.2	73.4	64.1	48.3
Mid Roof	103.4	78.0	69.6	
High Roof	100.0	75.7	64.3	

3. Calculation of the Proposed Standards for Vocational Vehicles

The proposed CO_2 emission standards for the vocational vehicles regulatory subcategories are calculated by determining the CO_2 emissions from a technology package that consists of both ICE-powered vehicles and ZEVs. The projected fraction of ZEVs that emit zero grams CO_2/ton-mile at the tailpipe are shown in Table II–24. The remaining fraction of vehicles in the technology package are ICE-powered vehicles that include the technologies listed in Table II–2 (reflecting the GEM inputs for the individual technologies that make up the technology packages that meets the existing MY 2027 CO_2 vocational vehicles emission standards). We request comment on ICE vehicle technologies that could support more stringent standards than those proposed.

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[515] We are proposing to use the same adoption rates projected for sleeper cab tractors, which are also projected to be FCEVs in MYs 2030–2032.

[516] We are proposing to use the same adoption rates projected for sleeper cab tractors, which are also projected to be FCEVs in MYs 2030–2032.

As discussed in Section II.C, vocational vehicle CO_2 emission standards are subdivided by weight class, SI-powered or CI-powered vehicles, and by operation. There are a total of 15 different vocational vehicle standards in the primary program for each model year, in addition to the optional custom chassis standards. The existing MY 2027 vocational vehicle emission standards are shown in Table II–27 (which, like tractors, are what the ICE-powered vehicles emit at in the proposed technology packages). The HD GHG Phase 2 structure enables the technologies that perform best during urban driving or the technologies that perform best at highway driving to each be properly recognized over the appropriate drive cycles. The HD GHG Phase 2 structure was developed recognizing that there is not a single package of engine, transmission, and driveline technologies that is suitable for all ICE-powered vocational vehicle applications. In this proposal, we are continuing the current approach of deeming tailpipe emissions of regulated GHG pollutants (including CO_2) to be zero from electric vehicles and hydrogen fuel cell vehicles.[517] Therefore, the need to recognize the variety in vocational vehicle CO_2 emissions may no longer be necessary for ZEVs because ZEVs are deemed to have zero CO_2 emissions. Similarly, the existing SI and CI distinction within vocational vehicle regulatory subcategory structure is not optimal for vocational ZEVs because they cannot be technically described as either SI-powered or CI-powered.

TABLE II–27—EXISTING MY 2027 AND LATER VOCATIONAL VEHICLE CO_2 EMISSION STANDARDS

[Grams/ton-mile]

	CI light heavy	CI medium heavy	CI heavy heavy	SI light heavy	SI medium heavy
Urban	367	258	269	413	297
Multi-Purpose	330	235	230	372	268
Regional	291	218	189	319	247
Optional Custom Chassis: School Bus	271				
Optional Custom Chassis: Other Bus	286				
Optional Custom Chassis: Coach Bus	205				
Optional Custom Chassis: Refuse Hauler	298				
Optional Custom Chassis: Concrete Mixer	316				
Optional Custom Chassis: Motor Home	226				
Optional Custom Chassis: Mixed-Use Vehicle	316				
Optional Custom Chassis: Emergency Vehicle	319				

Also discussed in Section II.C, the vehicle ABT program allows credits to exchange with all vehicles within a weight class. ABT CO_2 emission credits are determined using the equation in 40 CFR 1037.705. The credits are calculated based on the difference between the applicable standard for the vehicle and the vehicle's family emission limit multiplied by the vehicle's regulatory payload and useful life. For example, as shown in Table II–28, using the existing light heavy-duty vocational vehicle MY 2027 CO_2 emission standards, the amount of credit a ZEV would earn varies between 124 Mg and 177 Mg, depending on the regulatory subcategory it would be certified to. We recognize that in many cases it may not be clear to the manufacturer whether to certify the vocational ZEV to a SI or CI regulatory subcategory, *i.e.* for the manufacturer to know whether the ZEV was purchased in lieu of a comparable CI-powered or SI-powered vehicle. Furthermore, as just discussed, because ZEVs have zero CO_2vehicle exhaust emissions the programmatic basis for requiring the manufacturer to differentiate the ZEVs by operation to appropriately account for the variety of driveline configurations would not exist, though the amount of credit the ZEV would earn would depend on the regulatory subcategory selected for certification. In short, we recognize the difficulties in, and consequences of, determining which of the regulatory subcategories to which a ZEV should be certified under the existing HD GHG Phase 2 emission standards' structure for vocational vehicles. To address this concern, we are proposing a two-step approach. First, we propose to revise the ABT credit calculation regulations; this change would begin in MY 2027. Second, we derived the proposed MY 2027 and later standards accounting for the proposed changes to the ABT credit calculations. Note that BEVs, FCEVs, and H2–ICE vehicles would still be able to be certified to the vocational vehicle urban, multi-purpose, or regional standards or to the applicable optional custom chassis standards.

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[517] See 40 CFR 1037.150(f) for our proposed interim provision that CO_2 emissions would be deemed to be zero, with no CO_2-related testing, for BEVs, FCEVs, and vehicles powered by H2–ICE that solely use hydrogen fuel.

TABLE II—28 EXAMPLE CO_2 EMISSION CREDIT CALCULATIONS FOR LIGHT HEAVY-DUTY (LHD) BEV/FCEVS BY REGULATORY SUBCATEGORY BASED OFF THE EXISTING MY 2027 STANDARDS

	SI LHD urban	SI LHD multi-purpose	SI LHD regional	CI LHD urban	CI LHD multi-purpose	CI LHD regional
Existing MY 2027 Standard (gCO_2/ton-mile)	413	372	319	367	330	291
CO_2 credit per BEV or FCEV (Mg)	177	159	136	157	141	124

EPA proposes to revise the definition of the variable ''Std'' in 40 CFR 1037.705 to establish a common reference emission standard for vocational vehicles with tailpipe CO_2 emissions deemed to be zero (*i.e.,* BEVs, FCEVs, and vehicles with engines fueled with pure hydrogen).[518] Beginning in MY 2027, manufacturers would use the applicable Compression-Ignition Multi-Purpose (CI MP) standard for their vehicle's corresponding weight class when calculating ABT emission credits for vocational vehicles with tailpipe CO_2 emissions deemed to be zero.[519] We selected the CI MP standard because it is the regulatory subcategory with the highest production volume in MY 2021. We also recognize a need to balance two different timing considerations concerning the potential impacts of this proposed change. First, prior to the effective date of this proposed change, there is a potential for manufacturers producing BEVs, FCEVs, and certain H2–ICE vehicles to generate larger credits than they would after this change, depending on the vocational vehicle subcategory to which a vehicle is certified. Second, we recognize that manufacturers develop their emissions compliance plans several years in advance to manage their R&D and manufacturing investments. After taking these into account, we propose that this regulation revision become effective beginning in MY 2027 to provide manufacturers with sufficient time to adjust their production plans, if necessary. We request comment on this proposed revision.

Taking the proposed change to the ZEV ABT credit calculation into account, if we calculated the proposed standards by multiplying the fraction of ICE-powered vehicles in the technology package (by model year) by the applicable existing MY 2027 CO_2 emission standards, like we did for tractors, then this would lead to a scenario where it would take different levels of ZEV adoption rates to meet the proposed standards in each regulatory subcategory than we included in our assessment. Therefore, we used an alternate approach that maintains the same level of ZEV adoption rates in each regulatory subcategory within a weight class, taking the proposed change to the ZEV ABT credit calculation into account. The equation for calculating the proposed MY 2032 vocational vehicle standards is shown in Equation II–1. This equation is used to calculate the proposed standards for each vocational vehicle regulatory subcategory, using the existing MY 2027 CI MP standard for each corresponding weight class (LH, MH, HH). Equation II–2 through Equation II–4 show how the proposed Equation II–1 would be used for each regulatory subcategory for an example model year (MY 2032). The existing MY 2027 standards can be found in Table II–27, and the projected ZEV adoption rates by model year are in Table II–24. The same equations were used for the proposed MY 2027 through 2031 standards but replacing the MY 2032 Standards and ZEV adoption rates with values for the specific model year. The results of the calculations for the MY 2032 LHD vocational vehicles are shown in Table II–29. The calculations for the other model years and vocational vehicle subcategories are shown in DRIA Chapter 2.9.

Equation II–1: Proposed Vocational Vehicle Standard Calculation

$$\text{MY 2032 Std}_{\text{RegSubcat}} = \text{Existing 2027 Std}_{\text{RegSubcat}} - (\text{MY 2027 Existing CI MP Std}_{\text{RegSubcat}} * \text{MY 2032 ZEV\%})$$

Equation II–2: Proposed Vocational Vehicle Standard Calculation Light Heavy-Duty Regulatory Subcategories for MY 2032

$$\text{MY 2032 Std}_{\text{RegSubcat}} = \text{Existing 2027 Std}_{\text{RegSubcat}} - (330 \text{ g/mi} * 57\%)$$

Equation II–3: Proposed Vocational Vehicle Standard Calculation Medium Heavy-Duty Regulatory Subcategories for MY 2032

$$\text{MY 2032 Std}_{\text{RegSubcat}} = \text{Existing 2027 Std}_{\text{RegSubcat}} - (235 \text{ g/mi} * 35\%)$$

Equation II–4: Proposed Vocational Vehicle Standard Calculation Heavy Heavy-Duty Regulatory Subcategories for MY 2032

$$\text{MY 2032 Std}_{\text{RegSubcat}} = \text{Existing 2027 Std}_{\text{RegSubcat}} - (230 \text{ g/mi} * 40\%)$$

TABLE II–29—CALCULATIONS OF THE PROPOSED MY 2032 CO_2 EMISSION STANDARDS FOR LIGHT HEAVY-DUTY (LHD) VOCATIONAL VEHICLES

	SI LHD urban	SI LHD multi-purpose	SI LHD regional	CI LHD urban	CI LHD multi-purpose	CI LHD regional
Existing MY 2027 Standard (gCO_2/ton-mile)	413	372	319	367	330	291
ZEV Adoption Rate in Technology Package	57%	57%	57%	57%	57%	57%
Proposed CO_2 Emission Standard (gCO_2/ton-mile)	225	184	131	179	142	103

The calculations for the other model years and vocational vehicle subcategories are shown in DRIA Chapter 2.9. We welcome comment on this approach to taking the proposed change to the ZEV ABT credit

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[518] See the proposed updates to 40 CFR 1037.150(f).

[519] See 40 CFR 1037.105 for the compression-ignition multi-purpose CO_2 standards.

calculation into account in setting vocational vehicle standards. We also request comment alternatively on using the same approach for vocational vehicles as we are proposing for tractors (see Section II.F.2).

After considering the potential concerns with ZEVs fitting into the existing HD GHG Phase 2 vocational vehicle regulatory subcategories structure, we are proposing to maintain the existing HD GHG Phase 2 vocational vehicle regulatory subcategories with the proposed changes noted in this section. We request comment on possible alternative vocational vehicle regulatory subcategory structures, such as reducing the number of vocational vehicle subcategories to only include the Multi-Purpose standards in each weight class, and/or maintaining Urban, Multipurpose, and Regional but combining SI and CI into a standard for each weight class.

The HD GHG Phase 2 program includes optional custom chassis emission standards for eight specific vehicle types. Those vehicle types may either meet the primary vocational vehicle program standards or, at the vehicle manufacturer's option, they may comply with these optional standards. The existing optional custom chassis standards are numerically less stringent than the primary HD GHG Phase 2 vocational vehicle standards, but the ABT program is more restrictive for vehicles certified to these optional standards. Banking and trading of credits is not permitted, with the exception that small businesses that may use traded credits to comply. Averaging is only allowed within each subcategory for vehicles certified to these optional standards. If a manufacturer wishes to generate tradeable credits from the production of these vehicles, they may certify them to the primary vocational vehicle standards.

In this action, we are proposing to establish more stringent standards for several, but not all, of these optional custom chassis subcategories. We are proposing revised MY 2027 emission standards and new MY 2028 through MY 2032 and later emission standards for the school bus, other bus, coach bus, refuse hauler, and concrete mixer optional custom chassis regulatory subcategories. We are not proposing any changes to the existing ABT program restrictions for the optional custom chassis regulatory subcategories. Because vehicles certified to the optional custom chassis standards would continue to have restricted credit use and can only be used for averaging within a specific custom chassis regulatory subcategory, we do not have the same potential credit concern as we do for the primary vocational vehicle standards. Therefore, we determined the proposed optional custom chassis emission standards by multiplying the fraction of ICE-powered vehicles in the technology package (by model year) by the applicable existing MY 2027 CO_2 emission standards, like we did for determining the proposed tractor emission standards.

We are not proposing new standards for motor homes certified to the optional custom chassis regulatory subcategory because of the projected impact of the weight of batteries in BEVs in the MYs 2027–2032, as described in DRIA Chapter 2.8.1. Furthermore, we also are not proposing new standards for emergency vehicles certified to the optional custom chassis regulatory subcategory due to our assessment that these vehicles have unpredictable operational requirements and may have limited access to recharging facilities while handling emergency situations in the MYs 2027–2032 timeframe. Finally, we are not proposing new standards for mixed-use vehicle optional custom chassis regulatory subcategory because these vehicles are designed to work inherently in an off-road environment (such as hazardous material equipment or off-road drill equipment) or be designed to operate at low speeds such that it is unsuitable for normal highway operation and therefore may have limited access to on-site depot or public charging facilities in the MYs 2027–2032 timeframe.[520] We do not have concerns that manufacturers could inappropriately circumvent the proposed vocational vehicle standards or proposed optional custom chassis standards because vocational vehicles are built to serve a purpose. For example, a manufacturer cannot certify a box truck to the emergency vehicle custom chassis standards. We request comment on specific considerations and impacts the proposed standards would have on vehicles certified to these optional custom chassis standards. We also request comment and data regarding the potential for more stringent GHG standards for the motor homes, emergency vehicles, or mixed-use vehicles optional custom chassis regulatory subcategories in this time frame.

4. Summary of Costs To Meet the Proposed Emission Standards

We based the proposed standards on technology packages that include both ICE vehicle and ZEV technologies. In our analysis, the ICE vehicles include a suite of technologies that represent a vehicle that meets the existing MY 2027 Phase 2 CO_2 emission standards. We accounted for these technology costs as part of the HD GHG Phase 2 final rule. Therefore, our technology costs for the ICE vehicles are considered to be $0 because we did not add additional CO_2-reducing technologies to the ICE vehicles beyond those in the baseline vehicle. The incremental cost of a heavy-duty ZEV is the marginal cost of ZEV powertrain components compared to ICE powertrain components on a comparable ICE vehicle. This includes the removal of the associated costs of ICE-specific components from the baseline vehicle and the addition of the ZEV components and associated costs. DRIA Chapter 2.3.2 and 2.4.3 includes the ICE powertrain and BEV powertrain cost estimates for each of the 101 HD vehicle types. DRIA Chapter 2.5.2 includes the FCEV powertrain cost projections for the coach buses, heavy-haul tractors, sleeper cab tractors, and day cab tractors.

i. Manufacturer Costs

Table II–30 and Table II–31 show the ZEV technology costs for manufacturers relative to the reference case described in Section V.A.1, including the direct manufacturing costs that reflect learning effects, the indirect costs, and the IRA section 13502 Advanced Manufacturing Production Credit, on average aggregated by regulatory group for MYs 2027 and 2032, respectively.[521] The incremental ZEV adoption rate reflects the difference between the ZEV adoption rates in the technology packages that support our proposed standards and the reference case. As shown in Table II–30 and Table II–31, we project that some vocational vehicle types will achieve technology cost parity between comparable ICE vehicles and ZEVs for manufacturers by MY 2032. These vehicles in our analysis include school buses and single unit trucks (which include vehicles such as delivery trucks). Our analysis is consistent with other studies. For example, an EDF/Roush study found that by MY 2027, BEV transit buses, school buses, delivery vans, and refuse haulers would each cost less upfront

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[520] Mixed-use vehicles must meet the criteria as described in 40 CFR 1037.105(h)(1), 1037.631(a)(1), and 1037.631(a)(2).

[521] Indirect costs are described in detail in Section IV.B.2.

than a comparable ICE vehicle.[522] ICCT similarly found that "although zero-emission trucks are more expensive in the near-term than their diesel equivalents, electric trucks will be less expensive than diesel in the 2025–2030 time frame, due to declining costs of batteries and electric motors as well as increasing diesel truck costs due to emission standards compliance." [523] These studies were developed prior to passage of the IRA, and therefore we would expect the cost comparisons to be even more favorable after considering the IRA provisions. For example, the Rocky Mountain Institute found that because of the IRA, the TCO of electric trucks will be lower than the TCO of comparable diesel trucks about five years faster than without the IRA. They expect cost parity as soon as 2023 for urban and regional duty cycles that travel up to 250 miles and 2027 for long-hauls that travel over 250 miles.[524]

TABLE II–30—MANUFACTURER COSTS TO MEET THE PROPOSED MY 2027 STANDARDS RELATIVE TO THE REFERENCE CASE

[2021$]

Regulatory group	Incremental ZEV adoption rate in technology package (%)	Per-ZEV manufacturer RPE on average	Fleet-average per-vehicle manufacturer RPE
LHD Vocational	18	$1,750	$323
MHD Vocational	15	15,816	2,411
HHD Vocational	12	−505	−62
Day Cab Tractors	8	64,121	5,187
Sleeper Cab Tractors	0	N/A	0

TABLE II–31—MANUFACTURER COSTS TO MEET THE PROPOSED MY 2032 STANDARDS RELATIVE TO THE REFERENCE CASE

[2021$]

Regulatory group	Incremental ZEV adoption rate in technology package (%)	Per-ZEV manufacturer RPE on average	Fleet-average per-vehicle manufacturer RPE
LHD Vocational	45	−$9,515	−$4,326
MHD Vocational	24	1,358	326
HHD Vocational	28	8,146	2,300
Day Cab Tractors	30	26,364	8,013
Sleeper Cab Tractors	21	54,712	11,445

i. Purchaser Costs

We also evaluated the costs of the proposed standards for purchasers on average by regulatory group, as shown in Table II–32 and Table II–33. Our assessment of the upfront purchaser costs include the incremental cost of a ZEV relative to a comparable ICE vehicle after accounting for the two IRA tax credits (IRA section 13502, "Advanced Manufacturing Production Credit," and IRA section 13403, "Qualified Commercial Clean Vehicles") and the associated EVSE costs, if applicable. We also assessed the incremental annual operating savings of a ZEV relative to a comparable ICE vehicle. The payback periods shown reflect the number of years it would take for the annual operating savings to offset the increase in total upfront costs for the purchaser.

TABLE II–32—MY 2027 PURCHASER PER-ZEV UPFRONT COSTS, OPERATING COSTS, AND PAYBACK PERIOD

[2021$]

Regulatory group	Adoption rate in technology package (%)	Incremental per-ZEV RPE cost on average	EVSE costs Per-ZEV on average	Total incremental upfront per-ZEV costs on average	Annual incremental operating costs on average	Payback period (year) on average
LHD Vocational	22	−$1,733	$10,562	$8,828	−$4,474	3
MHD Vocational	19	482	14,229	14,711	−5,194	3

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[522] Nair, Vishnu; Sawyer Stone; Gary Rogers; Sajit Pillai; Roush Industries, Inc. "Technical Review: Medium and Heavy Duty Electrification Costs for MY 2027–2030." February 2022. Page 18. Last accessed on February 9, 2023 at *https://blogs.edf.org/climate411/files/2022/02/EDF-MDHD-Electrification-v1.6_20220209.pdf.*

[523] Hall, Dale and Nic Lutsey. "Estimating the Infrastructure Needs and Costs for the Launch of Zero-Emission Trucks." February 2019. Page 4. Last accessed on February 9, 2023 at *https://theicct.org/wp-content/uploads/2021/06/ICCT_EV_HDVs_Infrastructure_20190809.pdf.*

[524] Kahn, Ari, et al. "The Inflation Reduction Act Will Help Electrify Heavy-Duty Trucking". Rocky Mountain Institute. August 25, 2022. Available online: *https://rmi.org/inflation-reduction-act-will-help-electrify-heavy-duty-trucking/.*

TABLE II–32—MY 2027 PURCHASER PER-ZEV UPFRONT COSTS, OPERATING COSTS, AND PAYBACK PERIOD—Continued

[2021$]

Regulatory group	Adoption rate in technology package (%)	Incremental per-ZEV RPE cost on average	EVSE costs Per-ZEV on average	Total incremental upfront per-ZEV costs on average	Annual incremental operating costs on average	Payback period (year) on average
HHD Vocational	16	−9,531	19,756	10,225	−4,783	3
Day Cab Tractors	10	24,121	37,682	61,803	−7,275	8
Sleeper Cab Tractors	0	N/A	N/A	N/A	N/A	N/A

Note: The average costs represent the average across the regulatory group, for example the first row represents the average across all Light Heavy-Duty vocational vehicles.

TABLE II–33—MY 2032 PURCHASER PER-ZEV UPFRONT COSTS, OPERATING COSTS, AND PAYBACK PERIOD

[2021$]

Regulatory group	Adoption rate in technology package (%)	Incremental per-ZEV RPE cost on average	EVSE costs Per-ZEV on average	Total incremental upfront per-ZEV costs on average	Annual incremental operating costs on average	Payback period (year) on average
LHD Vocational	57	−$9,608	$10,552	$944	−$4,043	1
MHD Vocational	35	−2,907	14,312	11,405	−5,397	3
HHD Vocational	40	−8,528	17,233	8,705	−7,436	2
Day Cab Tractors	34	582	16,753	17,335	−6,791	3
Sleeper Cab Tractors	25	14,712	0	14,712	−2,290	7

As shown in Table II–33, under our proposal we estimate that the average upfront cost per vehicle to purchase a new MY 2032 vocational ZEV and associated EVSE compared to a comparable ICE vehicle (after accounting for two IRA tax credits, IRA section 13502, ''Advanced Manufacturing Production Credit,'' and IRA section 13403, ''Qualified Commercial Clean Vehicles''), would be offset by operational costs (*i.e.,* savings that come from the lower costs to operate, maintain, and repair ZEV technologies), such that we expect the upfront cost increase would be recouped due to operating savings in one to three years, on average for vocational vehicles. For a new MY 2032 day cab tractor ZEV and associated EVSE, under our proposal we estimate the average incremental upfront cost per vehicle would be recovered in three years, on average. Similarly, for sleeper cab tractors, we estimate that the initial cost increase would be recouped in seven years. We discuss this in more detail in DRIA Chapter 2.

The average per-vehicle purchaser costs shown in Table II–32 for MY 2027 are higher than the MY 2032 per-vehicle costs. The reduction in costs over time are reflective of technology learning, as discussed in Section IV.B. It is worth noting that though the upfront costs of a BEV day cab tractor, for example, are higher when one considers both the vehicle and the EVSE, purchasers would still recoup these upfront costs within eight years of ownership on average. Also of note, our proposed standards in MY 2027 have a lower adoption rate of 10 percent for these day cab tractors, in recognition of the higher cost in MY 2027 than in MY 2032. The upfront vehicle cost increase projected at $24,000 represents a less than a 25 percent increase when compared to the average price of $100,000 for a new day cab tractor. Purchasers also would have the option to consider alternatives to purchasing an EVSE at the time of purchasing a vehicle. For example, depending on the location of the vehicle, heavy-duty public charging may be a better solution than depot charging. The purchaser could instead of spending over $37,000 upfront on average for EVSE, they could instead spread the cost over time through public charging where the EVSE costs would be built into the electricity cost.

5. Lead Time Assessment

Two of the significant aspects of the IRA are the tax credit available for the manufacturing of batteries and the tax credit available for the purchase of HD zero-emission vehicles, where the IRA provisions' qualifications are met. The tax credits significantly reduce, and in many cases erase, the incremental cost of purchasing a HD ZEV when compared to the cost of purchasing a comparable ICE vehicle. Therefore, as explained in our payback analysis, we expect the IRA will incentivize the demand and purchaser acceptance for HD ZEVs. However, demand and purchaser acceptance are only two of the factors we consider when evaluating the feasibility of HD ZEV technologies in the MY 2027 through MY 2032 timeframe. As we propose standards for MYs 2027 through 2032, which are between four and nine years from now, we considered the lead time required for manufacturers to design, develop, and produce the ZEV and ICE vehicle technologies in the technology packages, in addition to lead time considerations for the charging and hydrogen refueling infrastructure. We welcome comment on our assessment of lead time in these areas.

Manufacturers require time to design, develop, and build new vehicles. Based on discussions with heavy-duty manufacturers, depending on the amount of content that is new on a vehicle, it could take two to four years or more years to design, develop and prove the safety and reliability of a new HD vehicle. A typical design process includes the design and building of prototype or demonstration vehicles that are evaluated over several months or years in real world operation. The manufacturers need to accumulate miles and experience a wide variety of environmental conditions on these prototype vehicles to demonstrate the product's durability and reliability. Then manufacturers would work to commercialize the vehicle and in turn build it in mass production. We also considered that manufacturers are likely limited in terms of the financial resources, human resources, and testing facilities to redesign all of their vehicles at the same time. Typically, manufacturers would focus on the applications with the best business case because these would be where the customers would be most willing to purchase, therefore the proposed standards phase in over a period of time starting in MY 2027 through MY 2032. For HD BEVs, we have considered that BEV technology has been demonstrated to be technically feasible in heavy-duty transportation and that manufacturers will learn from the research and development work that has gone into developing the significant number of LD and HD electric vehicle models that are on the road today, as noted in Section II.D.2 and DRIA Chapter 1.5.5, and our proposed standards are supported by technology packages with increasing BEV adoption rates beginning in MY 2027 (see also our discussion in this subsection regarding our consideration of adequate time for infrastructure development for HD BEVs). For HD FCEVS, as discussed in Section II.D.3 and II.D.4, along with DRIA Chapter 1.7.5, fuel cell technology in other sectors has been in existence for decades, has been demonstrated to be technically feasible in heavy-duty transportation, and there are a number of HD FCEV models that are commercially available today with more expected to become available by 2024. However, we included this technology for our proposed standards starting in MY 2030 in part to take into consideration additional lead time to allow manufacturers to design, develop, and manufacture HD FCEV models (see also our discussion in this subsection regarding our consideration of adequate time for infrastructure development for HD FCEVs).

We discuss in Sections II.D.1 and II.F.1 the need for ICE vehicles to continue to install CO_2-reducing technologies, such as advanced aerodynamics, efficient powertrains, and lower rolling resistance tires. In our technology assessment for this proposal, we included the technology packages we considered in setting the existing Phase 2 MY 2027 CO_2 emission standards. Each of these technologies exists today and continues to be developed by manufacturers. As noted in 2016 when we issued the HD GHG Phase 2 final rule, at that time we provided over ten years of lead time to the manufacturers to continue the development and deployment of these technologies. Our current assessment is that these ICE vehicle technologies continue to be feasible in the MY 2027 and later timeframe.

As a new vehicle is being designed and developed, we considered that manufacturers will also need time to significantly increase HD ZEV production volumes from today's volumes. In particular, manufacturers will need to build new or modify existing manufacturing production lines to assemble the new products that include ZEV powertrains. We also considered that manufacturers will require time to source new components, such as heavy-duty battery packs, motors, fuel cell stacks, and other ZEV components, including the sourcing of the critical materials, as discussed in Section II.D.2.ii. As described in Section II.D.5, we anticipate that manufacturers will not develop vehicles to cover all types of HD vehicles at once but will focus on those with the most favorable business case first, increase the adoption of those vehicles over time, and then develop other applications. We believe our approach described in Section II.D.5 shows the adoption rates for the applications we have considered would be achievable in the MY 2027 and later timeframe. We welcome comment on the manufacturer lead time requirements for HD ZEVs.

Purchasers of BEVs will also need to consider how they will charge their vehicles. Our assessment of the availability of public charging infrastructure, EVSE technology, and costs associated with depot charging are included in Section II.E.2 of this preamble, DRIA Chapter 1 and DRIA Chapter 2. As noted in DRIA Chapter 2, we anticipate that many first-time BEV owners may opt to purchase and install EVSE at or near the time of vehicle purchase and we therefore account for these capital costs upfront. In terms of EVSE for HD BEVs, this equipment is available today for purchase. However, it takes time for individual or fleet owners to develop charging site plans for their facility, obtain permits, purchase the EVSE, and have it installed. For the depots that may be charging a greater number of vehicles or with high-power DCFC ports, an upgrade to the electricity distribution system may be required. As noted in DRIA Chapter 1, we expect significant increases in HD charging infrastructure due to a combination of public and private investments. This includes Federal funding available through the BIL[525] and the IRA.[526] As discussed in DRIA Chapter 1.6.2.2, states, OEMs, utilities, EVSE providers and others are also investing in and supporting the deployment of charging infrastructure. For example, Daimler Trucks North America, Volvo Trucks, Navistar, and PACCAR are a few of the HD manufacturers investing in EVSE, sometimes packaging the sale of EVSE with the vehicle.[527] [528] [529] [530] Because of these projected increases and the funding available through the BIL and IRA, and as we are proposing more stringent standards that begin in MY 2027, our assessment supports that there is sufficient time for the infrastructure, especially for depot charging, to gradually increase over the remainder of this decade to levels that support the stringency of the proposed standards for the timeframe they would apply. We request comment on time considerations for all levels of HD charging infrastructure, including Level 2 up to 350 kW DCFC systems.

Purchasers of FCEVs will need to consider how they will obtain hydrogen to refuel the vehicles. As discussed in DRIA Chapter 1.8, there are currently 54 public retail hydrogen fueling stations in the United States, primarily for light-duty vehicles in California according to DOE's Alternative Fuels Data Center. When including private and planned stations in a search, there are over 130 refueling station locations nationwide.[531] There are also numerous nationally designated hydrogen-ready or hydrogen-pending Alternative Fueling Corridors. Corridor-ready designations

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[525] Infrastructure Investment and Jobs Act, Public Law 117–58, 135 Stat. 429 (2021), available at *https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf*.

[526] Inflation Reduction Act, Public Law 117–169, 136 Stat. 1818 (2022).

[527] Daimler Truck North America. "Daimler Trucks North America, Portland General Electric open first-of-its-kind heavy-duty electric truck charging site". April 21, 2021. Available online: *https://northamerica.daimlertruck.com/PressDetail/daimler-trucks-north-america-portland-general-2021-04-21*.

[528] Volvo Trucks USA. "Volvo Trucks Simplifies EV Charger Procurement with Vendor Direct Shipping Program". September 29, 2022. Available online: *https://www.volvotrucks.us/news-and-stories/press-releases/2022/september/volvo-trucks-simplifies-ev-charger-procurement-with-vendor-direct-shipping-program*.

[529] Navistar. "Navistar and In-Charge Energy Now Offer Carbon-Neurtral Electric Vehicle Charging". Available online: *https://news.navistar.com/2021-10-25-Navistar-and-In-Charge-Energy-Now-Offer-Carbon-Neutral-Electric-Vehicle-Charging*.

[530] Paccar Parts. "Electric Vehicle Chargers". Available online: *https://www.paccarparts.com/technology/ev-chargers/*.

[531] U.S. Department of Energy, Alternative Fuels Data Center. "Hydrogen Fueling Station Locations". Last accessed on January 27, 2023. Available online: *https://afdc.energy.gov/fuels/hydrogen_locations.html#/analyze?fuel=HY*.

have public hydrogen stations no greater than 100 miles apart and no greater than five miles off the highway. Corridor-pending designations have public hydrogen stations separated by more than 100 miles but no greater than five miles off the highway.[532] [533] In addition, DOE's draft Clean Hydrogen Strategy and Roadmap suggests a regional ''clean hydrogen hub'' approach to infrastructure. Under provisions of the BIL, DOE is investing $8 billion through 2026 to support the development of at least four hubs that can demonstrate the production, processing, delivery, storage, and end use of clean hydrogen.

DOE released a Liftoff Report on clean hydrogen to establish a common fact base moving forward for dialogue and coordinated action across the full technology value chain (*e.g.,* from upstream production to downstream end uses). The report considers the impact of hub funding and tax credits under BIL and IRA, including the hydrogen production tax credit (PTC). It identifies three phases of rapid market growth: near-term expansion (~2023–2026), industrial scaling (~2027–2034), and long-term growth (~2035+). The report acknowledges that there are both opportunities and challenges for sectors with few decarbonization alternatives like heavy-duty transportation end uses, including long-haul trucks. During the timeframe of this rule (*i.e.,* through 2032), the Liftoff Report supports a scenario where low-GHG hydrogen will be emerging for long-haul trucks.[534] We project that hydrogen consumption from FCEVs in this proposal would be a small proportion of total low-GHG hydrogen expected to be produced through 2030 in the United States.

To meet more immediate needs, end users may expect to rely on hydrogen deliveries from central production facilities. After evaluating the existing and future hydrogen refueling infrastructure,[535] we considered FCEVs only in the MY 2030 and later timeframe to better ensure we have provided adequate time for infrastructure development and because we expect that refueling needs can be met by MY 2030, as discussed in Section II.D.4 and in DRIA Chapter 2.1. We request comment on lead time considerations related to the development of HD hydrogen fueling infrastructure.

Giving consideration to these factors, our analysis supports that there is sufficient lead time to meet the proposed standards, which manufacturers may comply with through application of BEV technologies, FCEV technologies, or further improvements to ICE vehicles, including H2–ICE powered vehicles. However, we also considered and are requesting comment on an alternative standards reflecting a slower phase-in of HD ZEV adoption rates, and are also seeking comment on more stringent standards reflecting a more aggressive phase-in of HD ZEV adoption rates, as described in Section II.H.

Additionally, while we believe there is sufficient time for the charging and refueling infrastructure to develop for the reasons explained in this section, EPA recognizes that such infrastructure for BEVs and FCEVs is important for the success of the increasing development and adoption of these vehicle technologies. EPA carefully considered that there are significant efforts already underway to develop and expand heavy-duty electric charging and hydrogen refueling infrastructure both at the local, State and Federal government level as well as from private industry, as discussed in DRIA Chapters 1 and 2 and this section. Those are important early actions that, as we just explained, will support the increase in ZEV charging and refueling infrastructure needed for the future growth of ZEV technology of the magnitude EPA is projecting in this proposal's technology packages. EPA has heard from some representatives from the heavy-duty vehicle manufacturing industry both optimism regarding the heavy-duty industry's ability to produce ZEV technologies in future years at high volume, but also concern that a slow growth in ZEV refueling infrastructure can slow the growth of heavy-duty ZEV adoption, and that this may present challenges for vehicle manufacturers' ability to comply with future EPA GHG standards. EPA has a vested interest in monitoring industry's performance in complying with mobile source emission standards, including the highway heavy-duty industry. EPA monitors industry's performance through a range of approaches, including regular meetings with individual companies and regulatory requirements for data submission as part of the annual certification process. EPA also provides transparency to the public through actions such as publishing industry compliance reports (such as has been done during the heavy-duty GHG Phase 1 program).[536] EPA requests comment on what, if any, additional information and data EPA should consider collecting and monitoring during the implementation of the Phase 3 standards; we also request comment on whether there are additional stakeholders EPA should work with during implementation of the Phase 3 standards and what measures EPA should include to help ensure success of the Phase 3 program, including with respect to the important issues of refueling and charging infrastructure for ZEVs.

G. EPA's Basis That the Proposed Standards Are Feasible and Appropriate Under the Clean Air Act

1. Overview

As discussed in Section II.A of this preamble, there is a critical need for further GHG reductions to address the adverse impacts of air pollution from HD vehicles on public health and welfare. With continued advances in internal combustion emissions controls and vehicle zero emission technologies coming into the mainstream as key vehicle emissions controls, EPA believes substantial further emissions reductions are feasible and appropriate under the Clean Air Act.

The Clean Air Act authorizes EPA to establish emissions standards for motor vehicles to regulate emissions of air pollutants that contribute to air pollution which, in the Administrator's judgment, may reasonably be anticipated to endanger public health or welfare. Heavy-duty vehicles are significant contributors to the U.S. GHG emissions inventories, and additional reductions in GHGs from vehicles are needed to avoid the worst consequences of climate change as discussed in Section II.A.

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[532] U.S. Department of Transportation, Federal Highway Administration. ''Alternative Fuel Corridors: Hydrogen''. Available online: *https://hepgis.fhwa.dot.gov/fhwagis/ViewMap.aspx?map=Highway+Information|Hydrogen+(HY-Round+1,2,3,4,5+and+6)#.*

[533] U.S. Department of Transportation, Federal Highway Administration. ''Alternative Fuel Corridors; Frequently Asked Questions FAST Act Section 1413—Alternative Fuel Corridor Designations Updated December 2020 to Support Round 5''. Available online: *https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/resources/faq/.*

[534] U.S. Department of Energy. ''Pathways to Commercial Liftoff: Clean Hydrogen''. March 2023. Available online: *https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf.*

[535] U.S. Department of Energy. ''Pathways to Commercial Liftoff: Clean Hydrogen''. March 2023. Available online: *https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf.*

[536] See EPA Reports EPA–420–R–21–001B covering Model Years 2014–2018, and EPA report EPA–420–R–22–028B covering Model Years 2014–2020, available online at *https://www.epa.gov/compliance-and-fuel-economy-data/epa-heavy-duty-vehicle-and-engine-greenhouse-gas-emissions.*

This proposed rule also considers the large potential impact that the Inflation Reduction Act (IRA) will have on facilitating production and adoption of ZEV technologies. The IRA provides powerful incentives in reducing the cost to manufacture and purchase ZEVs, as well as reducing the cost of charging infrastructure, that will help facilitate increased market penetration of ZEV technology in the time frame considered in this rulemaking. Thus, it is an important element of EPA's cost and feasibility assessment, and EPA has considered the impacts of the IRA in our assessment of the appropriate proposed standards.

As we did in HD GHG Phase 1 and Phase 2 rulemakings, in this Phase 3 proposal we considered the following factors: the impacts of potential standards on emissions reductions of GHG emissions; technical feasibility and technology effectiveness; the lead time necessary to implement the technologies; costs to manufacturers; costs to purchasers including operating savings; reduction of non-GHG emissions; the impacts of standards on oil conservation and energy security; impacts of standards on the truck industry; other energy impacts; as well as other relevant factors such as impacts on safety.[537] See Section II.G.5 for further discussion of how we balanced the factors we considered for the proposed Phase 3 standards.

2. Consideration of Technological Feasibility, Compliance Costs and Lead Time

The technological readiness of the heavy-duty industry to meet the proposed standards for model years 2027–2032 and beyond is best understood in the context of over a decade of heavy-duty vehicle emissions reduction programs in which the HD industry has introduced emissions reducing technologies in a wide lineup of ever more efficient and cost-competitive vehicle applications. Electrification technologies have seen particularly rapid development over the last several years such that early HD ZEV models are in use today for some applications and and are expected to expand to many more applications, as discussed DRIA Chapters 1.5 and 2, and as a result the number of ZEVs projected in the proposal and across all the alternatives considered here is much higher than in any of EPA's prior rulemaking analyses.

As discussed in DRIA Chapter 1.5.5 and Section I, the ZEV technology necessary to achieve significantly more stringent standards has already been developed and deployed. Additionally, manufacturers have announced plans to rapidly increase their investments in ZEV technologies over the next decade. In addition, the IRA and the BIL provide many monetary incentives for the production and purchase of ZEVs in the heavy-duty market, as well as incentives for electric vehicle charging infrastructure. Furthermore, there have been multiple actions by states to accelerate the adoption of heavy-duty ZEVs, such as (1) a multi-state Memorandum of Understanding for the support of heavy-duty ZEV adoption;[538] and (2) the State of California's ACT program, which has also been adopted by other states and includes a manufacturer requirement for zero-emission truck sales.[539] Together with the range of ICE technologies that have been already demonstrated over the past decade, BEVs and FCEVs with no tailpipe emissions (and 0 g CO_2/ton-mile certification values) are capable of supporting rates of annual stringency increases that are much greater than were typical in earlier GHG rulemakings.

In setting standards for a future model year, EPA considers the extent deployment of advanced technologies would be available and warranted in light of the benefits to public health and welfare in GHG emission reductions, and potential constraints, such as cost of compliance, lead time, raw material availability, component supplies, redesign cycles, charging and refueling infrastructure, and purchasers' willingness to purchase (including payback). The extent of these potential constraints has diminished significantly in light of increased and further projected investment by manufacturers, increased and further projected acceptance by purchasers, and significant support from Congress to address such areas as upfront purchase price, charging infrastructure, critical mineral supplies, and domestic supply chain manufacturing. In response to the increased stringency of the proposed standards, manufacturers would be expected to adopt advanced technologies, such as increased electrification, at an increasing pace across more of their vehicles. To evaluate the feasibility of BEVs and FCEVs in our technology packages that support the proposed standards, EPA developed a tool called HD TRUCS, to evaluate the design features needed to meet the energy and power demands of various HD vehicle types when using ZEV technologies. The overarching design and functionality of HD TRUCS is premised on ensuring each of the 101 ZEV types could perform the same work as a comparable ICE vehicle counterpart. Within the HD TRUCS modeling that EPA conducted to support this proposal, we have imposed constraints to reflect the rate at which a manufacturer can deploy ZEV technologies that include consideration of time necessary to ramp up battery production, including the need to increase the availability of critical raw materials and expand battery production facilities, as discussed in Section II.D.2.ii.

Constraints on the technology adoption limits in our compliance modeling as well as other aspects of our lead time assessment are described in Section II.F. Overall, given the number and breadth of current low or zero emission vehicles and the constraints we have made to limit the rate of development for new HD vehicles, our assessment shows that there is sufficient lead time for the industry to more broadly deploy existing technologies and successfully comply with the proposed standards.

Our analysis projects that for the industry overall, nearly 50 percent of new vocational vehicles and 25 to 35 percent of new tractors in MY 2032 would be ZEVs. EPA believes that this is an achievable level based on our technical assessment for this proposal that includes consideration of the feasibility and lead time required for ZEVs and appropriate consideration of the cost of compliance for manufacturers. Our assessment of the appropriateness of the level of ZEVs in our analysis is also informed by public announcements by manufacturers about their plans to transition fleets to electrified vehicles, as described in Section I.A.2 of this preamble. More detail about our technical assessment, and our assessment of the production feasibility of ZEVs is provided in Section II.D and II.E of this Preamble and Chapters 1 and 2 of the DRIA. At the same time, we note that the proposed standards are performance-based and do not mandate any specific technology for any manufacturer or any vehicles. Moreover, the overall industry does not necessarily need to reach this level of ZEVs in order to comply—this

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[537] 81 FR 73512 (October 25, 2016) and 76 FR 57129 (September 15, 2011).

[538] NESCAUM MOU, available at *https://www.nescaum.org/documents/mhdv-zev-mou-20220329.pdf.*

[539] EPA granted the ACT rule waiver requested by California under CAA section 209(b) on March 30, 2023. The ACT had been adopted by five states under CAA section 177: Oregon, Washington, New York, New Jersey, and Massachusetts. Oregon and Washington adopted ACT as-is, whereas New York, New Jersey, and Massachusetts adopted ACT on a one-year delay.

is one of many possible compliance pathways that manufacturers could choose to take under the performance-based standards. For example, manufacturers that choose to increase their sales of hybrid vehicle technologies or apply more advanced technology to non-hybrid ICE vehicles would require a smaller number of ZEVs than we have projected in our assessment to comply with the proposed standards.

In considering feasibility of the proposed standards, EPA also considers the impact of available compliance flexibilities on manufacturers' compliance options. Manufacturers widely utilize the program's established averaging, banking and trading (ABT) provisions which provide a variety of flexible paths to plan compliance. We have discussed this dynamic in past rules, and we anticipate that this same dynamic will support compliance with this rulemaking. The GHG credit program was designed to recognize that manufacturers typically have a multi-year redesign cycle and not every vehicle will be redesigned every year to add emissions-reducing technology. Moreover, when technology is added, it will generally not achieve emissions reductions corresponding exactly to a single year-over-year change in stringency of the standards. Instead, in any given model year, some vehicles will be ''credit generators,'' over-performing compared to their respective CO_2 emission standards in that model year, while other vehicles will be ''debit generators'' and under-performing against their standards. As the proposed standards reach increasingly lower numerical levels, some vehicle designs that had generated credits against their CO_2 emission standard in earlier model years may instead generate debits in later model years. In MY 2032 when the proposed standards reach the lowest level, it is possible that only BEVs, FCEVs, and H2–ICE vehicles are generating positive credits, and all ICE vehicles generate varying levels of deficits. Even in this case, the application of ICE technologies can remain an important part of a manufacturer's compliance strategy by reducing the amount of debits generated by these vehicles. A greater application of ICE technologies (*e.g.,* hybrids) can enable compliance with fewer ZEVs than if less ICE technology was adopted, and therefore enable the tailoring of a compliance strategy to the manufacturer's specific market and product offerings. Together, a manufacturer's mix of credit-generating and debit-generating vehicles contribute to its sales-weighted average performance, compared to its standard, for that year.

Just as the averaging approach in the HD vehicle GHG program allows manufacturers to design a compliance strategy relying on the sale of both credit-generating vehicles and debit-generating vehicles in a single year, the credit banking and trading provisions of the program allow manufacturers to design a compliance strategy relying on overcompliance and undercompliance in different years, or even by different manufacturers. Credit banking allows credits to carry-over for up to five years and allows manufacturers up to three years to address any credit deficits. Credit trading is a compliance flexibility provision that allows one vehicle manufacturer to purchase credits from another, though trading of GHG credits has not occurred with HD GHG credits.

The proposed performance-based standards with ABT provisions give manufacturers a degree of flexibility in the design of specific vehicles and their fleet offerings, while allowing industry overall to meet the standards and thus achieve the health and environmental benefits projected for this rulemaking. EPA has considered the averaging portion of the ABT program in the feasibility assessments for previous rulemakings and continues that practice here. We also continue to acknowledge that the other provisions in ABT that provide manufacturers additional flexibility also support the feasibility of the proposed standards. By averaging across vehicles in the vehicle averaging sets and by allowing for credit banking across years, manufacturers have the flexibility to adopt emissions-reducing technologies in the manner that best suits their particular market and business circumstances. EPA's annual Heavy-Duty Vehicle and Engine Greenhouse Gas Emissions Compliance Report illustrates how different manufacturers have chosen to make use of the GHG program's various credit features.[540] It is clear that manufacturers are widely utilizing several of the credit programs available, and we expect that manufacturers will continue to take advantage of the compliance flexibilities and crediting programs to their fullest extent, thereby providing them with additional tools in finding the lowest cost compliance solutions in light of the proposed standards.

In addition to technological feasibility and lead time, EPA has considered the cost for the heavy-duty industry to comply with the proposed standards. See Section II.F.4 and Chapter 2 of the DRIA for our analysis of compliance costs for manufacturers. We estimate that the MY 2032 fleet average per-vehicle cost to manufacturers by regulatory group would range between a cost savings for LHD vocational vehicles to $2,300 for HHD vocational vehicles and between $8,000 and $11,400 per tractor. EPA notes the projected costs per vehicle for this proposal are similar to the fleet average per-vehicle costs projected for the HD GHG Phase 2 rule that we considered to be reasonable. The Phase 2 tractor standards were projected to cost between $10,200 and $13,700 per vehicle (81 FR 73621). The Phase 2 vocational vehicle standards were projected to cost between $1,486 and $5,670 per vehicle (81 FR 73718). Furthermore, the estimated MY 2032 costs to manufacturers represent less than about ten percent of the average price of a new heavy-duty tractor today (conservatively estimated at $100,000 in 2022).[541] For this proposal, EPA finds that the expected vehicle compliance costs are reasonable in light of the emissions reductions in air pollutants and the resulting benefits for public health and welfare.

3. Consideration of Emissions of GHGs

An essential factor that EPA considered in determining the appropriate level of the proposed standards is the reductions in GHG emissions and associated public health and welfare impacts.[542]

The proposed GHG standards would achieve significant reductions in GHG emissions. The proposed standards would achieve approximately 1.8 billion metric tons in net CO_2 cumulative emission reductions from calendar years 2027 through 2055 (see Section V of the preamble and Chapter 4 of the DRIA). As discussed in Section VI of this

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[540] ''The Final Phase 1 EPA Heavy-Duty Vehicle and Engine Greenhouse Gas Emissions Compliance Report (Model Years 2014–20),'' EPA–420–R–22–028. November 2022. Last accessed on February 9, 2023 at *https://www.epa.gov/compliance-and-fuel-economy-data/epa-heavy-duty-vehicle-and-engine-greenhouse-gas-emissions.*

[541] Note that these values are averages across all vehicles and there will be differences for each individual vehicle.

[542] As further explained in Section II.G.4, we note that we also expect the proposed GHG emission standards would lead to an increase in HD ZEVs, which would also result in reductions of vehicle emissions of non-GHG pollutants that contribute to ambient concentrations of ozone, particulate matter ($PM_{2.5}$), NO_2, CO, and air toxics. EPA did not select the proposed GHG emission standards based on non-GHG reductions of vehicle emissions; nonetheless, the GHG and non-GHG reductions of vehicle emissions of the proposed program reinforce our view that the proposed standards represent an appropriate weighing of the statutory factors and other relevant considerations.

preamble, these GHG emission reductions would make an important contribution to efforts to limit climate change and its anticipated impacts.

The proposed CO_2 emission standards would reduce adverse impacts associated with climate change and would yield significant benefits, including those we can monetize and those we are unable to fully monetize due to data and modeling limitations. The program would result in significant social benefits including $87 billion in climate benefits (with the average SC–GHGs at a 3 percent discount rate). A more detailed description and breakdown of these benefits can be found in Section VII of the preamble and Chapter 7 of the DRIA.

As discussed in Section VII, we monetize benefits of the proposed CO_2 standards and evaluate other costs in part to better enable a comparison of costs and benefits pursuant to E.O. 12866, but we recognize that there are benefits we are unable to fully quantify. EPA's consistent practice has been to set standards to achieve improved air quality consistent with CAA section 202, and not to rely on cost-benefit calculations, with their uncertainties and limitations, in identifying the appropriate standards. Nonetheless, our conclusion that the estimated benefits considerably exceed the estimated costs of the proposed program reinforces our view that the proposed standards represent an appropriate weighing of the statutory factors and other relevant considerations.

4. Consideration of Impacts on Purchasers, Non-GHG Emissions, Energy, Safety and Other Factors

Another factor that EPA considered in determining the proposed standards is the impact of the proposed HD CO_2 standards on purchasers, consistent with the approach we used in HD GHG Phase 1 and Phase 2. In this proposal, we considered willingness to purchase (such as practicability, payback, and costs for vehicle purchasers including EVSE) in determining the appropriate level of the proposed standards. Businesses that operate HD vehicles are under competitive pressure to reduce operating costs, which should encourage purchasers to identify and rapidly adopt vehicle technologies that provide a positive total cost of ownership. Outlays for labor and fuel generally constitute the two largest shares of HD vehicle operating costs, depending on the price of fuel, distance traveled, type of HD vehicle, and commodity transported (if any), so businesses that operate HDVs face strong incentives to reduce these costs.[543] [544] However, as noted in DRIA Chapter 6.2, there are a number of other considerations that may impact a purchaser's willingness to adopt new technologies. Within HD TRUCS, we considered the impact on purchasers through our evaluation of payback periods. The payback period is the number of years that it would take for the annual operational savings of a ZEV to offset the incremental upfront purchase price of a BEV or FCEV (after accounting for the IRA section 13502 battery tax credit and IRA section 13403 vehicle tax credit) and charging infrastructure costs (for BEVs) when compared to purchasing a comparable ICE vehicle. The average per-vehicle costs to a purchaser by regulatory group for a MY 2032 heavy-duty vehicle, including associated EVSE and after considering the IRA battery-manufacturer and vehicle-purchaser tax credits, are projected to range between $900 and $11,000 for vocational vehicles and $14,700 and $17,300 for tractors. As noted in Section II.F.4.ii, EPA concludes that the proposed standards would be beneficial for purchasers because the lower operating costs during the operational life of the vehicle would offset the increase in vehicle technology costs. For example, purchasers of MY 2032 vocational vehicles and day cab tractors on average by regulatory group would recoup the upfront costs through operating savings within the first three years of ownership. Furthermore, the purchasers would benefit from annual operating cost savings for each year after the payback occurs. EPA finds that these average costs to purchasers are reasonable considering the operating savings which more than offsets these costs, as was also the case with the HD GHG Phase 2 rule. See 81 FR 73482.

We also considered the practicability and suitability of the proposed standards as we applied an additional constraint within HD TRUCS that limited the maximum ZEV adoption rate to 80 percent for any given vehicle type. This conservative limit was developed after consideration of the actual needs of the purchasers, as discussed in Section II.F.1.

Within our analysis, to support the practicability and suitability of the proposed standards we also considered the lead time necessary for purchasers to install depot charging and the lead time necessary for development of hydrogen infrastructure that would be required for the use of these technologies. As further explained in DRIA Chapter 1.6 and Sections II.E.2 and II.F.5, our assessment supports that depot charging can be installed in time for the purchase and use of the volume of MY 2027 BEVs we project could be used to comply with the proposed standards. With respect to hydrogen infrastructure, as further explained in DRIA Chapter 1.8 and Section II.F.5, we recognize that this may take longer to develop, and therefore included a constraint for FCEVs such that we did not propose new standards for long-haul vehicles until MY 2030, when we expect refueling needs can be met for the volume of FCEVs we project could be used to comply with the proposed standards. Furthermore, we also assessed the impact of future HD BEVs on the grid, as discussed in Section II.E.2. Our assessment is that grid reliability is not expected to be adversely affected by the modest increase in electricity demand associated with HD BEV charging and thus was not considered to be a constraining consideration.

EPA considers our analysis of the impact of the proposed CO_2 emission standards on vehicle and upstream emissions for non-GHG pollutants as supportive of the proposed standards. The proposed standards would decrease vehicle emissions of non-GHG pollutants that contribute to ambient concentrations of ozone, particulate matter ($PM_{2.5}$), NO_2, CO, and air toxics. By 2055, when considering downstream vehicle, EGU, and refinery emissions, we estimate a net decrease in emissions from all pollutants modeled (*i.e.,* NO_X, $PM_{2.5}$, VOC, and SO_2) (see Section V of the preamble and Chapter 4 of the DRIA for more detail).

As also explained in Section II.G.3, and as discussed in Section VII, we monetize benefits of the proposed standards and evaluate other costs in part to better enable a comparison of costs and benefits pursuant to E.O. 12866, but we recognize that there are benefits we are unable to fully quantify. EPA's consistent practice has been to set standards to achieve improved air quality consistent with CAA section 202, and not to rely on cost-benefit calculations, with their uncertainties and limitations, in identifying the appropriate standards.

EPA also evaluated the impacts of the proposed HD GHG standards on energy, in terms of oil conservation and energy security through reductions in fuel consumption. This proposal is projected to reduce U.S. oil imports 4.3 billion gallons through 2055 (see Section VI.F).

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[543] American Transportation Research Institute, *An Analysis of the Operational Costs of Trucking,* September 2013. Docket ID: EPA–HQ–OAR–2014–0827–0512.

[544] Transport Canada, Operating Cost of Trucks, 2005. Docket ID: EPA–HQ–OAR–2014–0827–0070.

We estimate the benefits due to reductions in energy security externalities caused by U.S. petroleum consumption and imports would be approximately $12 billion under the proposed program. EPA considers this proposal to be beneficial from an energy security perspective and thus this factor was considered to be a supportive and not constraining consideration.

EPA estimates that the present value of monetized net benefits to society would be approximately $320 billion through the year 2055 (annualized net benefits of $17 billion through 2055), more than 5 times the cost in vehicle technology and associated electric vehicle supply equipment (EVSE) combined. Regarding social costs, EPA estimates that the cost of vehicle technology (not including the vehicle or battery tax credits) and EVSE would be approximately $9 billion and $47 billion respectively, and that the HD industry would save approximately $250 billion in operating costs (*e.g.,* savings that come from less liquid fuel used, lower maintenance and repair costs for ZEV technologies as compared to ICE technologies, etc.). The program would result in significant social benefits including $87 billion in climate benefits (with the average SC–GHGs at a 3 percent discount rate). Between $15 and $29 billion of the estimated total benefits through 2055 are attributable to reduced emissions of non-GHG pollutants, primarily those that contribute to ambient concentrations of $PM_{2.5}$. Finally, the benefits due to reductions in energy security externalities caused by U.S. petroleum consumption and imports would be approximately $12 billion under the proposed program. A more detailed description and breakdown of these benefits can be found in Section VIII of the preamble and Chapter 7 of the DRIA. Our conclusion that the estimated benefits considerably exceed the estimated costs of the proposed program reinforces our view that the proposed standards represent an appropriate weighing of the statutory factors and other relevant considerations.

Section 202(a)(4)(A) of the CAA specifically prohibits the use of an emission control device, system or element of design that will cause or contribute to an unreasonable risk to public health, welfare, or safety. EPA has a history of considering the safety implications of its emission standards, including the HD Phase 1 and Phase 2 rule. We highlight the numerous industry standards and safety protocols that exist today for heavy-duty BEVs and FCEVs that provide guidance on the safe design of these vehicles in Section II.D and DRIA Chapter 1 and thus this factor was considered to be a supportive and not constraining consideration.

5. Selection of Proposed Standards Under CAA 202(a)

Under section 202(a), EPA has a statutory obligation to set standards to reduce emissions of air pollutants from classes of motor vehicles that the Administrator has found contribute to air pollution that may be expected to endanger public health and welfare. In setting such standards, the Administrator must provide adequate lead time for the development and application of technology to meet the standards, taking into consideration the cost of compliance. EPA's proposed standards properly implement this statutory provision, as discussed in this Section II.G. In setting standards for a future model year, EPA considers the extent deployment of advanced technologies would be available and warranted in light of the benefits to public health and welfare in GHG emission reductions, and potential constraints, such as cost of compliance, lead time, raw material availability, component supplies, redesign cycles, charging and refueling infrastructure, and purchasers' willingness to purchase (including payback). The extent of these potential constraints has diminished significantly in light of increased and further projected investment by manufacturers, increased and further projected acceptance by purchasers, and significant support from Congress to address such areas as upfront purchase price, charging infrastructure, critical mineral supplies, and domestic supply chain manufacturing. The proposed standards would achieve significant and important reductions in GHG emissions that endanger public health and welfare. Furthermore, as discussed throughout this preamble, the emission reduction technologies needed to meet the proposed standards have already been developed and are feasible and available for manufacturers to utilize in their fleets at reasonable cost in the timeframe of these proposed standards, even after considering key elements including battery manufacturing capacity and critical materials availability.

As discussed throughout this preamble, the emission reduction technologies needed to meet the proposed standards are feasible and available for manufacturers to utilize in HD vehicles in the timeframe of these proposed standards. The proposed emission standards are based on one potential technology path (represented in multiple technology packages for the various HD vehicle regulatory subcategories per MY) that includes adoption rates for both ICE vehicle technologies and zero-emission vehicle technologies that EPA regards as feasible and appropriate under CAA section 202(a) for the reasons given in this Section II.G, and as further discussed throughout Section II and DRIA Chapter 2. For the reasons described in that analysis, EPA believes these technologies can be developed and applied in HD vehicles and adopted at the projected rates for these proposed standards within the lead time provided, as discussed in Section II.F.6 and in DRIA Chapter 2.

EPA also gave appropriate consideration of cost of compliance in the selection of the proposed standards as described in this Section II.G, and as further discussed in Section II.F and DRIA Chapter 2. The MY 2027 through MY 2031 emission standards were developed using less aggressive application rates and, therefore, are projected to have lower technology package costs than the proposed MY 2032 standards. Additionally, as described in this Section II.G and as further discussed in Section II.F and DRIA Chapter 2, we considered impacts on vehicle purchasers and willingness to purchase (including practicability, payback, and costs to vehicle purchasers) in applying constraints in our analysis and selecting the proposed standards.[545] For example, in MY 2032, we estimated that the incremental cost to purchase a ZEV would be recovered in the form of operational savings during the first one to three years of ownership, on average by regulatory group, for the vocational vehicles; approximately three years, on average by regulatory group, for short-haul tractors; and seven years, on average by regulatory group, for long-haul tractors, as shown in the payback analysis included in Section II.F.4. The length of ownership of new tractors varies. One study found that first ownership is customarily four to seven years for For-Hire companies and seven to 12 years for Private fleets.[546] Another survey

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[545] Although EPA sometimes describes purchaser response (including purchaser costs) as part of our analysis of feasibility, we emphasize that purchaser response is not a statutorily enumerated factor under section 202(a)(1)–(2). Rather EPA has considered purchaser response in exercising our discretion under the statute, and based on the record before us, the agency views purchaser response as a material aspect of the real-world feasibility of the proposed standards.

[546] Roeth, Mike, et al. ''Barriers to Increased Adoption of Fuel Efficiency Technologies in Freight Trucking,'' Page 24. July 2013. International Council for Clean Transportation. Available at *https://theicct.org/sites/default/files/publications/*

found that the average trade-in cycle for tractors was 8.7 years.[547] Therefore, we find that these tractor technologies on average by regulatory group pay for themselves within the customary ownership timeframe for the initial owner. As we discussed in the HD GHG Phase 2 rulemaking, vocational vehicles generally accumulate far fewer annual miles than tractors and would lead owners of these vehicles to keep them for longer periods of time.[548] To the extent vocational vehicle owners may be similar to owners of tractors in terms of business profiles, they are more likely to resemble private fleets or owner-operators than for-hire fleets. Regardless, the technologies would also pay for themselves on average by regulatory group within the ownership timeframe for vocational vehicles as well.

Moreover, the additional flexibilities beyond averaging already available under EPA's existing regulations, including banking and trading provisions in the ABT program—which, for example, in effect enable manufacturers to spread the compliance requirement for any particular model year across multiple model years—further support EPA's conclusion that the proposed standards provide sufficient time for the development and application of technology, giving appropriate consideration to cost.

The Administrator has significant discretion to weigh various factors under CAA section 202, and, as with the HD GHG Phase 1 and Phase 2 rules, the Administrator notes that the purpose of adopting standards under that provision of the Clean Air Act is to address air pollution that may reasonably be anticipated to endanger public health and welfare and that reducing air pollution has traditionally been the focus of such standards. Taking into consideration the importance of reducing GHG emissions and the primary purpose of CAA section 202 to reduce the threat posed to human health and the environment by air pollution, the Administrator finds it is appropriate to propose standards that, when implemented, would result in meaningful reductions of HD vehicle GHG emissions both near term and over the longer term, and to select such standards taking into consideration the enumerated statutory factors of technological feasibility and cost of compliance within the available lead time, as well as the discretionary factor of impacts on purchasers and willingness to purchase. In identifying the proposed standards, EPA's goal was to maximize emissions reductions given our assessment of technological feasibility and accounting for cost of compliance, lead time, and impacts on purchasers and willingness to purchase. The Administrator concludes that this approach is consistent with the text and purpose of CAA section 202.

There have been very significant developments in the adoption of ZEVs since EPA promulgated the HD GHG Phase 2 rule. One of the most significant developments for U.S. heavy-duty manufacturers and purchasers is the adoption of the IRA, which takes a comprehensive approach to addressing many of the potential barriers to wider adoption of heavy-duty ZEVs in the United States. As noted in Section I, the IRA provides tens of billions of dollars in tax credits and direct Federal funding to reduce the upfront cost of purchasing ZEVs, to increase the number of charging stations across the country, to reduce the cost of manufacturing batteries, and to promote domestic source of critical minerals and other important elements of the ZEV supply chain. By addressing all of these potential obstacles to wider ZEV adoption in a coordinated, well-financed, strategy, Congress significantly advanced the potential for ZEV adoption in the near term.

In developing this estimate, EPA considered a variety of constraints which have to date limited ZEV adoption and/or could limit it in the future, including: cost to manufacturers and purchasers; availability of raw materials, batteries, and other necessary supply chain elements; adequate electricity supply and distribution; and availability of hydrogen. EPA has consulted with analysts from other agencies, including the Federal Energy Regulatory Commission, DOE, DOT, and the Joint Office for Energy and Transportation, extensively reviewed published literature and other data, and, as discussed thoroughly in this preamble and the accompanying DRIA, has incorporated limitations into our modeling to address these potential constraints, as appropriate.

As discussed in Section II.G.4, there are additional considerations that support, but were not used to select, the proposed standards. These include the non-GHG emission and energy impacts, energy security, safety, and net benefits. EPA estimates that the present value of monetized net benefits to society would be approximately $320 billion through the year 2055 (annualized net benefits of $17 billion through 2055),[549] more than five times the cost in vehicle technology and associated electric vehicle supply equipment (EVSE) combined (see preamble Section VII and Chapter 8 of the DRIA). We recognize the these estimates do not reflect unquantified benefits, and the Administrator has not relied on these estimates in identifying the appropriate standards under CAA section 202. Nonetheless, our conclusion that the estimated benefits considerably exceed the estimated costs of the proposed program reinforces our view that the proposed standards represent an appropriate weighing of the statutory factors and other relevant considerations.

In addition to our proposed standards, we also considered and are seeking comment on a range of alternatives above and below the proposed standards, as specified and discussed in Section II.H and Section IX. Our approach and goal in selecting standards were generally the same for the range of alternative standards as they were for the proposed standards, while also recognizing that there are uncertainties in our projections and aiming to identify where additional information that may become available during the course of the rulemaking may support standards within that range as feasible and reasonable. EPA anticipates that the appropriate choice of final standards within this range will reflect the Administrator's judgments about the uncertainties in EPA's analyses as well as consideration of public comment and updated information where available. We considered an alternative with a slower phase-in with less stringent CO_2 emission standards; however, we did not select this level for the proposed standards because our assessment in this proposal is that feasible and appropriate standards are available that provide for greater GHG emission reductions than would be provided by this slower phase-in alternative. We also considered a more stringent alternative with emission standards similar to those required by the CA ACT program. At this time, we consider the proposed standards as the appropriate balancing of the factors. However, if our analysis for the final rule of relevant existing information, public comments, or new information that becomes available between the proposal and the final rule supports a set of standards within the range of alternatives we are requesting comment on, we may promulgate final CO_2 emission standards different from

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ICCT-NACFE-CSS_Barriers_Report_Final_20130722.pdf.

[547] American Transportation Research Institute. ''An Analysis of the Operational Costs of Trucking: 2021 Update.'' November 2021. Page 14.

[548] 81 FR 73719 (October 25, 2016).

[549] Using 3 percent discount rate and climate benefits calculated with the average SC–GHGs at a 3 percent discount rate.

those proposed if we determine that those emission standards are feasible and appropriate. For example, we could finalize different standards based on different ZEV adoption rates than described for the proposed standards based on different considerations within the inputs of HD TRUCS or other approaches that we have requested comment on in this proposal (*e.g.* payback schedules, consideration of technology development lead time, ZEV refueling infrastructure growth, consideration of the need for and level of emissions reductions which can be achieved through the standards to protect public health, etc.).

In summary, after consideration of the very significant reductions in GHG emissions, given the technical feasibility of the proposed standards and the moderate costs per vehicle in the available lead time, and taking into account a number of other factors such as the savings to purchasers in operating costs over the lifetime of the vehicle, safety, the benefits for energy security, and the significantly greater quantified benefits compared to quantified costs, EPA believes that the proposed standards are appropriate under EPA's section 202(a) authority.

H. Potential Alternatives

EPA developed and considered an alternative level of proposed stringency for this rule which we are seeking comment on. The results of the analysis of this alternative are included in Section IX of the preamble. We also request comment, including supporting data and analysis, if there are certain market segments, such as heavy-haul vocational trucks or long-haul tractors which may require significant energy content for their intended use, that it may be appropriate to set standards less stringent than the alternative for the specific corresponding regulatory subcategories in order to provide additional lead time to develop and introduce ZEV or other low emissions technology for those specific vehicle applications. As described in more detail throughout this preamble, we also are seeking comment on setting GHG standards that would reflect values less stringent than the lower stringency alternative for certain market segments, values in between the proposed standards and the alternative standards, values in between the proposed standards and those that would reflect ZEV adoption levels used in California's ACT, values that would reflect the level of ZEV adoption in the ACT program, and values beyond those that would reflect ZEV adoption levels in ACT such as the 50- to 60-percent ZEV adoption range represented by the publicly stated goals of several major OEMs for 2030.[550] [551] [552] [553] [554] For all of these scenarios we are requesting comment on, EPA anticipates that the same approach explained in Section II and DRIA Chapter 2 would generally be followed, including for estimating costs, though the rationale for the different ZEV adoption rates may be based on different considerations within the inputs of HD TRUCS or other approaches that we have requested comment on in this proposal (*e.g.* payback schedules, consideration of technology development lead time, ZEV refueling infrastructure growth, etc.). As explained in this Section I.D of the preamble, EPA has significant discretion in choosing an appropriate balance among factors in setting standards under CAA section 202(a)(1)–(2). If our analysis for the final rule of relevant existing information, public comments, or new information that becomes available between the proposal and final rule supports a slower or a more accelerated implementation of the proposed standards, we may promulgate final CO_2 emission standards different from those proposed (within the range between the less stringent alternative and the most stringent standards we request comment on in this section) if we determine that those emission standards are feasible and appropriate.

While our assessment in this proposal is that the proposed standards provide adequate lead time, in order to ensure fulsome comment on all of dynamics involved in the market responding to the proposed standards, we also considered an alternative with less stringent standards and a more gradual phase-in. As discussed in Section II.F.6, we considered while developing the proposed standards that manufacturers would need time to ramp up ZEV production from the numbers of ZEVs produced today to the higher adoption rates we project in the proposed standards that begin between four and eight years from now. Manufacturers would need to conduct research and develop electrified configurations for a diverse set of applications. They would also need time to conduct durability assessments because downtime is very critical in the heavy-duty market. Furthermore, manufacturers would require time to make new capital investments for the manufacturing of heavy-duty battery cells and packs, motors, and other EV components, along with changing over the vehicle assembly lines to incorporate an electrified powertrain. In addition, the purchasers of HD BEVs would need time to design and install charging infrastructure at their facilities or determine their hydrogen refueling logistics for FCEVs. Therefore, we developed and considered an alternative that reflects a more gradual phase-in of ZEV adoption rates to account for this uncertainty. The ZEV adoption rates associated with level of stringency of the proposed CO_2 emission standards shown in Section II.F.4 and the alternative CO_2 emission standards shown in Section IX.A.1 are shown in Table II–34. We are not proposing this alternative set of standards because, as already described, our assessment is that feasible and appropriate standards are available that provide for greater emission reductions than provided under this alternative. We request comment on whether our assessment that there is adequate lead time provided in the proposed standards is correct or if a more gradual phase in like the one described in this alternative would be more appropriate.

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[550] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

[551] Scania, 'Scania's Electrification Roadmap,' Scania Group, November 24, 2021, *https://www.scania.com/group/en/home/newsroom/news/2021/Scanias-electrification-roadmap.html.*

[552] AB Volvo, 'Volvo Trucks Launches Electric Truck with Longer Range,' Volvo Group, January 14, 2022, *https://www.volvogroup.com/en/news-and-media/news/2022/jan/news-4158927.html.*

[553] Deborah Lockridge, 'What Does Daimler Truck Spin-off Mean for North America?,' Trucking Info (November 11, 2021). *https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america.*

[554] Navistar presentation at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 9–11, 2022).

TABLE II–34—COMPARISON OF ZEV TECHNOLOGY ADOPTION RATES IN THE TECHNOLOGY PACKAGES CONSIDERED FOR THE PROPOSED STANDARDS AND ALTERNATIVE CONSIDERED

	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 and later (%)
Proposal						
Vocational	20	25	30	35	40	50
Short-Haul Tractors	10	12	15	20	30	35
Long-Haul Tractors	0	0	0	10	20	25
Alternative						
Vocational	14	20	25	30	35	40
Short-Haul Tractors	5	8	10	15	20	25
Long-Haul Tractors	0	0	0	10	15	20

In consideration of the environmental impacts of HD vehicles and the need for significant emission reductions, as well as the views expressed by stakeholders in comments on the HD2027 NPRM such as environmental justice communities, environmental nonprofit organizations, and state and local organizations for rapid and aggressive reductions in GHG emissions,[555] [556] [557] [558] we are also requesting comment on a more stringent set of GHG standards starting in MYs 2027 through 2032 than the proposed standards and requesting that commenters provide supporting information regarding whether such standards are feasible, appropriate, and consistent with our CAA section 202 authority for a national program. We specifically are seeking comment on values that would reflect the level of ZEV adoption used in California's ACT program (as shown in Table II–35), values in between the proposed standards and those that would reflect ZEV adoption levels in ACT, and values beyond those that would reflect ZEV adoption levels in ACT, such as the 50–60 percent ZEV adoption range represented by the publicly stated goals of several major OEMs for 2030.[559] [560] [561] [562] [563] Under any of these more stringent set of standards that we are requesting comment on, we estimate that the individual per-vehicle ZEV technology and operating costs reflecting these higher level of ZEV technology adoption rates would be the same as the individual per-vehicle ZEV costs of the proposed standards, as described in DRIA Chapter 2.8.2 because the costs were calculated as the incremental cost between a ZEV and a comparable ICE vehicle. Also under a scenario with more stringent standards, the total costs across the fleet would be higher but the total emission reductions would be greater. The MYs 2027 through 2032 and beyond emission standards reflecting the ZEV adoptions levels in California's ACT that we are requesting comment on can be found in a memo to the docket.[564]

TABLE II–35—COMPARISON OF ZEV TECHNOLOGY ADOPTION RATES BETWEEN THE PROPOSED STANDARDS AND CALIFORNIA ACT

	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 and later (%)
Proposed						
Vocational	20	25	30	35	40	50
Short-Haul Tractors	10	12	15	20	30	35
Long-Haul Tractors	0	0	0	10	20	25
CARB ACT						
Vocational	20	30	40	50	55	60
Tractors	15	20	25	30	35	40

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[555] ACEEE Comments to the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–2852–A1. Referencing Catherine Ledna et al., 'Decarbonizing Medium-& Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis' (NREL, March 2022), *https://www.nrel.gov/docs/fy22osti/82081.pdf*.

[556] EDF Comments to the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1265–A1, pp.16–17.

[557] ICCT Comments to the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1211–A1, p. 6.

[558] Moving Forward Network Comments to the HD2027 NPRM. See Docket Entry EPA–HQ–OAR–2019–0055–1277–A1, pp. 19–20.

[559] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf*.

[560] Scania, 'Scania's Electrification Roadmap,' Scania Group, November 24, 2021, *https://www.scania.com/group/en/home/newsroom/news/2021/Scanias-electrification-roadmap.html*.

[561] AB Volvo, 'Volvo Trucks Launches Electric Truck with Longer Range,' Volvo Group, January 14, 2022, *https://www.volvogroup.com/en/news-and-media/news/2022/jan/news-4158927.html*.

[562] Deborah Lockridge, 'What Does Daimler Truck Spin-off Mean for North America?,' Trucking Info (November 11, 2021). *https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america*.

[563] Navistar presentation at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 9–11, 2022).

[564] U.S. EPA. ''Memo to Docket: Potential Federal Heavy-Duty GHG Emission Standards Reflecting Technology Packages Including California's ACT Levels of ZEV Adoption.'' March 2023. Docket EPA–HQ–OAR–2022–0985.

I. Small Businesses

EPA is proposing to make no changes to (*i.e.,* maintain the existing) MY 2027 and later GHG vehicle emission standards for any heavy-duty manufacturers that meet the ''small business'' size criteria set by the Small Business Administration.[565] In other words, these manufacturers would not be subject to the proposed revised MY 2027 and new MYs 2028 through 2032 and later HD vehicle CO_2 emission standards but would remain subject to the HD vehicle CO_2 emission standards previous set in HD GHG Phase 2.[566] Additionally, we are proposing that qualifying small business manufacturers could continue to average within their averaging sets for each 2027 and later model year to achieve the applicable standards; however, we are proposing to restrict banking, trading, and the use of advanced technology credit multipliers for credits generated against the Phase 2 standards for qualifying manufacturers that utilize this small business interim provision.

We are also proposing that vehicle manufacturers that qualify as a small business may choose not to utilized the proposed interim provision and voluntarily certify their vehicles to the Phase 3 standards without ABT participation restrictions if they certify all their vehicle families within a given averaging set to the Phase 3 standards for the given MY. In other words, small businesses that opt into the Phase 3 program for a given MY for all their vehicle families within a given averaging set would be eligible for the full ABT program for those vehicle families for that MY, including advanced technology credit multipliers. While we are proposing not to apply the proposed new standards for vehicles produced by small businesses, we propose that some small business manufacturers would be subject to some other new requirements we are proposing in this rule related to ZEVs, such as the battery durability monitor and warranty provisions proposed in 40 CFR 1037.115(f) and described in Section III.B.

EPA may consider new GHG emission standards to apply for vehicles produced by small business vehicle manufacturers as part of a future regulatory action. At this time, we believe the proposed new standards, which were developed based on technology packages using increasing adoption of ZEVs, may create a disproportionate burden on small business vehicle manufacturers. As described in DRIA Chapter 9, we have identified a small number of manufacturers that would appear to qualify as small businesses under the heavy-duty vehicle manufacturer category. The majority of these small businesses currently only produce ZEVs, while one company currently produces ICE vehicles.

Since there would only be a small emissions benefit from applying the proposed standards to the relatively low production volume of ICE vehicles produced by small businesses, we believe that maintaining the existing HD vehicle CO_2 standards for these companies at this time would have a negligible impact on the overall GHG emission reductions that the program would otherwise achieve. We request comment on our assessment that the emission impact of this approach for small businesses would be small considering the number and type of vehicle manufacturers described in DRIA Chapter 9.

III. Compliance Provisions, Flexibilities, and Test Procedures

In this proposed rule, we are retaining the general compliance structure of existing 40 CFR part 1037 with some revisions described in this section. Vehicle manufacturers would continue to demonstrate that they meet emission standards using emission modeling and EPA's Greenhouse gas Emissions Model (GEM) and would use fuel-mapping or powertrain test information from procedures established and revised in previous rulemakings.[567]

The existing HD GHG Phase 2 program provides flexibilities, primarily through the HD GHG ABT program, that facilitate compliance with the emission standards. In addition to the general ABT provisions, the current HD GHG Phase 2 program also includes advanced technology credit (including for BEVs and FCEVs) and innovative technology credit provisions. As described in Section II of this preamble, the proposed revisions to the existing MY 2027 Phase 2 GHG emission standards and new proposed standards for MYs 2028 through 2032 are premised on utilization of a variety of technologies, including technologies that are considered advanced technologies in the existing HD GHG Phase 2 ABT program. As also explained in Section II, we consider averaging in supporting the feasibility of the proposed Phase 3 GHG standards in this rule. Averaging and other aspects of the ABT program would also continue to help provide additional flexibility for manufacturers to make necessary technological improvements and reduce the overall cost of the program, without compromising overall environmental objectives.

We are not proposing any changes to and are not reopening the use of credits from MY 2027 and earlier in MY 2027 and later. In other words, credits earned in HD GHG Phase 2 would be allowed to carry over into Phase 3, subject to the existing credit life limitation of five years, as described in 40 CFR 1037.740(c). Similarly, we are not proposing any revisions to and are not reopening the allowance that provides manufacturers three years to resolve credit deficits, as detailed in 40 CFR 1037.745.

In Section III.A, we describe the general ABT program and how we expect manufacturers to apply ABT to meet the proposed standards. In Section III.A, we propose a revision to the definition of ''U.S.-directed production volume'' to clarify consideration in this rulemaking of nationwide production volumes, including those that may in the future be certified to different state emission standards.[568] This proposed revision is intended to address a potential interaction between the existing definition of U.S.-directed production volume and the ACT regulation for HD vehicles.[569] Section III.A.2 includes proposed updates to advanced technology credit provisions after considering comments received on the HD2027 NPRM (87 FR 17592, March 28, 2022). In Section III.A.3, we request comment on other flexibilities, including how credits could be used across averaging sets. In Section III.B,

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[565] See our proposed updates to the definition of ''small business'' in 40 CFR 1037.801.

[566] See Section XI.C for our regulatory flexibility assessment of the potential burden on small businesses. See also Section III.C.2 for a description of the proposed revisions to 40 CFR 1037.150(c) that clarify the standards and proposed restrictions on participation in the ABT program for MYs 2027 and later that we are proposing would apply for qualifying small business vehicle manufacturers that utilize the proposed interim provision.

[567] See the HD GHG Phase 2 rule (81 FR 73478, October 25, 2016), the Heavy-Duty Engine and Vehicle Technical Amendment rule (86 FR 34308, June 29, 2021), and the HD2027 rule (88 FR 4296, January 24, 2023). In this rulemaking, EPA is not reopening any portion of our heavy-duty compliance provisions, flexibilities, and testing procedures, including those in 40 CFR parts 1037, 1036, and 1065, other than those specifically identified in this document as the subject of our proposal or a solicitation for comment. For example, while EPA is proposing to revise discrete elements of the HD ABT program, EPA is not reopening the general availability of ABT.

[568] The proposed definition update includes corresponding proposed clarifications throughout the HD engine and vehicle regulations of 40 CFR parts 1036 and 1037, respectively.

[569] EPA granted the ACT rule waiver requested by California under CAA section 209(b) on March 30, 2023.

we propose durability monitoring requirements for BEVs and PHEVs, clarify existing warranty requirements for PHEVs, and propose warranty requirements for BEVs and FCEVs. Finally, in Section III.C, we propose additional clarifying and editorial amendments to the HD highway engine provisions of 40 CFR part 1036, the HD vehicle provisions of 40 CFR part 1037 and the test procedures for HD engines in 40 CFR part 1065.

A. Proposed Revisions to the ABT Program

As noted in the introduction to this section, we are generally retaining the HD GHG Phase 2 ABT program that allows for emission credits to be averaged, banked, or traded within each of the averaging sets specified in 40 CFR 1037.740(a). To generate credits, a vehicle manufacturer must reduce CO_2 emission levels below the level of the standard for one or more vehicle families. The manufacturer can use those credits to offset higher emission levels from vehicles in the same averaging set such that the averaging set meets the standards on ''average'', ''bank'' the credits for later use, or ''trade'' the credits to another manufacturer. The credits are calculated based on the production volume of the vehicles in the averaging set and their respective emission levels relative to the standard. To incentivize the research and development of the new technologies, the current HD vehicle ABT program also includes credit multipliers for certain advanced technologies. In this Section III.A, we describe proposed changes to two aspects of the ABT program: the applicable production volume for use in calculating ABT credits and credit multipliers for advanced technologies. We also request comment on other potential flexibilities we could consider adopting in this rule.

1. U.S-Directed Production Volume

As described in Section II, the proposed Phase 3 GHG vehicle standards include consideration of nationwide production volumes. Correspondingly, we are proposing that the GHG ABT program for compliance with those standards would be applicable to the same production volumes considered in setting the standards. In Section II, we also request comment on how to account for ZEV adoption rates that would result from compliance with the California ACT program in setting the proposed GHG standards.[570] The existing HD GHG Phase 2 vehicle program has certain provisions (based off the regulatory definition of ''U.S.-directed production volume'') that would exclude production volumes that are certified to different state emission standards, including exclusion from participation in ABT. To address this potential interaction between the existing definition of U.S.-directed production volume and the ACT regulation for HD vehicles, we propose a revision to the definition of ''U.S.-directed production volume.'' The proposed revision would clarify that in this rulemaking we consider nationwide production volumes, including those that may in the future be certified to different state emission standards, within the proposed Phase 3 standards described in Section II and within the ABT GHG vehicle program.

The exclusion of engines and vehicles certified to different state standards in the existing definitions have not impacted the HD GHG program under parts 1036 and 1037 to-date because California has adopted GHG emission standards for HD engines and vehicles that align with the Federal HD GHG Phase 1 and Phase 2 standards.[571] [572] As discussed in Section I, the ACT regulation requires manufacturers to produce and sell increasing numbers of zero-emission medium- and heavy-duty highway vehicles. Given the distinct difference between what is required under the ACT compared to the existing Phase 2 vehicle program and the HD vehicle GHG standards proposed under this rulemaking, we are considering the impact of the ACT on the HD GHG vehicle program. To that end, we are proposing that the revision to this definition revision apply starting with MY 2024 to provide consistent treatment of any production volumes certified to ACT. We request comment on the MY 2024 start and whether other options should be considered for transitioning to this new definition.

The existing definition of ''U.S.-directed production volume'' for HD vehicles explicitly does not include vehicles certified to state emission standards that are different than the emission standards in 40 CFR part 1037.[573] The term U.S.-directed production volume is key in how the existing regulations direct manufacturers to calculate credits in the HD vehicle ABT GHG program, in 40 CFR part 1037, subpart H. In the existing regulations, vehicle production volumes that are excluded from that term's definition cannot generate credits. EPA first excluded such production volumes from participation in HD ABT in a 1990 rulemaking on NO_X emissions from HD engines. In the preamble to that rulemaking, which established NO_X and PM banking and trading and expanded the averaging program for HD engines, EPA explained that HDEs certified under the California emission control program are excluded from this program.[574] We further explained that HDEs certified under the California emission control program may not generate credits for use by Federal engines (49-state) or use credits generated by Federal engines.[575] In addition, we explained that while fifty-state engines participating in the Federal banking, trading or averaging programs may be sold in California if their FELs are lower than the applicable emission standard, California engines may not generate credits for the Federal program.[576]

In 2001, in a rulemaking that established criteria pollutant emission standards phasing in to MY 2010 and later for HD engines and vehicles, EPA adopted a definition for ''U.S.-directed production.'' The adopted definition included similar regulatory language to our existing part 1037 definition.[577] Regarding compliance with the MY 2007–2009 emission standards phase-in requirements, which were based on percentage of production volumes meeting the MY 2010 and later standards, EPA again noted our intent to exclude production volumes certified to different state standards. We explained that we were clarifying that this phase-in excludes California complete heavy-

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[570] EPA granted the ACT rule waiver requested by California under CAA section 209(b) on March 30, 2023.

[571] California Air Resources Board. ''Final Regulation Order for Phase 1 Greenhouse Gas Regulations.'' December 5, 2014, available at *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2013/hdghg2013/hdghgfrot13.pdf.*

[572] California Air Resources Board. ''Final Regulation Order for Phase 2 Greenhouse Gas Regulations and Tractor-Trailer GHG Regulations.'' April 1, 2019, available at *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2018/phase2/finalatta.pdf?_ga=2.122416523.1825165293.1663635303-1124543041.1635770745.*

[573] An equivalent definition of ''U.S-directed production volume'' can be found at 40 CFR 1036.801 for HD engines.

[574] 55 FR 30592, July 26, 1990.

[575] 55 FR 30592, July 26, 1990.

[576] 55 FR 30592, July 26, 1990.

[577] 66 FR 5002, 5159, January 18, 2001 (amending 40 CFR 86.004–2 to add a definition for ''*U.S.-directed* production'' where ''U.S.-directed production means the engines and/or vehicles (as applicable) produced by a manufacturer for which the manufacturer has reasonable assurance that sale was or will be made to ultimate purchasers in the United States, excluding engines and/or vehicles that are certified to state emission standards different than the emission standards in [40 CFR part 86].'').

duty vehicles, which are already required to be certified to the California emission standards.[578] We further explained that the phase-in also excludes vehicles sold in any state that has adopted California emission standards for complete heavy-duty vehicles.[579] We also explained that it would be inappropriate to allow manufacturers to ''double-count'' the vehicles by allowing them to count those vehicles both as part of their compliance with this phase-in and for compliance with California requirements.[580] In addition, we noted that we would handle HD engines similarly if California were to adopt different emission standards than those being established by this rule.[581]

In the HD GHG Phase 1 rule, EPA adopted the existing definitions of U.S.-directed production volume in 40 CFR 1036.801 and 1037.801, which were unchanged in HD GHG Phase 2 and currently apply for HD engines and vehicles.[582]

We are proposing a revision to the definition of ''U.S.-directed production volume'' in 40 CFR 1037.801 such that it represents the total nationwide production volumes, including vehicles certified to state emission standards that are different than the emission standards of 40 CFR part 1037. As described in Section II, the proposed standards are feasible and appropriate based on nationwide adoption rates of technology packages that include adoption of ZEV technologies. Manufacturers may be motivated to produce ZEVs by this rule and in response to other initiatives and we want to support any U.S. adoption of these technologies by allowing manufacturers to account for their nationwide production volumes to comply with the proposed standards. We recognize that the existing definition of ''U.S.-directed production volume'' may cause challenges to manufacturer plans, including long-term compliance planning, due to the uncertainty surrounding whether additional states may adopt more stringent standards in the future.

Given that EPA granted the ACT rule waiver requested by California under CAA section 209(b) on March 30, 2023, the existing definition of U.S.-directed production volume excludes all vehicles (ICE vehicles and ZEVs) certified to meet the ACT program in California and any other states that adopt the ACT.[583] In this scenario, the ZEV production volumes destined for California and other states would correspond to a large portion of the nationwide production on which the proposed EPA standards are based, and it would be challenging for vehicle manufacturers to comply with the proposed standards if they could not account for those ZEVs. As described in Section II, we request comment on how to account for ZEV adoption rates that would result from compliance with the California ACT program in setting the proposed GHG standards. If we were to finalize standards that account for the ACT program, we expect to similarly base the final standards on nationwide production volumes that would continue to rely on our proposal to revise the current definition of U.S.-directed production volume to include nationwide production.

We are proposing this revision consistent with our intended approach of considering such production volumes in setting the stringency of the Phase 3 standards in this rulemaking, as well as allowing inclusion of such production volumes in demonstrating compliance with the standards through participation in the HD vehicle ABT GHG program. We believe this approach would address both the potential ''double counting'' issue EPA previously articulated in past HD rulemakings and the potential difficulties surrounding manufacturers' long-term compliance planning (due to the uncertainty surrounding whether additional states may adopt the California ACT program in the future) we recognize in the context of this rulemaking. Our proposed revision would also align with the approach in the LD GHG program.

In addition to this proposed revision to the definition of ''U.S.-directed production volume'', we are proposing additional conforming amendments throughout 40 CFR part 1037 to streamline references to the revised definition; see Section III.E.3 for further discussion on one of those proposed revisions.[584]

2. Advanced Technology Credits for CO_2 Emissions

In HD GHG Phase 1, we provided advanced technology credits for hybrid powertrains, Rankine cycle waste heat recovery systems on engines, all-electric vehicles, and fuel cell electric vehicles to promote the implementation of advanced technologies that were not included in our technical basis of the feasibility of the Phase 1 emission standards (see 40 CFR 86.1819–14(k)(7), 1036.150(h), and 1037.150(p)). The HD GHG Phase 2 CO_2 emission standards that followed Phase 1 were premised on the use of mild hybrid powertrains in vocational vehicles and waste heat recovery systems in a subset of the engines and tractors, and we removed mild hybrid powertrains and waste heat recovery systems as options for advanced technology credits. At the time of the HD GHG Phase 2 final rule, we believed the HD GHG Phase 2 standards themselves provided sufficient incentive to develop those specific technologies. However, none of the HD GHG Phase 2 standards were based on projected utilization of the other even more-advanced Phase 1 advanced credit technologies (*e.g.,* plug-in hybrid electric vehicles, all-electric vehicles, and fuel cell electric vehicles). For HD GHG Phase 2, EPA promulgated advanced technology credit multipliers through MY 2027, as shown in Table III–1 (see also 40 CFR 1037.150(p)).

TABLE III–1—ADVANCED TECHNOLOGY MULTIPLIERS IN EXISTING HD GHG PHASE 2 FOR MYS 2021 THROUGH 2027

Technology	Multiplier
Plug-in hybrid electric vehicles	3.5
All-electric vehicles	4.5
Fuel cell electric vehicles	5.5

As stated in the HD GHG Phase 2 rulemaking, our intention with these multipliers was to create a meaningful incentive for those manufacturers considering developing and applying these qualifying advanced technologies into their vehicles. The multipliers under the existing program are consistent with values recommended by CARB in their HD GHG Phase 2 comments.[585] CARB's values were based on a cost analysis that compared the costs of these advanced technologies to costs of other GHG-reducing

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[578] 66 FR at 5043, January 18, 2001.

[579] 66 FR at 5043, January 18, 2001.

[580] 66 FR at 5043, January 18, 2001.

[581] 66 FR at 5043, January 18, 2001.

[582] 76 FR 57397 and 57431, September 15, 2011; 81 FR 74043 and 74123, October 25, 2016.

[583] As of September 2022, the following states have adopted California's ACT program: Massachusetts, New York, New Jersey, Washington, and Oregon.

[584] As discussed in Section III.C.3, we are also proposing a similar update to the heavy-duty highway engine definition of ''U.S.-directed production volume'' in 40 CFR 1036.801, with additional proposed updates where it is necessary to continue to exclude production volumes certified to different standards (*i.e.,* the ABT program for highway heavy-duty engines).

[585] Letter from Michael Carter, CARB, to Gina McCarthy, Administrator, EPA and Mark Rosekind, Administrator, NHTSA, June 16, 2016. EPA Docket ID EPA–HQ–OAR–2014–0827_attachment 2.

technologies. CARB's cost analysis showed that multipliers in the range we ultimately promulgated as part of the HD GHG Phase 2 final rule would make these advanced technologies more competitive with the other GHG-reducing technologies and could allow manufacturers to more easily generate a viable business case to develop these advanced technologies for HD vehicles and bring them to market at a competitive price.

In establishing the multipliers in the HD GHG Phase 2 final rule, we also considered the tendency of the HD sector to lag behind the light-duty sector in the adoption of a number of advanced technologies. There are many possible reasons for this, such as:

- HD vehicles are more expensive than light-duty vehicles, which makes it a greater monetary risk for purchasers to invest in new technologies.
- These vehicles are primarily work vehicles, which makes predictable reliability and versatility important.
- Sales volumes are much lower for HD vehicles, especially for specialized vehicles.

At the time of the HD GHG Phase 2 rulemaking, we concluded that as a result of factors such as these, and the fact that adoption rates for the aforementioned advanced technologies in HD vehicles were essentially non-existent in 2016, it seemed unlikely that market adoption of these advanced technologies would grow significantly within the next decade without additional incentives.

As we stated in the HD GHG Phase 2 final rule preamble, our determination that it was appropriate to provide large multipliers for these advanced technologies, at least in the short term, was because these advanced technologies have the potential to lead to very large reductions in GHG emissions and fuel consumption, and advance technology development substantially in the long term. However, because the credit multipliers are so large, we also stated that they should not necessarily be made available indefinitely. Therefore, they were included in the HD GHG Phase 2 final rule as an interim program continuing only through MY 2027.

The HD GHG Phase 2 CO_2 emission credits for HD vehicles are calculated according to the existing regulations at 40 CFR 1037.705. For BEVs and FCEVs, the family emission level (FEL) value for CO_2 emissions is deemed to be 0 grams per ton-mile.[586] Under those existing regulations, the CO_2 emission credits for HD BEVs built between MY 2021 and MY 2027 would be multiplied by 4.5 (or the values shown in Table III–1 for the other technologies) and, for discussion purposes, can be visualized as split into two shares.[587] The first share of credits would come from the reduction in CO_2 emissions realized by the environment from a BEV that is not emitting from the tailpipe, represented by the first 1.0 portion of the multiplier. Therefore, each BEV or FCEV produced receives emission credits equivalent to the level of the standard, even before taking into account the effect of a multiplier. The second share of credits does not represent CO_2 emission reductions realized in the real world but rather, as just explained, was established by EPA to help incentivize a nascent market: in this example, the emission credits for BEVs built between MY 2021 and 2027 receive an advanced technology credit multiplier of 4.5, *i.e.,* an additional 3.5 multiple of the standard.

The HD GHG Phase 2 advanced technology credit multipliers represent a tradeoff between incentivizing new advanced technologies that could have significant benefits well beyond what is required under the standards and providing credits that do not reflect real world reductions in emissions, which could allow higher emissions from credit-using engines and vehicles. At low adoption levels, we believe the balance between the benefits of encouraging additional electrification as compared to any negative emissions impacts of multipliers would be appropriate and would justify maintaining the current advanced technology multipliers. At the time we finalized the HD GHG Phase 2 program in 2016, we balanced these factors based on our estimate that there would be very little market penetration of ZEVs in the heavy-duty market in the MY 2021 to MY 2027 timeframe, during which the advanced technology credit multipliers would be in effect. Additionally, the primary technology packages in our technical basis of the feasibility of the HD GHG Phase 2 standards did not include any ZEVs.

In our assessment conducted during the development of HD GHG Phase 2, we found only one manufacturer had certified HD BEVs through MY 2016, and we projected "limited adoption of all-electric vehicles into the market" for MYs 2021 through 2027.[588] However, as discussed in Section II, we are now in a transitional period where manufacturers are actively increasing their PHEV, BEV, and FCEV HD vehicle offerings and are being further supported through the IRA tax credits, and we expect this growth to continue through the remaining timeframe for the HD GHG Phase 2 program and into the proposed Phase 3 program timeframe.

i. Advanced Technology Credits in the HD2027 NPRM

We requested comment in the HD2027 NPRM on three approaches that would reduce the number of incentive credits produced by battery electric vehicles in the MY 2024 through MY 2027 timeframe. The three approaches considered in the HD2027 NPRM (87 FR 17605–17606) are summarized as follows:

- *Approach 1:* The MY 2024 through MY 2027 ZEVs certified in California to meet the ACT program would not receive the advanced technology credit multipliers that currently exist.
- *Approach 2:* The advanced technology credits generated by a manufacturer would be capped on an annual basis. Advanced technology credits generated for EVs on an annual basis that are under a cap would remain unchanged. Above the cap, the multipliers would effectively be a value of 1.0; in other words, after a manufacturer reaches their cap in any model year, the multipliers would no longer be available and would have no additional effect on credit calculations. This advanced technology credit cap approach would limit the credits generated by a manufacturer's use of the advanced technology credit multipliers for battery electric vehicles to the following levels of CO_2 per manufacturer per model year beginning in MY 2024 and extending through MY 2027:
  - ○ Light Heavy-Duty Vehicle Averaging Set: 42,000 Mg CO_2.
  - ○ Medium Heavy-Duty Vehicle Averaging Set: 75,000 Mg CO_2.
  - ○ Heavy Heavy-Duty Vehicle Averaging Set: 325,000 Mg CO_2.
- *Approach 3:* Phase-out the magnitude of the credit multipliers from MY 2024 through MY 2027.

EPA received a number of comments on the HD2027 NPRM in response to our request for comment on potential approaches to modify the existing Advanced Technology Credit multipliers. The entire set of comments may be found in Section 28 of EPA's Response to Comments Document for the HD2027 final rule.[589]

Several commenters supported Approach 1, sometimes along with

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[586] 40 CFR 1037.150(f).

[587] 40 CFR 1037.705.

[588] 81 FR 75300 (October 25, 2016).

[589] U.S. EPA, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards—Response to Comments." Section 28. Docket EPA–HQ–OAR–2019–0055.

Approach 3. A common theme in these comments was that the incentive provided by the credit multipliers is not warranted for ZEVs that will already be produced due to state requirements. Some commenters also stated that the credit multipliers should not apply to any state that adopts ACT and should not be limited to California. Another commenter suggested an alternate approach whereby credit multipliers would not be provided for the vehicle segments targeted in the HD2027 NPRM for early adoption, such as some vocational vehicles and short-haul tractors, but remain available for other vehicle segments.

Other commenters raised concerns with Approach 1. For example, some commenters stated that the states' adoption of the ACT rule is unpredictable and may have a negative impact on manufacturer and supplier development plans. Another commenter raised a concern that eliminating the credit multipliers for ZEVs sold in California could impact manufacturers unequally and have a greater negative impact on manufacturers with more ZEV sales in California. One commenter suggested that this approach would create a disincentive for additional states to adopt ACT. Another commenter recommended that if EPA selects this approach, then EPA should consider allowing credit multipliers for ZEVs sold in California that exceed the ACT sales requirements. Finally, another commenter raised concerns about the implementation of this approach because it is difficult for manufacturers to account for sales by state in the heavy-duty market.

No commenters expressed support for Approach 2, and some commenters raised potential concerns with this approach. For example, a commenter stated this approach creates a disincentive to produce ZEVs above the annual cap and would negatively impact manufacturers that sell a greater number of ZEVs by making a smaller percentage of their fleet eligible for the credit multipliers. One commenter questioned whether a cap approach, while an incentive to small manufacturers and low volume ZEV producers, would incentivize additional sales beyond what is required by the states that adopt ACT under CAA section 177.

Many commenters supported a phase out or elimination of the credit multipliers, similar to Approach 3. A theme among many of the commenters was to phase out the credit multiplier as soon as practicable, with some commenters suggesting the phase out begin as early as MY 2024. On the other hand, two commenters suggested an annual decrease in the value of the credit multipliers to prevent a potential pre-buy situation. Common themes expressed by the commenters supporting an elimination of phase-out of the credit multipliers included stating that the credit multipliers are no longer necessary because of state requirements and that the credit multipliers reduce the overall effectiveness of the HD GHG regulatory program. One concern raised by a commenter is that the existing credit multipliers would slow the progression of CO_2-reducing technologies for HD vehicles that are powered by ICE. Some commenters suggested removing the credit multipliers for all of the existing technologies qualifying for advanced technology credits, including PHEVs, BEVs, and FCEVs.

Some of the commenters opposed any changes to the existing credit multipliers. Some commenters indicated that the credit multipliers are necessary to justify the research and development of these new and higher-cost technologies into new markets. They also noted that the credit multipliers provide a role in the overall suite of incentives for ZEVs and infrastructure in the HD market. Two commenters suggested extending the credit multipliers beyond MY 2027 to allow the HD ZEV market to further mature.

ii. Proposed Changes to the Advanced Technology Credit Multipliers

While we did anticipate some growth in electrification would occur due to the credit incentives in the HD GHG Phase 2 final rule when we finalized the rule, we did not expect the level of innovation since observed, the IRA or BIL incentives, or that California would adopt the ACT rule at the same time these advanced technology multipliers were in effect. Based on this new information, we believe the existing advanced technology multiplier credit levels may no longer be appropriate for maintaining the balance between encouraging manufacturers to continue to invest in new advanced technologies over the long term and potential emissions increases in the short term. We believe that, if left as is, the multiplier credits could allow for backsliding of emission reductions expected from ICE vehicles for some manufacturers in the near term (*i.e.,* the generation of excess credits which could delay the introduction of technology in the near or mid-term) as sales of advanced technology vehicles which can generate the incentive credit continue to increase.

After considering the comments received on the HD2027 NPRM and the proposed HD vehicle Phase 3 GHG standards and program described in Section II and this Section III, we propose to phase-out the advanced technology credit multipliers for HD plug-in hybrid and battery electric vehicles after MY 2026, one year earlier than what is currently in the regulations. We weighed several considerations in proposing this one year earlier phase-out. We do not foresee a need for any advanced technology credits for these technologies to extend past MY 2026. We recognize the need to continue to incentivize the development of BEVs in the near-term model years, prior to MY 2027. However, our analysis of the feasibility of PHEVs and BEVs described in Section II indicates there is sufficient incentive for those technologies for the model years we are proposing HD vehicle Phase 3 GHG emission standards (MYs 2027 through 2032). We note that we did not rely on credits generated from credit multipliers in developing the proposed HD vehicle Phase 3 emission standards, however this flexibility further supports the feasibility of the proposed Phase 3 emission standards.

As explained earlier in this subsection, we recognize that a portion of the credits that result from an advanced technology multiplier do not represent CO_2 emission reductions realized in the real world and thus should be carefully balanced amongst the other considerations. We considered that we are proposing to revise the existing regulatory definition of ''U.S.-directed production volume,'' as discussed in Section II, such that vehicle production volumes sold in California or Section 177 states that adopt ACT would be included in the ABT credit calculations and continuing to allow these multipliers could create a large bank of credits with the potential to delay the real world benefits of the proposed program. We also took into consideration that the IRA and other new incentives are available that could help reduce the role of the multipliers. Finally, we recognize that some manufacturers' long-term product plans for PHEV or BEV technologies may have extended to model years closer to MY 2027 when the HD GHG Phase 2 standards were at their most stringent levels. We are proposing a MY 2026 phase-out for PHEV and BEV credit multipliers, in part, because it is expected to have a lesser impact on current manufacturer product plans. We request comment on our proposed MY

2026 phase-out date or whether we should consider other approaches to account for ACT or incentive programs.

We propose to revise existing 40 CFR 1037.150(p) to reflect the proposed phase-out of advanced technology credit multipliers for BEVs and PHEVs and clarify the applicable standards for calculating credits. We propose parallel edits to existing 40 CFR 1037.615(a) to clarify when the advanced technology credit calculations described in that section would apply. We are not proposing any changes to the existing advanced technology multipliers for fuel cell electric vehicles, which continue to apply through MY 2027. We believe it is still appropriate to incentivize fuel cell technology, because it has been slower to develop in the HD market, as discussed in Section II.D, but request comment on this approach for FCEVs. Additionally, we are retaining and are not reopening the existing off-cycle provisions of 40 CFR 1037.610 that allow manufacturers to request approval for other ''innovative'' technologies not reflected in GEM.

3. Other Potential HD CO_2 Emission Credit Flexibilities

We recognize that the proposed HD GHG Phase 3 standards would require significant investments from manufacturers to reduce GHG emissions from HD vehicles. We request comment on the potential need for additional flexibilities to assist manufacturers in the implementation of Phase 3.

Specifically, we request comment on providing the flexibility for manufacturers to use advanced technology credits across averaging sets, subject to a cap. In HD GHG Phase 1, the advanced technology credits earned a multiplier of 1.5 and they could be applied to any heavy-duty engine or vehicle averaging set.[590] To prevent market distortions, we capped the amount of advanced credits that could be brought into any service class in any model year of the Phase 1 program at 60,000 Mg. In HD GHG Phase 2, we adopted larger advanced technology multipliers, and we discontinued the allowance for advanced technology credits to be used across averaging sets. The primary reason for the averaging set restriction was to reduce the risk of market distortions if we allowed the use of the credits across averaging sets combined with the larger credit multipliers.[591] As discussed in Section III.A.2, we are proposing to phase-out the advanced technology credit multipliers for HD plug-in hybrid and battery electric vehicles after MY 2026, one year earlier than what is currently in the regulations, and under the existing regulations the fuel cell electric vehicle advanced technology multipliers end after MY 2027.

We recognize the proposed Phase 3 standards would require the increasing use of CO_2 emission reducing technologies. During this proposed Phase 3 standards transition, we are considering whether additional flexibilities in the Phase 3 program emissions credit ABT program design may be warranted, similar to the Phase 1 provision which allowed credits generated from advanced technologies to be transferred across averaging sets. We request comment on including a similar flexibility for the Phase 3 program. For example, we may consider an interim provision that would allow vehicle CO_2 credits generated by PHEVs, BEVs, and FCEVs to be used across vehicle averaging sets or possibly across engine averaging sets as specified in 40 CFR part 1036. If we were to adopt such an allowance, we would expect this flexibility to begin with MY 2027 and end after the last year the new Phase 3 standards phase-in, which as proposed is after MY 2032. We also would expect to restrict the number of credits (*i.e.,* the quantity of CO_2 megagrams) that could be transferred from one averaging set to another in a given model year, considering the level of the standards and our goal to prevent market distortions, and we request comment on what an appropriate restriction should be. We also may set different credits transfer cap values per averaging set that vary across the various averaging sets. We request comment on the model years and credit volume limitations we should consider for such an allowance for PHEV, BEV, and FCEV generated CO_2 credits. We also request comment on extending this flexibility with some restrictions to the PHEV, BEV, and FCEV generated CO_2 credits from chassis-certified Class 2b and Class 3 vehicles. More specifically, we request comment on allowing PHEV, BEV, and FCEV generated CO_2 credits in the chassis-certified Class 2b and Class 3 vehicle category (under the part 86, subpart S ABT program for MYs 2027–2032) to be used in the HD Phase 3 light heavy-duty and medium heavy-duty vehicle averaging sets (under the part 1037 ABT program for MYs 2027–2032) in a single direction of movement (*i.e.,* not into the heavy heavy-duty averaging set, and not allowing HD Phase 3 credits from light heavy-duty and medium heavy-duty averaging sets to be transferred into the chassis-certified Class 2b and Class 3 vehicle category), and similarly request comment on what appropriate restrictions to MYs and credit volume limitations should be included if adopted.

We also request comment on considerations of a program similar to CARB's credit program included in their ACT rule. As briefly described in DRIA Chapter 1.3.3, CARB would apply vehicle class-specific ''weight class modifiers'' (*i.e.,* credit multipliers) for credits generated by ZEVs and near zero-emission vehicles to further incentivize adoption electrification of the larger vehicle classes.[592]

B. Battery Durability Monitoring and Warranty Requirements

This section describes our proposal to adopt battery durability monitoring requirements for BEVs and PHEVs and to clarify how warranty applies for several advanced technologies. Our proposal is motivated by three factors: BEV, PHEV, and FCEV are playing an increasing role in vehicle manufacturers' compliance strategies to control GHG emissions from HD vehicles; BEV, PHEV, and FCEV durability and reliability are important to achieving the GHG emissions reductions projected by this proposed program; and that GHG emissions credit calculations are based on mileage over a vehicle's full useful life.

1. Battery and Plug-In Hybrid Electric Vehicle Durability Monitoring Requirements

EPA's HD vehicle GHG emission standards apply for the regulatory useful life of the HD vehicle, consistent with CAA section 202(a)(1) (''Such standards shall be applicable to such vehicles and engines for their useful life''). Accordingly, EPA has historically required manufacturers to demonstrate the durability of their emission control systems on vehicles, including under our CAA section 206 authority. Without durability demonstration requirements, EPA would not be able to assess whether vehicles originally manufactured in compliance with relevant emissions standards would remain compliant over the course of their useful life. Recognizing that BEVs, PHEVs, and FCEVs are playing an increasing role in manufacturers' compliance strategies, and that emission credit calculations are based on mileage over a vehicle's useful life, the same logic applies to BEV, PHEV, and FCEV

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[590] 40 CFR 1036.740(c) and 1037.740(b).

[591] 81 FR 73498 (October 25, 2016).

[592] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Section 1963.2. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.*

durability. Under 40 CFR part 1037, subpart H, credits are calculated by determining the family emission limit (FEL) each vehicle achieves beyond the standard and multiplying that by the production volume and a useful life mileage attributed to each vehicle subfamily.[593] Having a useful life mileage figure for each vehicle subfamily is integral to calculating the credits attributable to that vehicle, whether those credits are used for calculating compliance through averaging, or for banking or trading. Compliance with standards through averaging depends on all vehicles in the regulatory subcategory, or averaging set, achieving their certified level of emission performance throughout their useful life. As explained in Section II and this Section III, EPA also anticipates most if not all manufacturers would include the averaging of credits generated by BEVs and FCEVs as part of their compliance strategies for the proposed standards, thus this is a particular concern given that the calculation of credits for averaging (as well as banking and trading) depend on the battery and emission performance being maintained for the full useful life of the vehicle. Thus, without durability requirements applicable to such vehicles guaranteeing certain performance over the entire useful life of the vehicles, EPA is mindful that there would not be a guarantee that a manufacturer's overall compliance with emission standards would continue throughout that useful life. Similarly, EPA is concerned that we would not have assurance that the proposed standards would achieve the emission reductions projected by this proposed program. Therefore, EPA is proposing new battery durability monitoring for HD BEVs and PHEVs as a first key step towards this end, beginning with MY 2027.

As implemented by light-duty vehicle manufacturers in current BEVs and PHEVs, lithium-ion battery technology has been shown to be effective and durable for use and we expect that this will also be the case for HD BEVs and PHEVs. It is also well known that the energy capacity of a battery will naturally degrade to some degree with time and usage, resulting in a reduction in driving range as the vehicle ages. The degree of this energy capacity and range reduction effectively becomes an issue of durability if it negatively affects how the vehicle can be used, or how many miles it is likely to be driven during its useful life.

Vehicle and engine manufacturers are currently required to account for potential battery degradation in both hybrid and plug-in hybrid vehicles that could result in an increase in CO_2 emissions (see, *e.g.,* existing 40 CFR 1037.241(c) and 1036.241(c)).[594] In addition, engine manufacturers are required to demonstrate compliance with criteria pollutant standards using fully aged emission control components that represent expected degradation during useful life (see, *e.g.,* 40 CFR 1036.235(a)(2) and 1036.240). EPA is applying this well-established approach to the durability of BEV and PHEV batteries by proposing to require battery durability monitoring.

The proposed requirements are similar to the battery durability monitor regulation framework developed by the United Nations Economic Commission for Europe (UN ECE) and adopted in 2022 as Global Technical Regulation (GTR) No. 22. The proposed durability monitoring regulations would require manufacturers of BEVs and PHEVs to develop and implement an on-board state-of-certified-energy (SOCE) monitor that can be read by the vehicle user. We are not proposing durability monitoring requirements for FCEVs at this time because the technology is currently still emerging in heavy-duty vehicle applications and we are still learning what the appropriate metric might be for quantifying FCEV performance.

The importance of battery durability in the context of zero-emission and hybrid vehicles, such as BEVs and PHEVs, is well documented and has been cited by several authorities in recent years. In their 2021 report, the National Academies of Science (NAS) identified battery durability as an important issue with the rise of electrification. Among the findings outlined in that report, NAS noted that: ''battery capacity degradation is considered a barrier for market penetration of BEVs,'' and that ''[knowledge of] real-world battery lifetime could have implications on R&D priorities, warranty provision, consumer confidence and acceptance, and role of electrification in fuel economy policy.'' NAS also noted that ''life prediction guides battery sizing, warranty, and resale value [and repurposing and recycling]'', and discussed at length the complexities of state of health (SOH) estimation, life-cycle prediction, and testing for battery degradation.[595]

Several rulemaking bodies have also recognized the importance of battery durability in a world with rapidly increasing numbers of zero-emission vehicles. In 2015, the United Nations Economic Commission for Europe began studying the need for a GTR governing battery durability in light-duty vehicles. In 2021, it finalized United Nations GTR No. 22, ''In-Vehicle Battery Durability for Electrified Vehicles,'' [596] which provides a regulatory structure for contracting parties to set standards for battery durability in light-duty BEVs and PHEVs. In 2022, the United Nations Economic Commission for Europe began studying the need for a GTR governing battery durability in heavy-duty vehicles. EPA representatives chaired the informal working group that developed the GTR and worked closely with global regulatory agencies and industry partners to complete its development in a form that could be adopted in various regions of the world, including potentially the United States. The European Commission and other contracting parties have also recognized the importance of durability provisions and are working to adopt the GTR standards in their local regulatory structures. In addition, the California Air Resources Board, as part of the Zero-Emission Powertrains (ZEP) Certification program, has also included battery durability and warranty requirements as part of a suite of customer assurance provisions designed to ensure that zero-emission vehicles maintain similar standards for usability, useful life, and maintenance as for ICE vehicles.[597]

EPA concurs with the emerging consensus that battery durability is an important issue. The ability of a zero-emission vehicle to achieve the expected emission reductions during its lifetime depends in part on the ability of the battery to maintain sufficient

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[593] The useful life values for the HD vehicle standards are located in 40 CFR 1037.105(e) and 1037.106(e).

[594] As discussed in Section III.C.3.vi, we are proposing to remove 40 CFR 1037.241(b), which if finalized, 40 CFR 1037.241(c) will be moved to 40 CFR 1037.241(b).

[595] National Academies of Sciences, Engineering, and Medicine 2021. ''Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy 2025–2035''. Washington, DC: The National Academies Press. *https://doi.org/10.17226/26092, p. 5–113 to 5–115.*

[596] United Nations Economic Commission for Europe, Addendum 22: United Nations Global Technical Regulation No. 22, United Nations Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles, April 14, 2022. Available at: *https://unece.org/sites/default/files/2022-04/ECE_TRANS_180a22e.pdf.*

[597] California Air Resources Board. ''Attachment C: California Standards and Test Procedures for New 2021 and Subsequent Model Heavy-Duty Zero-Emissions Powertrains'', available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/zepcert/froattc.pdf* (last accessed September 20, 2021) (see Section D for details of CARB rated energy capacity test procedure requirements).

driving range, capacity, power, and general operability for a period of use comparable to that expected of a comparable ICE vehicle. Durable and reliable electrified vehicles are therefore critical to ensuring that projected emissions reductions are achieved by this proposed program.

Because vehicle manufacturers can use electrification as an emissions control technology to comply with EPA standards as well as generate credits for use in averaging, and also banking and trading, EPA believes that it is appropriate to set requirements to ensure that electrified vehicles certifying to EPA standards are durable and capable of providing the anticipated emissions reductions, including those that they are credited under our provisions. For example, in order for the environmental emission reductions that are credited to BEVs and PHEVs to be fully realized under this proposed rule's structure, it is important that their potential to achieve a similar mileage during their lifetime be comparable to that assumed for ICE vehicles in the same vehicle service class. In addition, under the EPA GHG program, BEVs and PHEVs generate credits that can be traded among manufacturers and used to offset debits generated by vehicles using other technologies that do not themselves meet the proposed standards. In either case, if credits generated by zero-emission vehicles are to offset debits created by other vehicles on an equivalent basis, it is thus important that they should be capable of achieving a similar mileage, and this depends, in part, on the life of the battery. Further, if BEVs and PHEVs were less durable than comparable ICE vehicles, this could result in increased use of ICE vehicles. In particular, and especially for vehicles with shorter driving ranges, loss of a large portion of the original driving range capability as the vehicle ages could reduce the ability for zero-emission miles to displace greater-than-zero-emission miles traveled, as well as undermine purchaser confidence in this emerging but highly effective technology.

We proposed a specific durability testing requirement in the HD2027 NPRM and received comment on that proposal, including comment stating that the requirements could result in increases in the battery capacity beyond what was needed to meet the job of the customer. Due to these concerns and because we are still evaluating the range of durability metrics that could be used for quantifying HD BEV performance, EPA is not proposing specific durability testing requirements in this rule. However, EPA is including in this proposal a requirement for a battery durability monitor that would be applicable to HD BEVs and PHEVs. The battery durability monitor proposal would require manufacturers to provide a customer-facing battery state-of-health (SOH) monitor for all heavy-duty BEVs and PHEVs. We are proposing a new 40 CFR 1037.115(f) that would require manufacturers to install a customer-accessible SOH monitor which estimates, monitors, and communicates the vehicle's state of certified energy (SOCE) as it is defined in GTR No. 22.[598] Specifically, manufacturers would implement onboard algorithms to estimate the current state of health of the battery, in terms of the state of its usable battery energy (UBE) expressed as a percentage of the original UBE when the vehicle was new.

For HD PHEVs, we are proposing that manufacturers would use the existing powertrain test procedures defined in 40 CFR 1036.545 to determine UBE.[599] The powertrain test procedures requires that PHEVs be tested in charge depleting and charge sustaining modes using a range of vehicle configurations. For the determination of UBE, we are proposing that the PHEV manufacturer would select the most representative vehicle configuration.

For HD BEVs, we are proposing that manufacturers develop their own test procedures for determining UBE. This is due to the range of HD BEV architectures, and the limited test facilities for conducting powertrain testing of BEVs with e-axles. With the SOCE being a relative measure of battery health and not absolute UBE, we believe that leaving the test procedure up to the manufacturer will still provide a meaningful measure of the health of the battery. We also believe that requiring the SOH to be customer-accessible will provide assurance that the SOH monitor is relatively accurate while also providing more time for EPA to work with manufacturers to develop a standardized test procedure for determining UBE for HD BEVs.

We proposed a specified test procedure to determine UBE in the HD2027 NPRM and received comment on that proposal, including comment requesting changes to the proposed test procedure, which EPA considered in developing this proposal's approach. EPA requests comment both on this rule's proposed approach and on an alternative approach of EPA defining a test procedure to determine UBE, such as the test procedure EPA proposed in the HD2027 NPRM, CARB zero-emission powertrain certification, and the test procedures being considered by the UN ECE EVE IWG.[600] Regarding our request for comment on the HD2027 NPRM test procedure, we note that one of the main concerns with the test procedure in submitted comments on the HD2027 NPRM was that commenters stated the powertrain test cell required for powertrains with e-axles were not widely available, and we believe there has been some indication that this is changing; we request comment on this issue. Regarding our request for comment on the test procedures being considered by the UN ECE EVE IWG, we note that some of these test procedures don't rely on chassis or powertrain dynamometers, like the charge-discharge test procedure, and request comment on this issue.

Many of the organizations and authorities that have examined the issue of battery durability, including the UN Economic Commission for Europe, the European Commission, and the California Air Resources Board, have recognized that monitoring driving range as an indicator of battery durability performance (instead of or in addition to UBE) may be an attractive option because driving range is a metric that is more directly experienced and understood by the consumer. While we are not proposing to require that heavy-duty BEVs and PHEVs implement a state-of-certified-range (SOCR) monitor, we are requesting comment on whether we should require the SOCR monitor defined in GTR No. 22.

2. Battery and Fuel Cell Electric Vehicle Component Warranty

EPA is proposing new warranty requirements for BEV and FCEV batteries and associated emission-related electric powertrain components (*e.g.,* fuel-cell stack, electric motors, and inverters) and is proposing to clarify how existing warranty requirements apply for PHEVs.[601] The proposed warranty requirements build on existing emissions control warranty provisions by establishing specific new requirements tailored to the emission control-related role of the high-voltage

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[598] We are proposing to incorporate by reference the UN Economic Commission for Europe document as described in Section XI.I.

[599] We are proposing to move the existing powertrain procedure from its current location in 40 CFR 1037.550 to the heavy-duty highway engine provisions as a new 40 CFR 1036.545. See Section III.C.3 for more information.

[600] Memorandum to Docket EPA–HQ–OAR–2022–0985: ''Draft Test Procedures for Determining UBE''. James Sanchez. February 1, 2023.

[601] Note, EPA is not reopening the existing emission-related warranty periods for HD engines and vehicles in parts 1036 and 1037.

battery and fuel-cell stack in durability and performance of BEVs and FCEVs.

As described in the previous section, the National Academies of Science (NAS) in their 2021 report [602] identified battery warranty along with battery durability as an important issue with the rise of electrification. The proposed vehicle warranty requirements for battery and other emission-related electric powertrain components of HD BEVs and FCEVs would be similar to those that EPA has the authority to require and has historically applied to emission control-related components for HD vehicles, including HD ICE vehicles, under EPA's HD vehicle regulations, and would similarly implement and be under the authority of CAA section 207.[603] EPA believes that this practice of ensuring a minimum level of warranty protection should be extended to the high-voltage battery and other emission-related electric powertrain components of HD BEV, PHEV, and FCEV for multiple reasons. Recognizing that BEVs, PHEVs, and FCEVs are playing an increasing role in manufacturers' compliance strategies, the high-voltage battery and the powertrain components that depend on it are emission control devices critical to the operation and emission performance of HD vehicles, as they play a critical role in reducing the vehicles' emissions and allowing BEVs and FCEVs to have zero tailpipe emissions. As explained in Section II and this Section III, EPA also anticipates most if not all manufacturers would include the averaging of credits generated by BEVs and FCEVs as part of their compliance strategies for the proposed standards, thus this is a particular concern given that the calculation of credits for averaging (as well as banking and trading) depend on the battery and emission performance being maintained for the full useful life of the vehicle. Additionally, warranty provisions are a strong complement to the proposed battery durability monitoring requirements. We believe a component under warranty is more likely to be properly maintained and repaired or replaced if it fails, which could help ensure that credits granted for BEV and FCEV production volumes represent real emission reductions achieved over the life of the vehicle. Finally, we expect manufacturers provide warranties at the existing 40 CFR 1037.120 levels for the BEVs they currently produce, and the proposed requirements to certify to offering those warranty periods and document them in the owner's manual would provide additional assurance for owners that all BEVs have the same minimum warranty period.[604]

For heavy-duty vehicles, EPA is proposing that manufacturers identify BEV and FCEV batteries and associated electric powertrain components as component(s) covered under emission-related warranty in the vehicle's application for certification. We propose those components would be covered by the existing regulations' emissions warranty periods [605] of 5 years or 50,000 miles for Light HDV and 5 years or 100,000 miles for Medium HDV and Heavy HDV (see proposed revisions to 40 CFR 1037.120).

We are not proposing new battery warranty requirements for PHEVs as ''hybrid system components'' are covered under the existing regulations in 40 CFR part 1036 and 40 CFR part 1037. In the HD2027 rule, we finalized as proposed that when a manufacturer's certified configuration includes hybrid system components (*e.g.,* batteries, electric motors, and inverters), those components are considered emission-related components, which would be covered under the warranty requirements (see, *e.g.,* 88 FR 4363, January 24, 2023). We are proposing revisions to 40 CFR 1036.120(c) to clarify that the warranty requirements of 40 CFR part 1036 apply to hybrid system components for any hybrid manufacturers certifying to the part 1036 engine standards. In 40 CFR 1037.120(c), we are also proposing a clarifying revision to remove the sentence stating that the emission-related warranty does not need to cover components whose failure would not increase a vehicle's emissions of any regulated pollutant while extending the existing statement that warranty covers other emission-related components in a manufacturer's application for certification to specifically include any other components whose failure would increase a vehicle's CO_2 emissions.

C. Additional Proposed Revisions to the Regulations

In this subsection, we discuss proposed revisions to 40 CFR parts 1036, 1037, 1065.

1. Updates for Cross-Sector Issues

This section includes proposed updates that would make the same or similar changes in related portions of the CFR or across multiple standard-setting parts for individual industry sectors.

i. LLC Cycle Smoothing and Accessory Load

EPA finalized a new LLC duty-cycle in the HD2027 rule that included a procedure for smoothing the nonidle nonmotoring points immediately before and after idle segments within the duty-cycle.[606] It was brought to our attention that the smoothing procedure in 40 CFR 1036.514(c)(3) allows smoothing based on the idle accessory torque but says nothing about how to address the contribution of curb idle transmission torque (CITT), while 40 CFR 1065.610(d)(3)(v) through (viii) requires smoothing based on CITT and says nothing about how to address idle accessory torque. This could create confusion and difficulties for common cases where CITT is required in addition to the 40 CFR 1036.514 idle accessory torques. 40 CFR 1036.514(c)(3), as currently written, would only apply if the transmission was in neutral, because it only allows you to account for the accessory load and not CITT, which was not EPA's intent. To illustrate the concern, for example, a MHD engine could have an LLC idle accessory load of 23.5 foot-pounds, which is 19 percent of a typical automatic transmission CITT of 124 foot-pounds. To resolve this potential issue, we are proposing to remove the smoothing instructions in 40 CFR 1036.514 and incorporate them into 40 CFR 1065.610.

The original intent of the 40 CFR 1065.610 duty-cycle generation procedure was to avoid discontinuities in the reference torque values. It was written with the assumption that idle load in neutral was zero, meaning the vehicle or machine idle accessory load was zero. When we introduced the required LLC idle accessory load in 40 CFR 1036.514, we failed to realize that amendments would be needed to 40 CFR 1065.610(d)(3) to clarify how to handle the accessory load in the denormalization process. The engine mapping section 40 CFR 1065.510 is another area of concern as it does not address the possibility of droop in the idle governor, which would result in different idle speeds when the transmission is in drive versus neutral. This results in an additional

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[602] National Academies of Sciences, Engineering, and Medicine 2021. ''Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy 2025–2035''. Washington, DC: The National Academies Press. *https://doi.org/10.17226/26092.*

[603] See Section I.D. of this preamble for further discussion of EPA's authority under CAA section 207.

[604] The Freightliner eCascadia includes a powertrain warranty of 5 yr/150K or 300K miles (depending on battery pack size). DDCTEC 16046—eCascadia Spec Sheet_6.0.pdf.

[605] EPA promulgated the existing HD vehicle warranty periods in 40 CFR part 1037 under our CAA section 207 authority.

[606] 88 FR 4296 (January 24, 2023).

complication as the required idle accessory torque will be different in drive versus neutral to keep the accessory power at the level specified in Table 1 to 40 CFR 1036.514(c)(4).

40 CFR 1065.610(d)(4) is a related paragraph that allows a different deviation for an optional declared minimum torque that applies to variable- and constant-speed engines and both idle and nonidle nonmotoring points in the cycle. Its scope of application is wider than 40 CFR 1065.610(d)(3). 40 CFR 1065.610(d)(4) applies to all nonidle nonmotoring points in the cycle, not just the ones immediately preceding or following an idle segment and using it instead of (d)(3) would not get the intended constant idle accessory power loads or the intended smoothing.

There is also an existing historical conflict between 40 CFR 1065.510(f)(4) and 1065.610(d)(4). 40 CFR 1065.510(f)(4) requires that manufacturers declare non-zero idle, or minimum torques, but 40 CFR 1065.610(d)(4), permissible deviations, make their use in cycle generation optional. This results in an inconsistency between the two sections as 40 CFR 1065.510(f)(4) requires these parameters to be declared, but 40 CFR 1065.610(d)(4) does not require them to be used.

Additionally, there is a historical conflict in 40 CFR 1065.610(d)(3)(v). This paragraph, as written, includes zero percent speed and, if the paragraph is executed in the order listed, it would include idle points that were changed to neutral in the previous step for neutral while stationary transmissions. This conflict would change the torque values of those idle-in-neutral points back to the warm-idle-in-drive torque and the speed would be left unaltered at the idle-in-neutral speed. This was clearly not the intent of this paragraph, yet we note that this conflict spans back all the way to when these procedures were located in 40 CFR 86.1333–90.

The smoothing of idle points also raises the need for smoothing of the few occurances of non-idle points in the duty-cycles where the vehicle may be moving, the torque converter may not be stalled, and the warm-idle-in-drive torque may not be appropriate. This would result in the smoothing of consecutive points around nonidle nonmotoring points with normalized speed at or below zero percent and reference torque from zero to the warm-idle-in-drive torque value where the reference torque is set to the warm-idle-in-drive torque value.

To address all of these concerns, we are proposing to make changes to 40 CFR 1065.510, 1065.512, and 1065.610. Note, other proposed changes to these subsections not specifically mentioned here are edits to fix citations to relocated or new paragraphs and to improve the clarity of the test procedures. The proposed changes to 40 CFR 1065.610 include basing the smoothing of points preceding an idle segment and following an idle segment on the warm-idle-in-drive torque value (sum of CITT and idle accessory torque). Exceptions to this are for manual transmissions and for the first 24 seconds of initial idle segments for automatic transmissions. Here the warm-idle-in-neutral torque value (idle accessory torque) is used. We are proposing to include manual transmissions in the required deviations for reference torque determination for variable-speed engines in 40 CFR 1065.610(d)(3) for completeness. The proposed amendments to 40 CFR 1065.610(d)(3) include the option to skip these deviations for a manual transmission where optional declared idle torque and the optional declared power are not declared (idle torque is zero). This provides labs that have not yet implemented these required deviations the option to not implement them if they only need to run tests with manual transmissions with zero idle torque. We also proposed the addition of manual transmissions to 40 CFR 1065.512(b)(2) where these required deviations in 40 CFR 1065.610 are cited.

We are also proposing changes to 40 CFR 1065.510(b) and (f) to address the effect of droop in the idle governor and how to determine idle speed when idle torque is a function of idle speed (where a component is specified as power or CITT is specified as a function of speed and the idle speeds need to be determined for each setpoint of the idle governor). We are also proposing the addition of an option to declare the warm idle speed(s) equal to the idle speed setpoint for electronically governed variable-speed engines with an isochronous low-speed governor. Recent updates to the mapping test procedure in 40 CFR 1065.510 regarding running the map at the minimum user-adjustable idle speed setpoint and using the map for any test assumed that one could declare the warm idle speed(s) equal to the idle speed setpoint for electronically governed variable-speed engines.[607] We are proposing changes to make it clear that this option is allowed, which would help simplify the mapping process.

To resolve the conflict between 40 CFR 1065.510(f)(4) and 1065.610(d)(4), we are proposing to move the requirement to declare torques to 40 CFR 1065.510(f)(5), which would make it optional and consistent with 40 CFR 1065.610(d)(4).

To resolve the conflict in 40 CFR 1065.610(c)(3)(v), which we are proposing to reorganize as 40 CFR 1065.610(c)(3)(vii), we are proposing to restrict the applicability of the paragraph from ''all points'' to ''all nonidle nonmotoring points.'' To address the smoothing of consecutive nonidle nonmotoring points that immediately follow and precede any smoothed idle points we are proposing to change their reference torques to the warm-idle-in-drive torque value by adding a new 40 CFR 1065.610(c)(3)(xi).

We are also proposing revisions to 40 CFR 1036.514 to reorganize and clarify the process for cycle denormalization of speed and torque where accessory load is included and to add more specific transmission shift points for greater than 200 seconds idle segments for LLC engine and hybrid powertrain testing. Shifting the transmission to neutral during very long idle segments is more representative of in-use operation than leaving it in drive, so we are proposing more specific shift points instead of a range to reduce lab-to-lab variability. The proposal would require setting the reference speed and torque values to the warm-idle-in-drive values for the first three seconds and the last three seconds of the idle segment for an engine test, requiring keeping the transmission in drive for the first 3 seconds of the idle segment, shifting the transmission from drive to park or neutral immediately after the third second in the idle segment, and shifting the transmission into drive again three seconds before the end of the idle segment.

ii. Calculating Greenhouse Gas Emission Rates

We are proposing to revise 40 CFR 1036.550(b)(2) and 40 CFR 1054.501(b)(7) to clarify that when determining the test fuel's carbon mass fraction, W_C, the fuel properties that must be measured are α (hydrogen) and β (oxygen). These paragraphs, as currently written, imply that you cannot use the default fuel properties in 40 CFR 1065.655 for α, β, γ (sulfur), and δ (nitrogen). The fuel property determination in 40 CFR 1065.655(e) makes it clear that if you measure fuel properties and the default γ and δ values for your fuel type are zero in Table 2 to 40 CFR 1065.655, you do not need to measure those properties. The sulfur (γ) and nitrogen (δ) content of these highly refined gasoline and diesel fuels are not enough to affect the W_C determination

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[607] 88 FR 4296 (January 24, 2023).

and the original intent was to not require their measurement. We are proposing this change to ensure there is no confusion on the requirement. We are also proposing to update 40 CFR 1036.550(b)(2) and 40 CFR 1054.501(b)(7) so that they reference 40 CFR 1065.655(e), which includes the default fuel property table whose number had been previously changed and we did not make the corresponding update in 40 CFR 1036.550(b)(2) and 40 CFR 1054.501(b)(7).

iii. ABT Reporting

We are proposing to allow manufacturers to correct previously submitted vehicle and engine GHG ABT reports, where a mathematical or other error in the GEM-based or fleet calculations used for compliance was discovered after the 270-day final report submission deadline. In the Phase 1 program, EPA chose the 270-day deadline for submitting a final GHG ABT report to coincide with existing criteria pollutant report requirements that manufacturers follow for heavy-duty engines.[608] The 270-day deadline was based on our interest in manufacturers maintaining good quality assurance/quality control (QA/QC) processes in generating ABT reports. We continue to believe that aligning the ABT report deadlines for criteria and GHG pollutants can provide consistency within a manufacturer's certification and compliance processes, but further consideration of the inherent differences and complexities in how credits are calculated and accounted for in the two programs led us to consider a time window beyond 270 days for allowing corrections to the GHG report. Certifying an engine or vehicle fleet with attribute-based features (Phase 1) or GEM (Phase 2) involves a greater risk of error compared to EPA's engine or vehicle test-based programs for criteria pollutants, where direct measurement of criteria pollutant emissions at time of certification is well established. Whether an indirect, physics-based model for quantifying GHG emissions such as GEM, or a unique technology-, attribute-, or engine production volume-based credit accounting system, unintentional errors, if not detected prior to submitting the final GHG ABT report and not realized until the accounting process for the following model year was initiated, could negatively affect a manufacturer's credit balance. For example, the loss of these credits could result in a manufacturer purchasing credits or making unplanned investments in additional technologies to make up for the credits lost due to the report error.

Under the proposed revisions to 40 CFR 1036.730(f) and 1037.730(f), EPA would consider requests to correct previously submitted MY 2021 or later ABT reports only when notified of the error within a time period of 24 months from the September 30 final report deadline. For requests to correct reports for MY 2020 or earlier, we are proposing an interim deadline of October 1, 2024 (see proposed new 40 CFR 1036.150(aa) and 1037.150(y)). We believe that corrections to ABT reports, where justified, will have no impact on emissions compliance as the actual performance of a manufacturer's fleet was better than what was reported in error, and correcting the report simply adjusts the credit balance for the model year in question to the appropriate value, such that those credits can then be used in future model years.

This proposed narrowly focused allowance for correcting accounting, typographical, or GEM-based errors after a manufacturer submits the 270-day final report (see proposed revisions in 40 CFR 1037.730) is intended to address the disproportionate financial impact of an unintentional error in the complex modeling and accounting processes that manufacturers use to determine compliance and credit balances for a given model year. We are proposing a 10 percent discount to these credit corrections to the final report, which will reduce the value of the credits that are restored upon approval of the request. The 10 percent discount is intended to balance the goal of encouraging accuracy in ABT reports and use of robust QA/QC processes against the considerations for allowing manufacturers the ability to correct unforeseen errors.

iv. Migration of 40 CFR 1037.550 to 40 CFR 1036.545

We are proposing to migrate the powertrain test procedure in 40 CFR 1037.550 to 40 CFR 1036.545. Over the course of the development of this test procedure, its use expanded to include certification of engines to the criteria pollutant standards in 40 CFR part 1036 (including test procedures in 40 CFR 1036.510, 1036.512, and 1036.514) and the procedure can be used in place of the engine GHG testing procedures (40 CFR 1036.535 and 1036.540) for hybrid engines and hybrid powertrains. We are proposing to migrate the test procedure to 40 CFR 1036.545 as-is, with the following exceptions. We are proposing to add a new figure that provides an overview of the steps involved in carrying out testing under this section. We are proposing to clarify that if the test setup has multiple locations where torque is measured and speed is controlled, the manufacturer would be required to sum the measured torque and validate that the speed control meets the requirements defined in the proposed 40 CFR 1036.545(m). Positive cycle work, $W_{[\mathrm{cycle}]}$, would then be determined by integrating the sum of the power measured at each location in the proposed 40 CFR 1036.545(o)(7). We are also proposing to clarify that manufacturers may test the powertrain with a chassis dynamometer as long as they measure speed and torque at the powertrain's output shaft or wheel hubs. We are also proposing to replace all references to 40 CFR 1037.550 throughout 40 CFR part 1036 and part 1037 with new references to 40 CFR 1036.545. For test setups where speed and torque are measured at multiple locations, determine W[cycle] by integrating the sum of the power measured at each location.

v. Median Calculation for Test Fuel Properties in 40 CFR 1036.550

40 CFR 1036.550 currently requires the use of the median value of measurements from multiple labs for the emission test fuel's carbon-mass-specific net energy content and carbon mass fraction for manufacturers to determine the corrected CO_2 emission rate using equation 40 CFR 1036.550–1. The current procedure does not provide a method for determining the median value. We are proposing to add a new calculation for the median value in the statistics calculation procedures of 40 CFR 1065.602 as a new paragraph (m). We also propose to reference the new paragraph (m) in 40 CFR 1036.550(a)(1)(i) and (a)(2)(i) for carbon-mass-specific net energy content and carbon mass fraction, respectively. This proposed new calculation procedure would ensure that labs are using the same method to calculate the median value. This proposed calculation is a standard statistical method for determining median and it would require order ranking the data in increasing order from smallest value to largest.

Determining the median from data sets containing an even number of data points would require dividing the number of data points by two to determine the rank of one of the data points whose value would be used to determine the median. This data point would then be added to the next highest ranked data point and the sum would be divided by two to determine the median.

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[608] See the HD GHG Phase 1 rule (76 FR 57284, September 15, 2011).

Determining the median from data sets containing an odd number of data points would be determined by adding one to the number of data points and dividing the sum by two to determine the rank of the data point whose value would be the median.

2. Updates to 40 CFR Part 1036 Heavy-Duty Highway Engine Provisions

i. Manufacturer Run Heavy Duty In-Use Testing

We are proposing a clarification to 40 CFR 1036.405(d) regarding the starting point for the 18-month window manufacturers have to complete an in-use test order. Under the current provision, the clock for the 18-month window starts after EPA has received the manufacturer's proposed plan for recruiting, screening, and selecting vehicles. There is concern that manufacturers could delay testing by unnecessarily prolonging the selection process. To alleviate this concern and keep the testing timeline within the originally intended 18-month window, we are proposing to start the clock on the 18-month window when EPA issues the order for the manufacturer to test a particular engine family.

In the HD2027 final rule, we adopted a new 40 CFR 1036.420 that includes the pass criteria for individual engines tested under the manufacturer run in-use testing program. Table 1 to 40 CFR 1036.420 contains the accuracy margins for each criteria pollutant. We are proposing to correct an inadvertent error in the final rule's amendatory text for the regulations that effects the accuracy margin for carbon monoxide (CO), which is listed in Table 1 as 0.025 g/hp-hr. The HD2027 preamble is clear that the CO accuracy margin that we finalized was intended to be 0.25 g/hp-hr and we are proposing to correct Table 1 to reflect the value in the preamble.[609]

ii. Low Load Cycle (LLC)—Cycle Statistics

We are proposing to update 40 CFR 1036.514 to address the ability of gaseous fueled non-hybrid engines with single point fuel injection to pass cycle statistics to validate the LLC duty cycle. We referenced, in error in 40 CFR 1036.514(e), the alternate cycle statistics for gaseous fueled engines with single point fuel injection in the cycle average fuel map section in 40 CFR 1036.540(d)(3) instead of adding LLC specific cycle statistics in 40 CFR 1036.514(e). We are proposing the addition of a new Table 1 in 40 CFR 1036.514(b) to provide cycle statistics that are identical to those used by the California Air Resources Board for the LLC and to remove the reference to 40 CFR 1036.540(d)(3) in 40 CFR 1036.514(e).

iii. Low Load Cycle (LLC)—Background Sampling

We are proposing to remove the provision in 40 CFR 1036.514(d) that allows periodic background sampling into the bag over the course of multiple test intervals during the LLC because the allowance to do this is convered in 40 CFR 1065.140(b)(2). The LLC consists of a very long test interval and the intent of the provision was to address emission bag sampling systems that do not have enough dynamic range to sample background constantly over the entire duration of the LLC. 40 CFR 1065.140(b)(2) affords many flexibilities regarding the measurement of background concentrations, including sampling over multiple test intervals as long as it does not affect your ability to demonstrate compliance with the applicable emission standards.

iv. U.S.-Directed Production Volume

In the recent HD2027 rule, we amended the heavy-duty highway engine provision in 40 CFR 1036.205 and several other sections to replace ''U.S.-directed production volume'' with the more general term ''nationwide'' where we intended manufacturers report total nationwide production volumes, including production volumes that meet different state standards.

In this rule, for the reasons explained in Section III.A.1, we are proposing a broader change to the definition of ''U.S.-directed production volume'' for vehicles in 40 CFR 1037.801 to include production volumes for vehicles certified to different standards. We are proposing to adopt the same updated definition of ''U.S.-directed production volume'' in 40 CFR 1036.801 to maintain consistency between the engine and vehicle regulations' definitions, and are proposing to reinstate the term ''U.S.-directed production volume'' where we currently use ''nationwide'' in 40 CFR part 1036 to avoid having two terms with the same meaning.[610]

Since certain existing part 1036 requirements use the existing term and definition to exclude production volumes certified to different state standards (*i.e.,* the NO_X ABT program for HD engines), we are proposing corresponding clarifying updates throughout 40 CFR part 1036 to ensure no change to those existing exclusions in tandem with the proposed change to the definition of the term ''U.S.-directed production volume.'' For example, we are also proposing to update 40 CFR 1036.705(c) to establish this paragraph as the reference for specifying the engines that are excluded from the production volume used to calculate emission credits for HD highway engines, and we propose that a new 40 CFR 1036.705(c)(4) be the location where we exclude engines certified to different state emission standards for the HD engine program.[611] The proposed changes also include replacing several instances of ''U.S.-directed production volume'' with a more general ''production volume'' where the text clearly is connected to ABT or a more specific reference to the production volume specified in 40 CFR 1036.705(c).[612]

v. Correction to NO_X ABT FEL Cap

We are proposing to amend 40 CFR 1036.104(c)(2) to remove paragraph (iii) which corresponds to a FEL cap of 70 mg/hp-hr for MY 2031 and later Heavy HDE that we proposed in HD2027 but did not intend to include in the final amendatory text. In the final rule for the HD2027 rule, we did not intend to include in the final amendatory text paragraph (iii) alongside the final FEL cap of 50 mg/hp-hr for MY 2031 and later which applies to all HD engine service classes including Heavy HDE in paragraph (ii) described by EPA in the preamble and supporting rule record. We are proposing to correct this error and remove paragraph (iii). This correction will not impact the stringency of the final NO_X standards because even without correction paragraph (ii) controls.[613]

vi. Rated Power and Continuous Rated Power Coefficient of Variance in 40 CFR 1036.520

We are proposing to correct an error and include a revision to a provision we intended to include in HD2027, regarding determining power and vehicle speed values for powertrain

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[609] See HD2027 final rule preamble (88 FR 4353, January 24, 2023) (''PEMS measurement allowance values in 40 CFR 86.1912 are 0.01 g/hp-hr for HC, 0.25 g/hp-hr for CO, 0.15 g/hp-hr for NO_X, and 0.006 g/hp-hr for PM. We are maintaining the same values for HC, CO, and PM in this rulemaking.'').

[610] See proposed revisions in 40 CFR 1036.205(v), 1036.250(a), 1036.405(a), 1036.605(e), 1036.725(b), and 1036.730(b).

[611] The proposed revision would also move the statement to keep records relating to those production volumes from its current location in 40 CFR 1036.705(c) to 40 CFR 1036.735 with the other ABT recordkeeping requirements.

[612] See proposed revisions in 40 CFR 1036.150(d) and (k), 1036.725(b), and 1036.730(b).

[613] EPA is not reopening the final HD2027 standards or any other portion of that rule besides those specifically identified in this document as subject to new proposed revisions.

testing. In 40 CFR 1036.520, paragraphs (h) and (i) describe how to determine rated power and continuous rated power, respectively, from the 5 Hz data in paragraph (g) averaged from the 100 Hz data collected during the test. We inadvertently left out the coefficient of variance (COV) limits of 2 percent that are needed for making the rated and continuous rated power determinations in the HD2027 final 40 CFR 1036.520(h) and (i), which were intended to be based on the COVs calculated in 40 CFR 1036.520(g) and we correctly included in the HD2027 final 40 CFR 1036.520(g). We are proposing to add the 2 percent COV limit into 40 CFR 1036.520(h) and (i). We are also proposing to correct a paragraph reference error in 40 CFR 1036.520(h). The paragraph references the data collected in paragraph (f)(2) of the section. The data collection takes place in paragraph (d)(2) of the section.

vii. Selection of Drive Axle Ratio and Tire Radius for Hybrid Engine and Hybrid Powertrain Testing

We are proposing to combine and modify the drive axle ratio and tire radius selection paragraphs in 40 CFR 1036.510(b)(2)(vii) and (viii). When testing hybrid engines and hybrid powertrains a series of vehicle parameters must be selected. The paragraphs for selecting drive axle ratio and tire radius are separate from each other, however the selection of the drive axle ratio must be done in conjunction with the tire radius as not all tire sizes are offered with a given drive axle ratio. We are proposing to combine these paragraphs into one to eliminate any possible confusion on the selection of these two parameters.

The maximum vehicle speed for SET testing of hybrid engines and powertrains is determined based on the vehicle parameters and maximum achievable speed for the configuration in 40 CFR 1036.510. This is not the case for the FTP vehicle speed which reaches a maximum of 60 miles per hour. It has been brought to our attention that there are some vehicle configurations that cannot achieve the FTP maximum speed of 60 mile per hour. To resolve this, we are proposing changes to 40 CFR 1036.510(b)(2)(vii) instructing the manufacturer to select a representative combination of drive axle ratio and tire size that ensure a vehicle speed of no less than 60 miles per hour. We are also proposing to include, as a reminder, that manufacturers may request approval for selected drive axle ratio and tire radius consistent with the provisions of 40 CFR 1036.210. We are also proposing to add a provision for manufacturers to follow the provisions of 40 CFR 1066.425(b)(5) if the hybrid powertrain or hybrid engine is used exclusively in vehicles which are not capable of reaching 60 mi/hr. This would allow the manufacturer to seek approval of an alternate test cycle and cycle-validation criteria for powertrains where the representative tire radius and axle ratio do not allow the vehicle to achieve the maximum speeds of the specified test cycle.

viii. Determining Power and Vehicle Speed Values for Powertrain Testing

We are proposing to revise 40 CFR 1036.520(d)(2) to address the possibility of clutch slip when performing the full load acceleration with maximum driver demand at 6.0 percent road grade where the initial vehicle speed is 0 mi/hr. The proposed revision would allow hybrid engines and hybrid powertrains to modify the road grade in the first 30 seconds or increase the initial speed from 0 miles per hour to 5 miles per hour to mitigate clutch slip. This road grade alteration or change in initial speed should reduce the extreme force on the clutch when accelerating at 6.0 percent grade.

We are proposing to revise 40 CFR 1036.520(d)(3) to address situations where the powertrain does not reach maximum power in the highest gear 30 seconds after the grade setpoint has reached 0.0 percent. To address this we are proposing to replace the 30 second time limit with a speed change stability limit of 0.02 m/s^2 which would trigger the end of the test.

ix. Request for Comment on Determining Vehicle Mass in 40 CFR 1036.510

As engines and powertrains evolve with time, changes to vehicle mass may be needed to maintain equivalent cycle work between the powertrain and engine test procedures. We request comment on updating equation 40 CFR 1036.510–1 to better reflect the relationship of vehicle mass and rated power. With the increase in rated power of heavy-duty engines, at least one manufacturer has raised to EPA that there is some concern that equation 40 CFR 1036.510–1 might need updating to better reflect the relationship of vehicle mass and rated power. If you provide comment that the equation should be updated, we request that you provide data to justify the change and show that the change would provide comparable values of cycle work and power versus time, for both the engine and powertrain versions of the duty cycles. For the engine duty cycles (*e.g.,* FTP and SET), the cycle work of the duty cycle is a function of the engine torque curve. For the powertrain duty cycles (*e.g.,* vehicle FTP and vehicle SET), the cycle work of the duty cycle is a function of the rated power of the powertrain.

x. Test Procedure for Engines Recovering Kinetic Energy for Electric Heaters

We are proposing a clarification in the existing definition for hybrid in 40 CFR 1036.801 to add a sentence stating that systems recovering kinetic energy to power an electric heater for the aftertreatment would not qualify as a hybrid engine or hybrid powertrain. Under the existing hybrid definition, systems that recover kinetic energy, such as regenerative braking, would be considered ''hybrid components'' and manufacturers would be required to use the powertrain test procedures to account for the electric heater or use the engine test procedures and forfeit the emission reductions from heating the aftertreatment system. With the proposed clarification to the hybrid definition, engines that use regenerative braking only to power an electric heater for aftertreatment devices would not be considered hybrid engines and, therefore, would not be required to use the powertrain test procedures; instead, those engines could use the test procedures for engines without hybrid components.

We are proposing to supplement the new definitions with direction for testing these systems in 40 CFR 1036.501. In a proposed new 40 CFR 1036.501(g), we would clarify that an electric heater for aftertreatment can be installed and functioning when creating fuel maps using 40 CFR 1036.505(b), and measuring emissions over the duty cycles specified in 40 CFR 1036.510(b), 40 CFR 1036.512(b), and 40 CFR 1036.514(b). This proposed allowance would be limited to hybrid engines where the system recovers less than 10 percent of the total positive work over each applicable transient cycle and the recovered energy is exclusively used to power an electric heater in the aftertreatment. Since the small amount of recovered energy is stored thermally and can't be used to move the vehicle, we believe that the engine test procedures are just as representative of real-world operation as the powertrain test procedures. We request comment on using a different limit than 10 percent of the total positive work over the transient cycle for this flexibility. The proposed limit of 10 percent is based on the amount of negative work versus positive work typical of conventional engines over the transient cycle. After evaluating a range of HDE, we have observed that the negative work from the transient FTP cycle during engine motoring is less than 10 percent of the positive work of the transient FTP cycle.[614] In the same paragraph (g), we also propose that manufacturers have the option to use the powertrain test procedures for these systems, which would not have the same restrictions we are proposing for the amount of recovered energy.

xi. Updates to 40 CFR Part 1036 Definitions

We propose new and updated definitions in 40 CFR 1036.801 in support of several proposed requirements in Section II or this Section III. We propose to add a reference to two new definitions proposed in 40 CFR part 1065: Carbon-containing fuel and ''neat''. The proposed definition of carbon-containing fuel will help identify the applicable test procedures for engines using fuels that do not contain carbon and would not produce CO_2. The proposed definition of ''neat'' would indicate that a fuel is not mixed or diluted with other fuels, which would help distinguish between fuels that contain no carbon, such as hydrogen, and fuels that that contain carbon through mixing, such as hydrogen where a diesel pilot is used for combustion. We also propose to update the definition for U.S.-directed production volume to be equivalent to nationwide production.

We propose to consolidate the definitions of hybrid, hybrid engine, and hybrid powertrain into a single definition of ''hybrid'' with subparagraphs distinguishing hybrid engines and powertrains. The proposed definition of hybrid retains most of the existing definition, except that we propose to remove the unnecessary ''electrical'' qualifier from batteries and propose to add a statement relating to recovering energy to power an electric heater in the aftertreatment (see Section III.C.2.x). The revised definitions for hybrid engines and powertrains, which are proposed as subparagraphs under ''hybrid'', are more complementary of each other with less redundancy. As noted in Section III.C.2.x, we propose to update the definitions of hybrid engine and hybrid powertrain to exclude systems recovering kinetic energy for electric heaters.

We propose several editorial revisions to definitions as well. We propose to update the definition of mild hybrid such that it is *relating* to a hybrid engine or hybrid powertrain. We propose to revise the existing definition of small manufacturer to clarify that the employee and revenue limits include the totals from *all* affiliated companies and added a reference to the definition of affiliated companies in 40 CFR 1068.30.

xii. Miscellaneous Corrections and Clarifications in 40 CFR Part 1036

We are proposing to update 40 CFR 1036.150(j) to clarify that the alternate standards apply for model year 2023 and earlier loose engines, which is consistent with existing 40 CFR 86.1819–14(k)(8).

We propose to update the provision describing how to determine deterioration factors for exhaust emission standards in 40 CFR 1036.245 so it would also apply for hybrid powertrains.

xiii. Off-Cycle Test Procedure for Engines That Use Fuels Other Than Carbon-Containing Fuel

We are proposing a new paragraph 40 CFR 1036.530(j) for engines that use fuels other than carbon-containing fuel. The off-cycle test procedures in 40 CFR 1036.530 use CO_2 as a surrogate for engine power. This approach works for engines that are fueled with carbon-containing fuel, since power correlates to fuel mass rate and for carbon-containing fuels, fuel mass rate is proportional to the CO_2 mass rate of the exhaust. For fuels other than carbon-containing fuels, the fuel mass rate is not proportional to the CO_2 mass rate of the exhaust. To address this issue, we are proposing, for fuels other than carbon-containing fuels, to use engine power directly instead of relying on CO_2 mass rate to determine engine power. For field testing where engine torque and speed is not directly measured, engine broadcasted speed and torque can be used as described in 40 CFR 1065.915(d)(5).

xiv. Onboard Diagnostic and Inducement Amendments

EPA is proposing to make changes to specific aspects of paragraphs within 40 CFR 1036.110 and 1036.111 to add clarifications and correct minor errors in the OBD and inducement provisions adopted in the HD2027 final rule.[615] Specifically, EPA is proposing the following:

- *40 CFR 1036.110(b)(6):* Proposing to correct a reference to the CARB regulation to be consistent with our intent as described in the preamble of the final rule (see 88 FR 4372) to not require manufacturer self-testing and reporting requirements in 13 CCR 1971.1(l)(4).
- *40 CFR 1036.110(b)(9):* Proposing to clarify that the list of data parameters readable by a generic scan tool is limited to components that are subject to existing OBD monitoring requirements (*e.g.,* through comprehensive component requirements in 13 CCR 1971.1(g)(3)). For example, if parking brake status was not included in an engine's OBD certificate, it would not be a required data parameter.
- *40 CFR 1036.110(b)(11):* Proposing to add a reference to 13 CCR 1971.5. The final rule referenced 13 CCR 1971.1 to point to OBD testing deadlines; however, there are additional OBD testing deadlines specified in 1971.5.
- *40 CFR 1036.110(c)(1) and 40 CFR 1036.125(h)(8)(iii):* Proposing to correct terminology within these provisions by referring to inducements related to ''DEF level'' instead of ''DEF quantity,'' to make the intent clearer that the system must use the level of DEF in the DEF tank for purposes of evaluating the specified inducement triggering condition. We separately refer to the quantity of DEF injection for managing the functioning of the SCR catalyst, which is unrelated to the level of DEF in the DEF tank.
- *40 CFR 1036.111:* Proposing to edit for clarity, to eliminate confusion with onboard diagnostic terminology. More specifically, proposing edits to adjust inducement-related terminology to refer to ''inducement triggering conditions'' instead of ''fault conditions.'' Inducement algorithms are executed through OBD algorithms, but the inducement triggers are separate from OBD fault conditions related to the malfunction indicator light.
- *40 CFR 1036.111(a)(2):* Proposing to clarify how to determine the speed category when there is less than 30 hours of accumulated data. The regulation as adopted sets the inducement schedule based on average vehicle speed over the preceding 30 hours of non-idle operation. That instruction will cover most circumstances; however, there is no specific instruction for an inducement triggering condition that occurs before the vehicle accumulates 30 hours of non-idle operation. As described in the final rule, we depend on 30 hours of non-idle operation to establish which inducement schedule is appropriate for a vehicle. We are also aware that a newly purchased vehicle would have

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[614] Memorandum to Docket EPA–HQ–OAR–2022–0985: ''Analysis of Motoring and Positive Cycle Work for Current Heavy-Duty Engines''. James Sanchez. April 4, 2023.

[615] EPA is not reopening any aspect of our OBD and inducement provisions other than those proposed clarifications and corrections specifically identified in this section.

accumulated several hours of very low-speed operation before being placed into service. We are therefore proposing to specify that engines should not be designed to assess the speed category for inducement triggering conditions until the vehicle has accumulated 30 hours of non-idle operation. We are proposing that manufacturers should program engines with a setting categorizing them as high-speed vehicles until they accumulate 30 hours of data to avoid applying an inappropriate speed schedule.

- *40 CFR 1036.111(d)(1), Table 2:* Proposing to correct a typographical error for the middle set of columns that should read ''Medium-speed'' instead of repeating ''Low-speed.'' The table was correctly published in the preamble to the final rule (see 88 FR 4378). We are proposing to add an inadvertently omitted notation in the table to identify the placement of a footnote to the table.

xv. Engine Data and Information To Support Vehicle Certification

We are proposing to update 40 CFR 1036.505 to clarify that when certifying vehicles with GEM, for any fuel type not identified in Table 1 of 40 CFR 1036.550, the manufacturer would identify the fuel type as diesel fuel for engines subject to compression-ignition standards, and would identify the fuel type as gasoline for engines subject to spark-ignition standards. This proposed change to 40 CFR 1036.505, is intended to clarify what was originally intended for fuels that are not specified in Table 1 of 40 CFR 1036.550. This proposed clarification would address the potential situation where, if a fuel is input into GEM other than the fuel types identified in Table 1 of 40 CFR 1036.550, GEM will output an error.

3. Updates to 40 CFR Part 1037 Heavy-Duty Motor Vehicle Provisions

i. Standards for Qualifying Small Businesses

As noted in Section II.I, we are proposing that qualifying small manufacturers would continue to be subject to the existing MY 2027 and later standards. We are proposing to revise 40 CFR 1037.150(c) to specify the standards that apply for qualifying small business vehicle manufacturers in light of this proposal to adopt new standards for those model years. Specifically, we are renumbering the current paragraphs to apply through MY 2026 and adding new paragraphs that would apply for MY 2027 and later, including three tables that show the small business CO_2 emission standards for vocational vehicles, custom chassis vocational vehicles, and tractors. The proposed updates also include the proposed limitations on generating credits for averaging only (no banking, trading, or use of credit multipliers) unless the small manufacturer certifies to the Phase 3 standards.

ii. Vehicles With Engines Using Fuels Other Than Carbon-Containing Fuels

In the HD2027 final rule, we adopted revisions to 40 CFR 1037.150(f) to include fuel cell electric vehicles, in addition to battery electric vehicles, in the provision that deems tailpipe emissions of regulated GHG pollutants as zero and does not require CO_2-related emission testing. As discussed in Section II.D.1, hydrogen-fueled internal combustion engines are a newer technology under development and since hydrogen has no carbon, H2 ICEs fueled with neat hydrogen would produce zero HC, CO, and CO_2 engine-out emissions. Therefore, we are proposing to include vehicles using engines fueled with neat hydrogen in 40 CFR 1037.150(f) so that their CO_2 tailpipe emissions are deemed to be zero and manufacturers are not required to perform any engine testing for CO_2 emissions. This proposed revision would not change the requirements for H2 ICE engines, including those fueled with neat hydrogen, to meet the N_2O GHG standards or the criteria pollutant emission standards in 40 CFR part 1036. We request comment on this proposed revision to include H2 ICE in 40 CFR 1037.150(f).

Additionally, we are proposing to revise 40 CFR 1037.150(f) to replace ''electric vehicles'' with ''battery electric vehicles'', and ''hydrogen fuel cell vehicles'' with ''fuel cell electric vehicles'', consistent with proposed revisions to those definitions (see Section III.C.3.xiii).

iii. ABT Calculations

We are proposing clarifying revisions to the definitions of two variables of the emission credit calculation for ABT in 40 CFR 1037.705. As noted in Section II.C, we propose to update the emission standard variable (variable ''Std'') to establish a common reference emission standard when calculating ABT emission credits for vocational vehicles with tailpipe CO_2 emissions deemed to be zero (*i.e.,* BEVs, FCEVs, and vehicles with engines fueled with pure hydrogen), which would be the CI Multi-Purpose vehicle regulatory subcategory standard for the applicable weight class. We also propose to revise the ''Volume'' variable to replace the term ''U.S.-directed production volume'' with a reference to the paragraph (c) where we are also proposing updates consistent with the proposed revision to the definition of U.S.-directed production volume. With the proposed revision to paragraph (c), we intend for 40 CFR 1037.705(c) to replace ''U.S.-directed production volume'' as the primary reference for the appropriate production volume to apply with respect to the ABT program and propose to generally replace throughout part 1037.

iv. U.S.-Directed Production Volume

The CAA requires that every HD engine and vehicle be covered by a certificate of conformity indicating compliance with the applicable EPA regulations.[616] In the existing 40 CFR 1037.205, which describes requirements for the application for certification, we currently use the term U.S.-directed production volume and are now proposing that manufacturers should, instead, be reporting total nationwide production volumes that include any production volumes certified to different state standards.

In the recent HD2027 rule, we amended the corresponding heavy-duty highway engine provision in 40 CFR 1036.205 to replace ''U.S.-directed production volume'' with the more general term ''nationwide'', noting that manufacturers were already reporting the intended total nationwide production, including production that meets different state standards. In this rule, for the reasons explained in Section III.A.1, we are proposing a broader change to the definition of ''U.S.-directed production volume'' and the proposed new definition would not require us to change the term used in 1037.205 to ensure manufacturers report nationwide production volumes.[617] We are proposing revisions to the introductory paragraph of 40 CFR 1037.705(c), consistent with the proposed revisions to the corresponding HD engine provisions, to establish this paragraph as the reference for which engines are excluded from the production volume used to calculate emission credits for HD highway (see Section III.C.2.iv). Similarly, the proposed changes include replacing several instances of ''U.S.-directed production volume'' with a more general ''production volume'' where the

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[616] CAA sections 203 and 206, 42 U.S.C. 7522 and 7525.

[617] As noted in Section III.C.2.iv, we are proposing to adopt the same updated definition of ''U.S.-directed production volume'' in 40 CFR 1036.801, with additional corresponding proposed updates to not revise existing exclusions of production volumes certified to different standards (*i.e.,* the NO_X ABT program for HD engines).

text clearly is connected to ABT or a more specific reference to the production volume specified in 40 CFR 1037.705(c).[618]

v. Revisions to Hybrid Powertrain Testing and Axle Efficiency Testing

We are proposing to add a new figure to 40 CFR 1037.550 to give an overview on how to carry out hybrid powertrain testing in that section. We are proposing in the axle efficiency test in 40 CFR 1037.560(e)(2) to allow the use of an alternate lower gear oil temperature range on a test point by test point basis in addition to the current alternate that requires the use of the same lower temperature range for all test points within the test matrix. This would provide more representative test results as not all test points within a matrix for a given axle test will result in gear oil temperatures within the same range.

vi. Removal of Trailer Provisions

As part of the HD GHG Phase 2 rulemaking, we set standards for certain types of trailers used in combination with tractors (see 81 FR 73639, October 25, 2016). We are proposing to remove the regulatory provisions related to trailers in 40 CFR part 1037 to carry out a decision by the U.S. Court of Appeals for the D.C. Circuit, which vacated the portions of the HD GHG Phase 2 final rule that apply to trailers.[619] The proposed revisions include removal of specific sections and paragraphs describing trailer provisions and related references throughout the part. Additionally, we are proposing new regulatory text for an existing test procedure that currently refers to a trailer test procedure. The existing 40 CFR 1037.527 describes a procedure for manufacturers to measure aerodynamic performance of their vocational vehicles by referring to the A to B testing methodology for trailers in 40 CFR 1037.525. We are proposing to copy the regulatory text describing A to B testing from the trailer procedure into 40 CFR 1037.527 (such that it replaces the cross-referencing regulatory text).

vii. Removal of 40 CFR 1037.205(q)

We are proposing to correct an inadvertent error and remove the existing 40 CFR 1037.205(q). This paragraph contains requirements we proposed in HD2027 but did not finalize and thus did not intend to include in the final rule's amendatory instructions, regarding information for battery electric vehicles and fuel cell electric vehicles to show they meet the standards of 40 CFR part 1037.

viii. Adding Full Cylinder Deactivation to 40 CFR 1037.520(j)(1)

We are proposing to credit vehicles with engines that include full cylinder deactivation during coasting at 1.5 percent. We believe this is appropriate since the same 1.5 percent credit is currently provided for tractors and vocational vehicles with neutral coasting, and both technologies reduce CO_2 emissions by reducing the engine braking during vehicle coasting.[620] Cylinder deactivation can reduce engine braking by closing both the intake and exhaust valves when there is no operator demand to reduce the pumping losses of the engine when motoring. Because of this, only vehicles with engines where both exhaust and intake valves are closed when the vehicle is coasting would qualify for the 1.5 percent credit.

ix. Removal of Chassis Testing Option Under 40 CFR 1037.510 and Reference Update

We are proposing to remove the chassis dynamometer testing option for testing over the duty cycles as described in 40 CFR 1037.510(a). The chassis dynamometer testing was available as an option for Phase 1 testing in 40 CFR 1037.615. We are proposing to remove it to avoid confusion as the chassis dynamometer testing option is only allowed when performing off-cycle testing following 40 CFR 1037.610 and is not allowed for creating the cycle average fuel map for input into GEM. Note that manufacturers may continue to test vehicles on a chassis dynamometer to quantify off-cycle credits under 40 CFR 1037.610.

We are also proposing to correct paragraph reference errors in 40 CFR 1037.510(a)(2)(iii) and (iv). These paragraphs reference the warmup procedure in 40 CFR 1036.520(c)(1). The warmup procedure is actually located in 40 CFR 1036.520(d).

x. Utility Factor Clarification for Testing Engines With a Hybrid Power Takeoff Shaft

We are proposing to clarify the variable description for the utility factor fraction UF_{RCD} in 40 CFR 1037.540(f)(3)(ii). The current description references the use of an ''approved utility factor curve''. The original intent was to use the power take off utility factors that reside in Appendix E to 40 CFR part 1036 to generate a utility factor curve to determine UF_{RCD}. We are proposing to clarify this by replacing ''approved utility factor curve'' with a reference to the utility factors in Appendix E.

xi. Heavy-Duty Vehicles at or Below 14,000 Pounds GVWR

The standards proposed in this rule would apply for all heavy-duty vehicles above 14,000 pounds GVWR, except as noted in existing 40 CFR 1037.150(l). We are not proposing changes to the option for manufacturers to voluntarily certify incomplete vehicles at or below 14,000 pounds GVWR to 40 CFR part 1037 instead of certifying under 40 CFR part 86, subpart S; the proposed standards in this rule would also apply for those incomplete heavy-duty vehicles. We propose to remove 40 CFR 1037.104, which currently states that HD vehicles subject to 40 CR part 86, subpart S, are not subject to the 40 CFR 1037 standards; instead, we propose that manufacturers refer to 40 CFR 1037.5 for excluded vehicles.[621]

In a parallel rulemaking to set new emission standards for light-duty and medium-duty vehicles under 40 CFR part 86, subpart S, we intend to propose a requirement for those vehicles at or below 14,000 pounds GVWR with a high tow rating to have installed engines that have been certified to the engine-based criteria emission standards in 40 CFR part 1036. This would apply for both complete vehicles and incomplete vehicles with Gross Combined Weight Rating above 22,000 pounds. Some of those vehicles would continue to meet GHG standards under 40 CFR 86.1819 instead of meeting the engine-based GHG standards in 40 CFR part 1036 and the vehicle-based GHG standards in 40 CFR part 1037. In particular, under the parallel proposed rule, manufacturers of incomplete vehicles at or below 14,000 pounds GVWR with a high tow rating would continue to have the option of either meeting the greenhouse gas standards under 40 CFR parts 1036 and 1037, or instead meeting the greenhouse gas standards with chassis-based measurement procedures under 40 CFR part 86, subpart S.

xii. Updates to Optional Standards for Tractors at or Above 120,000 Pounds

In HD GHG Phase 2 and in a subsequent rulemaking, we adopted optional heavy Class 8 tractor CO_2 emission standards for tractors with a GCWR above 120,000 pounds (see 40

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[618] See proposed revisions in 40 CFR 1037.150(c) and 1037.730(b).

[619] *Truck Trailer Manufacturers Association* v. *EPA,* 17 F.4th 1198 (D.C. Cir. 2021).

[620] See the HD GHG Phase 2 rule (81 FR 73598, October 25, 2016), for more information on how 1.5 percent was determined for neutral coasting.

[621] This proposed change includes removing the reference to 40 CFR 1037.104 in 40 CFR1037.1.

CFR 1037.670).[622] We did this because most manufacturers tend to rely on U.S. certificates as their evidence of conformity for products sold into Canada to reduce compliance burden. Therefore, in Phase 2 we adopted provisions that allow the manufacturers the option to meet standards that reflect the appropriate technology improvements, along with the powertrain requirements that go along with higher GCWR. While these heavy Class 8 tractor standards are optional for tractors sold into the U.S. market, Canada adopted these as mandatory requirements as part of their regulatory development and consultation process. We propose to sunset the optional standards after MY 2026.[623]

xiii. Updates to 40 CFR Part 1037 Definitions

We are proposing several updates to the definitions in 40 CFR 1037.801. As noted in Section III.C.3.vi, we are proposing to remove the trailer provisions, which include removing the following definitions: Box van, container chassis, flatbed trailer, standard tractor, and tank trailer. We also propose to revise several definitions to remove references to trailers or trailer-specific sections, including definitions for: Class, heavy-duty vehicle, low rolling resistance tire, manufacturer, model year, Phase 1, Phase 2, preliminary approval, small manufacturer, standard payload, tire rolling resistance, trailer, and vehicle.

We also propose new and updated definitions in support of several proposed requirements in Section II or this Section III. We propose to replace the existing definition of ''electric vehicle'' with more specific definitions for the different vehicle technologies and energy sources that could be used to power these vehicles. Specifically, we propose new definitions for battery electric vehicle, fuel cell electric vehicle, and plug-in hybrid electric vehicle. We also propose to replace the existing definition of ''hybrid engine or hybrid powertrain'' with a definition of ''hybrid'' that refers to a revised definition in 40 CFR part 1036.[624] We also propose to update U.S.-directed production volume to be equivalent to nationwide production.

We propose several editorial revisions to definitions as well. We propose to revise the definition of vehicle to remove the text of existing paragraph (2)(iii) and move the main phrase of that removed paragraph (*i.e.,* ''when it is first sold as a vehicle'') to the description of ''complete vehicle'' to further clarify that aspect of the existing definition. We propose to revise the existing definition of small manufacturer, in addition to the proposed revisions removing reference to trailers, to clarify that the employee and revenue limits include the totals from *all* affiliated companies and added a reference to the definition of affiliated companies in 40 CFR 1068.30.

xiv. Miscellaneous Corrections and Clarifications in 40 CFR Part 1037

We are proposing to revise several references to 40 CFR part 86 revisions. Throughout 40 CFR part 1037, we are proposing to replace references to 40 CFR 86.1816 or 86.1819 with a more general reference to the standards of part 86, subpart S. We propose these revisions to reduce the need to update references to specific part 86 sections if new standards are added to a different section in a future rule. We are not proposing to revise any references to specific part 86 paragraphs (*e.g.,* 40 CFR 86.1819–14(j)).

We propose to move the duplicative statements in 40 CFR 1036.105(c) and 1037.106(c) regarding CH_4 and N_2O standards from their current locations to 40 CFR 1037.101(a)(2)(i) where we currently describe the standards that apply in part 1037. We also propose to update 40 CFR 1037.101(a)(2)(i) to more accurately state that only CO_2 standards are described in 40 CFR 1037.105 and 1037.106, by removing reference to CH_4 and N_2O in that sentence. We propose to update the section title for 40 CFR 1037.102 to include the term ''Criteria'' and the list of components (*i.e.,* NO_X, HC, PM, and CO) covered by the section to be consistent with the naming convention used in 40 CFR part 1036.

4. Updates to 40 CFR Part 1065 Engine Testing Procedures

i. Engine Testing and Certification With Fuels Other Than Carbon-Containing Fuels

Alternative fuels and fuels other than carbon-containing fuels are part of the fuel pathway for sustainable biofuel, e-fuel, and clean hydrogen development under the U.S. National Blueprint for Transportation Decarbonization.[625] This blueprint anticipates a mix of battery electric, sustainable fuel, and hydrogen use to achieve a net zero carbon emissions level by 2050 for the heavy-duty sector. EPA is proposing updates to 40 CFR part 1065 to facilitate certification of engines using fuels other than carbon-containing fuels for all sectors that use engine testing to show compliance with the standards. This includes a new definition of ''carbon-containing fuel'' in 40 CFR 1065.1001, and the proposed addition of a new chemical balance procedure in section 40 CFR 1065.656 that would be used in place of the carbon-based chemical balance procedure in 40 CFR 1065.655 when an engine is certified for operation using fuels other than carbon-containing fuels (*e.g.,* hydrogen or ammonia).[626] Since these fuels do not contain carbon, the current carbon-based chemical balance cannot be used as it is designed based on comparisons of the amount of carbon in the fuel to the amount measured post combustion in the exhaust. The chemical balance for fuels other than carbon-containing fuels looks at the amount of hydrogen in the fuel versus what is measured in the exhaust. The proposed amendments also facilitate certification of an engine on a mix of carbon-containing fuels and fuels other than carbon-containing fuels.

The proposed addition of the certification option for fuels other than carbon-containing fuels relies on inputs requiring hydrogen, ammonia, and water concentration measurement from the exhaust. Therefore, we are proposing the addition of new sections in 40 CFR part 1065 and proposing revisions to some existing sections to support the procedure in 40 CFR 1065.656. We are proposing a new 40 CFR 1065.255 to provide specifications for hydrogen measurement devices, a new 40 CFR 1065.257 to provide specifications for water measurement using a Fourier Transform Infrared (FTIR) analyzer, and a new 40 CFR 1065.277 to provide specifications for ammonia measurement devices. These additions also require a proposed new 40 CFR 1065.357 to address CO_2 interference when measuring water using an FTIR analyzer, a proposed new 40 CFR 1065.377 to address H_2O interference and any other interference species as deemed by the instrument manufacturer or using good engineering judgment when measuring NH_3 using an FTIR or laser infrared analyzers, and the

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[622] 81 FR 73582 (October 25, 2016) and 86 FR 34338 (June 29, 2021).

[623] This proposed sunset would remove the standards listed in the rightmost column of existing Table 1 of § 1037.670; we note that the column is intended for model years 2027 and later standards, but is mistakenly labeled ''Model years 2026 and later''.

[624] See Section III.C.2.xii for a description of the updated definition of hyrid.

[625] The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation. DOE/EE–2674. January 2023. Available at: *https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf.*

[626] We are also proposing a definition for ''carbon-containing fuel'' in 40 CFR 1036.801 that references the proposed new 40 CFR part 1065 definition.

proposed addition of calibration gases for these new analyzer types to 40 CFR 1065.750. We are also proposing to add drift check requirements to 40 CFR 1065.550(b) to address drift correction of the H_2, O_2, H_2O, and NH_3 measurements needed in the 40 CFR 1065.656 procedure. This also includes the proposed addition of drift check requirements in 40 CFR 1065.935(g)(5)(ii) for testing with PEMS. We are also proposing to add a new 40 CFR 1065.750(a)(6) to address the uncertainty of the water concentrations generated to perform the linearity verification of the water FTIR analyzer in 40 CFR 1065.257. We are proposing two options to generate a humid gas stream. The first is via a heated bubbler where dry gas is passed through the bubbler at a controlled water temperature to generate a gas with the desired water content. The second is a device that injects heated liquid water into a gas stream. We are proposing linearity verification of the humidity generator once a year to an uncertainty of ± 3 percent;[627] however, we are not proposing to require that the calibration of the humidity generator should be NIST traceable and request comment on whether that calibration should be NIST traceable. We are proposing a requirement for a leak check after the humidity generator is assembled, as these devices are typically disassembled and stored when not in use and subsequent assembly prior to use could lead to leaks in the system. We are proposing to include calculations to determine the uncertainty of the humidity generator from measurements of dewpoint and absolute pressure. We are proposing a new definition for ''carbon-containing fuel'' and ''lean-burn'' in 40 CFR 1065.1001 to further support the addition of the certification option for engines using fuels other than carbon-containing fuels. We request comment on these proposed changes and their ability to allow certification of engines using fuels other than carbon-containing fuels.

We also request comment on whether we should add specifications for alternative test fuels, like methanol, and fuels other than carbon-containing fuels like hydrogen and ammonia, to 40 CFR part 1065, subpart H. Currently, 40 CFR 1065.701(c) allows the use of test fuels that we do not specify in 40 CFR part 1065, subpart H, with our approval. If a comment is submitted that fuel specifications should be included for these alternate test fuels, we request that the comment include specifications for the fuels the comment specifies should be included.

ii. Engine Speed Derate for Exhaust Flow Limitation

We are proposing a change to 40 CFR 1065.512(b)(1) to address the appearance of three options for generating new reference duty-cycle points for the engine to follow. The option in the existing 40 CFR 1065.512(b)(1)(i) isn't actually an option and instead gives direction on how to operate the dynamometer (torque control mode). Under our proposed revision, this sentence would be retained and moved into a new 40 CFR 1065.512(b)(1)(i) that contains some existing text split off from the current 40 CFR 1065.512(b)(1). The two remaining options in the current 40 CFR 1065.512(b)(1)(ii) and (iii) would be redesignated as 40 CFR 1065.512(b)(1)(i)(A) and (B). The proposed restructuring of 40 CFR 1065.512(b)(1) and its subparagraphs address the proposed edits described in the following paragraph.

We are proposing a change to 40 CFR 1065.512(b)(1) to address cycle validation issues where an engine with power derate intended to limit exhaust mass flowrate might include controls that reduce engine speed under cold-start conditions, resulting in reduced exhaust flow that assists other aftertreatment thermal management technologies (*e.g.* electric heater). In this case, normalized speeds would generate reference speeds above this engine speed derate, which would adversely affect cycle validation. To address this, the proposed changes would provide two options. The first option is if the engine control module (ECM) broadcasts the engine derate speed that is below the denormalized speed, the broadcast speed would then be used as the reference speed for duty-cycle validation. The second option is if an ECM broadcast signal is not available, the engine would be operated over one or more practice cycles to determine the engine derate speed as a function of cycle time. Under this option, any cycle reference speed that is greater than the engine derate speed would be replaced with the engine derate speed.

iii. Accelerated Aftertreatment Aging

We recently finalized a new accelerated aftertreatment aging procedure for use in deterioration factor determination in 40 CFR 1065.1131 through 1065.1145. We request comment on the need for potential changes to the procedure based on experience that manufacturers and test labs have gained since the procedure was finalized.

iv. Nonmethane Cutter Water Interference Correction

We recently finalized options and requirements for gaseous fueled engines to allow a correction for the effect of water on the nonmethane cutter (NMC) performance, as gaseous fueled engines produce much higher water content in the exhaust than gasoline or diesel fuels, impacting the final measured emission result.[628] The correction is done by adjusting the methane and ethane response factors used for the Total Hydrocarbon (THC) Flame Ionization Detector (FID) and the combine methane response factor and penetration fraction and combined ethane response factor and penetration fraction of the NMC FID. These response factors and penetration fractions are then used to determine NMHC and methane concentrations based on the molar water concentration in the raw or diluted exhaust. EPA is aware that test labs that have attempted to implement this correction have reported that this new option is lacking clarity with respect to the implementation of these corrections from both a procedural and emission calculation perspective. Test labs and manufacturers have also requested the option to use the water correction for all fuels, not just gaseous fuels. Test labs and manufacturers have also stated that in their view, as written, 40 CFR 1065.360(d)(12) indicates that the water correction for the methane response factor on the THC FID is required; we note that was not our intent and are thus proposing to clarify that provision.

In addition to general edits that improve the consistency of terminology and the rearrangement of some paragraphs to improve the flow of the procedure, we are proposing the following changes to 40 CFR 1065.360, 1065.365, and 1065.660 to address the concerns raised regarding implementation and use of the NMC performance corrections. In 40 CFR 1065.360 and 1065.365, we are proposing to allow the optional use of the water correction for the applicable response factors and penetration fractions for engines operated on any fuel, as the use of the correction improves the quality of the emission measurement even though the effect is less pronounced for liquid fuels. In 40 CFR 1065.360, we are proposing revisions to clarify that determination of the FID methane response factor as a

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[627] The proposed verification schedule in 40 CFR 1065.750(a)(6) says: ''Calibrate the humidity generator upon initial installation, within 370 days before verifying the H_2O measurement of the FTIR, and after major maintenance.''.

[628] 86 FR 34543 (June 29, 2021).

function of molar water concentration is optional for all fuels. In 40 CFR 1065.365, we are proposing to remove the recommendation of a methane penetration fraction of greater than 0.85 for the NMC FID because the procedure will account for the effect of the penetration fraction regardless of the level of NMC methane penetration. We are also proposing a corresponding change in relation to another change proposed in this rule, such that the requirements for linearity performance of the humidity generator would meet the proposed uncertainty requirements in 40 CFR 1065.750(a)(6) that we are proposing to address the accuracy of humidity generators used in the calibration of the FTIRs used for water measurement. In 40 CFR 1065.660, we are proposing to modify equations 1065.660–2 and 1065.660–9 by adding the variable for the methane response factor and penetration fraction for the NMC FID back into the equations, which we previously removed for simplification because the value was set to a constant of one. This modification would have no effect on the outcome of the calculations in the event that the effect of water on the NMC performance is not being accounted for because the procedure directs that the methane response factor and penetration fraction for the NMC FID are set to one. In the event that the effect of water is being accounted for, these modified equations would make it easier to understand the requirements of the procedure.

v. ISO 8178 Exceptions in 40 CFR 1065.601

40 CFR 1065.601(c)(1) allows the use of ISO 8178 mass-based emission calculations instead of the calculations specified in 40 CFR part 1065 subpart G with two exceptions. We are proposing to update the section reference to the exception in 40 CFR 1065.601(c)(1)(i) for NO_X humidity and temperature correction from ISO 8178–1 Section 14.4 to ISO 8178–4 Section 9.1.6 to address updates made to ISO 8178 over the last 20 years that changed the location of this correction. We are also proposing to remove the exception for the use of the particulate correction factor for humidity in ISO 8178–1 Section 15.1 because this correction factor no longer exists in ISO 8178.

vi. Work System Boundary in 40 CFR 1065.210

Figure 1 in 40 CFR 1065.210 provides diagrams for the work inputs, outputs, and system boundaries for engines. We are proposing to update the diagram for liquid cooled engines in Figure 1 to paragraph (a) of 40 CFR 1065.210 to include electric heaters that use work from an external power source. We are also proposing to update 40 CFR 1065.210(a) to include an example of an engine exhaust electrical heater and direction on how to simulate the efficiency of the electrical generator, to account for the work of the electrical heater. We are proposing an efficiency of 67 percent, as this is the value used in 40 CFR 86.1869–12(b)(4)(xiii) as the baseline alternator efficiency when determining off-cycle improvements of high efficiency alternators. We request comment on the proposed value of 67 percent and request that commenters provide data if you comment that a value different than 67 percent should be used.

IV. Proposed Program Costs

In this section, we present the costs we estimate would be incurred by manufacturers and purchasers of HD vehicles impacted by the proposed standards. We also present the social costs of the proposed standards. Our analyses characterize the costs of the technology package described in section II.E of the preamble; however, as we note there, manufacturers may elect to comply using a different combination of HD vehicle and engine technologies than what we have identified. We break the costs into the following categories and subcategories:

(1) Technology Package Costs, which are the sum of direct manufacturing costs (DMC) and indirect costs. This may also be called the ''package RPE.'' This includes:

a. DMC, which include the costs of materials and labor to produce a product or piece of technology.

b. Indirect costs, which include research and development (R&D), warranty, corporate operations (such as salaries, pensions, health care costs, dealer support, and marketing), and profits.[629] We estimate indirect costs using retail price equivalent (RPE) markups.

(2) Manufacturer Costs, or ''manufacturer RPE,'' which is the package RPE less any applicable battery tax credits. This includes:

a. Package RPE. Traditionally, the package RPE is the manufacturer RPE in EPA cost analyses.

b. Battery tax credit from IRA section 13502, ''Advanced Manufacturing Production Credit,'' which serve to reduce manufacturer costs. The battery tax credit is described further in Sections I and II of this preamble and Chapters 1 and 2 of the DRIA.

(3) Purchaser Costs, which are the sum of purchaser upfront vehicle costs and operating costs. This includes:

a. Manufacturer RPE. In other words, the purchaser incurs the manufacturer's package costs less any applicable battery tax credits. We refer to this as the ''manufacturer RPE'' in relation to the manufacturer and, at times, the ''purchaser RPE'' in relation to the purchaser. These two terms are equivalent in this analysis.

b. Vehicle tax credit from IRA section 13403, ''Qualified Commercial Clean Vehicles,'' which serve to reduce purchaser costs. The vehicle tax credit is described further in Sections I and II of this preamble and Chapters 1 and 2 of the DRIA.

c. Electric Vehicle Supply Equipment (EVSE) costs, which are the costs associated with charging equipment. Our EVSE cost estimates include indirect costs so are sometimes referred to as ''EVSE RPE.''

d. Purchaser upfront vehicle costs, which include the manufacturer (also referred to as purchaser) RPE plus EVSE costs less any applicable vehicle tax credits.

e. Operating costs, which include fuel costs, electricity costs, costs for diesel exhaust fluid (DEF), and maintenance and repair costs.

(4) Social Costs, which are the sum of package RPE, EVSE RPE, and operating costs and computed on at a fleet level on an annual basis. This includes:

a. Package RPE which excludes applicable tax credits.

b. EVSE RPE.

c. Operating costs which include pre-tax fuel costs, DEF costs and maintenance and repair costs.

d. Note that fuel taxes and battery and vehicle tax credits are not included in the social costs. Taxes and tax credits are transfers as opposed to social costs.

We describe these costs and present our cost estimates in the text that follows. All costs are presented in 2021 dollars, unless noted otherwise. We used the MOVES scenarios discussed in DRIA Chapter 4, the reference and proposed cases,[630] to compute technology costs and operating costs as well as social costs on an annual basis. Our costs and tax credits estimated on a per vehicle basis do not change between the reference and proposal cases, but the estimated vehicle populations that would be ICE vehicles, BEVs or FCEVs do change between the reference and proposal cases. We expect an increase in BEV and FCEV sales and a decrease in ICE vehicle sales in the proposal compared to the reference case and these changes in vehicle populations are the determining factor

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[629] Technology costs represent costs that manufacturers are expected to attempt to recapture via new vehicle sales. As such, profits are included in the indirect cost calculation. Clearly, profits are not a ''cost'' of compliance—EPA is not imposing new regulations to force manufacturers to make a profit. However, profits are necessary for manufacturers in the heavy-duty industry, a competitive for-profit industry, to sustain their operations. As such, manufacturers are expected to make a profit on the compliant vehicles they sell, and we include those profits in estimating technology costs.

[630] As discussed in DRIA Chapter 4.2.2, the reference case is a no-action scenario that represents emissions in the U.S. without the proposed rulemaking and the proposed case represents emissions in the U.S. with the proposed GHG standards.

for total cost differences between the reference and proposal cases.

But first we discuss the relevant IRA tax credits and how we have considered them in our estimates. Note that the analysis that follows sometimes presents undiscounted costs and sometimes presents discounted costs. We discount future costs and benefits to properly characterize their value in the present or, as directed by the Office of Management and Budget in Advisory Circular A–4, in the year costs and benefits begin. Also in Circular A–4, OMB directs use of both 3 and 7 percent discount rates as we have done with some exceptions.[631] We request comment, including data, on all aspects of the cost analysis. In particular, we request comment on our assessment of the IRA tax credits (see Sections IV.C.2 and IV.D.2) and operating costs (see Section IV.D.5). We also request comment, including data, on alternative approaches to estimating cost that may help inform our cost estimates for the final rulemaking.

A. IRA Tax Credits

Our cost analysis quantitatively includes consideration of two IRA tax credits, specifically the battery tax credit and the vehicle tax credit discussed in Sections I.C.2 and II.E.4 of the preamble and Chapters 1.3.2, 2.4.3, and 3.1 of the DRIA. We note that a detailed discussion of how these tax credits were considered in our consideration of costs in our technology packages may be found in Section II.E of the preamble and Chapter 2.4.3 of the DRIA. The battery tax credits are expected to reduce manufacturer costs, and in turn purchaser costs, as discussed in Section IV.C The vehicle tax credits are expected to reduce purchaser costs, as discussed in Section IV.D.2. For the cost analysis discussed in this Section IV, both the battery tax credit and vehicle tax credit were estimated for MYs 2027 through 2032 and then aggregated for each MOVES source type and regulatory class.

We request comment on our assessment of the impact of the IRA tax credits.

B. Technology Package Costs

Technology package costs include estimated technology costs associated with compliance with the proposed MY 2027 and later CO_2 emission standards (see Chapter 3 of the DRIA). Individual technology piece costs are presented in Chapter 2 and 3 of the DRIA. In general, for the first MY of each proposed emission standard, the per vehicle individual technology piece costs consist of the DMC estimated for each vehicle in the model year of the proposed standards and are used as a starting point in estimating both the technology package costs and total incremental costs. Following each year of when costs are first incurred, we have applied a learning effect to represent the cost reductions expected to occur via the ''learning by doing'' phenomenon.[632] The ''learning by doing'' phenomenon is the process by which doing something over and over results in learning how to do that thing more efficiently which, in turn, leads to reduced resource usage, *i.e.,* cost savings. This provides a year-over-year cost for each technology as applied to new vehicle production, which is then used to calculate total technology package costs of the proposed standards.

This technology package cost calculation approach presumes that the expected technologies would be purchased by the vehicle original equipment manufacturers (OEMs) from their suppliers. So, while the DMC estimates for the OEM in Section IV.B.1 include the indirect costs and profits incurred by the supplier, the indirect cost markups we apply in Section IV.B.2 cover the indirect costs incurred by OEMs to incorporate the new technologies into their vehicles and profit margins for the OEM typical of the heavy-duty vehicle industry. To address these OEM indirect costs, we then applied industry standard ''retail price equivalent'' (RPE) markup factors to the DMC to estimate indirect costs associated with the new technology. These factors represent an average price, or retail price equivalent (RPE), for products assuming all products recapture costs in the same way. We recognize that this is rarely the case since manufacturers typically price certain products higher than average and others lower than average (*i.e.,* they cross-subsidize). For that reason, the RPE should not be considered a price but instead should be considered more like the average cross-subsidy needed to recapture both costs and profits to support ongoing business operations. Both the learning effects applied to direct costs and the application of markup factors to estimate indirect costs are consistent with the cost estimation approaches used in EPA's past HD GHG regulatory programs.[633] The sum of the DMC and indirect costs represents our estimate of technology ''package costs'' or ''package RPE'' per vehicle year-over-year. These per vehicle technology package costs are multiplied by estimated sales for the proposed and reference scenarios. Then the total technology package-related costs for manufacturers (total package costs or total package RPE) associated with the proposed HD vehicle CO_2 standards is the difference between the proposed and reference scenarios.

1. Direct Manufacturing Costs

To produce a unit of output, manufacturers incur direct and indirect manufacturing costs. DMC include cost of materials and labor costs. Indirect manufacturing costs are discussed in the following section, IV.A.2. The DMCs presented here include the incremental technology piece costs associated with compliance with the proposed standards as compared to the technology piece costs associated with the comparable baseline vehicle.[634] We based the proposed standards on technology packages that include both ICE vehicle and ZEV technologies. In our analysis, the ICE vehicles include a suite of technologies that represent a vehicle that meets the existing MY 2027 Phase 2 CO_2 emission standards. Therefore, our direct manufacturing costs for the ICE vehicles are considered to be $0 because we did not add additional CO_2-reducing technologies to the ICE vehicles beyond those in the baseline vehicle. The DMC of the BEVs or FCEVs are the technology piece costs of replacing an ICE powertrain with a BEV or FCEV powertrain for a comparable vehicle.

Throughout this discussion, when we refer to reference case costs we are referring to our cost estimate of the no-action case (impacts absent this proposed rule) which include costs associated with replacing a comparable ICE powertrain with a BEV or FCEV powertrain for ZEV adoption rates in the reference case.

We have estimated the DMC by starting with the cost of the baseline vehicle, removing the cost of the ICE powertrain, and adding the cost of a BEV or FCEV powertrain, as presented in Chapter 2 and 3 of the DRIA. In other words, net incremental costs reflect adding the total costs of components added to the powertrain to make it a BEV or FCEV, as well as removing the

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[631] See Advisory Circular A–4, Office of Management and Budget, September 17, 2003.

[632] ''Cost Reduction through Learning in Manufacturing Industries and in the Manufacture of Mobile Sources, Final Report and Peer Review Report,'' EPA–420–R–16–018, November 2016.

[633] See the 2011 heavy-duty greenhouse gas rule (76 FR 57106, September 15, 2011); the 2016 heavy-duty greenhouse gas rule (81 FR 73478, October 25, 2016).

[634] Baseline vehicles are ICE vehicles meeting the Phase 2 standards discussed in DRIA chapter 2.2.2 and the Low NO_X standards discussed in DRIA chapter 2.3.2.

total costs of components removed from a comparable ICE vehicle to make it a BEV or FCEV.

Chapter 4 of the DRIA contains a description of the MOVES vehicle source types and regulatory classes. In short, we estimate costs in MOVES for vehicle source types that have both regulatory class populations and associated emission inventories. Also, throughout this section, LHD refers to light heavy-duty vehicles, MHD refers to medium heavy-duty vehicles, and HHD refers to heavy heavy-duty vehicles.

The direct costs are then adjusted to account for learning effects on BEV, FCEV and ICE vehicle powertrains on an annual basis going forward beginning with the first year of the analysis, *e.g.* MY 2027, for the proposed and reference scenarios. Overall, we anticipate the number of ICE powertrains (including engines and transmissions) manufactured each year will decrease as more ZEVs enter the market. This scenario may lead to an increase in component costs for ICE powertrains. On the other hand, with the inclusion of new hardware costs projected to meet the HD2027 emission standards, we would expect learning effects would reduce the incremental cost of these technologies. Chapter 3 of the DRIA includes a detailed description of the approach used to apply learning effects in this analysis and we request data and information to refine our learning effects. The resultant DMC per vehicle and how those costs decrease over time on a fleet level are presented in Section IV.E.1 of this preamble. We request comment on this approach, including methods for accounting for the projected future ICE costs.

2. Indirect Manufacturing Costs

Indirect manufacturing costs are all the costs associated with producing the unit of output that are not direct manufacturing costs—for example, they may be related to research and development (R&D), warranty, corporate operations (such as salaries, pensions, health care costs, dealer support, and marketing) and profits. An example of a R&D cost for this proposal includes the engineering resources required to develop a battery state of health monitor as described in Section III.B.1. An example of a warranty cost is the future cost covered by the manufacturer to repair defective BEV or FCEV components and meet the warranty requirements proposed in Section III.B.2. Indirect costs are generally recovered by allocating a share of the indirect costs to each unit of goods sold. Although direct costs can be allocated to each unit of goods sold, it is more challenging to account for indirect costs allocated to a unit of goods sold. To ensure that regulatory analyses capture the changes in indirect costs, markup factors (which relate total indirect costs to total direct costs) have been developed and used by EPA and other stakeholders. These factors are often referred to as retail price equivalent (RPE) multipliers and are typically applied to direct costs to estimate indirect costs. RPE multipliers provide, at an aggregate level, the proportionate share of revenues relative shares of revenue where:

Revenue = Direct Costs + Indirect Costs
Revenue/Direct Costs = 1 + Indirect Costs/
Direct Costs = RPE multiplier
Resulting in:
Indirect Costs = Direct Costs × (RPE − 1)

If the relationship between revenues and direct costs (*i.e.,* RPE multiplier) can be shown to equal an average value over time, then an estimate of direct costs can be multiplied by that average value to estimate revenues, or total costs. Further, that difference between estimated revenues, or total costs, and estimated direct costs can be taken as the indirect costs. Cost analysts and regulatory agencies have frequently used these multipliers to predict the resultant impact on costs associated with manufacturers' responses to regulatory requirements and we are using that approach in this analysis.

The proposed cost analysis estimates indirect costs by applying the RPE markup factor used in past EPA rulemakings (such as those setting GHG standards for heavy-duty vehicles and engines).[635] The markup factors are based on company filings with the Securities and Exchange Commission for several engine and engine/vehicle manufacturers in the heavy-duty industry.[636] The RPE factors for the HD vehicle industry as a whole are shown in Table IV–1. Also shown in Table IV–1 are the RPE factors for light-duty vehicle manufacturers.[637]

TABLE IV–1—RETAIL PRICE EQUIVALENT FACTORS IN THE HEAVY-DUTY AND LIGHT-DUTY INDUSTRIES

Cost contributor	HD truck industry[638]	LD vehicle industry
Direct manufacturing cost	1.00	1.00
Warranty	0.03	0.03
R&D	0.05	0.05
Other (admin, retirement, health, etc.)	0.29	0.36
Profit (cost of capital)	0.05	0.06
RPE	1.42	1.50

For this analysis, EPA based indirect cost estimates for diesel and compressed natural gas (CNG) regulatory classes on the HD Truck Industry RPE value shown in Table IV–1. We are using an RPE of 1.42 to compute the indirect costs associated with the replacement of a diesel-fueled or CNG-fueled powertrain with a BEV or FCEV powertrain. For this analysis, EPA based indirect cost estimates for gasoline regulatory classes on the LD Vehicle RPE value shown in Table IV–1. We are using an RPE of 1.5 to compute the indirect costs associated with the replacement of a gasoline-fueled powertrain with a BEV or FCEV powertrain. The heavy-duty vehicle industry is becoming more vertically integrated and the direct and indirect manufacturing costs we are analyzing are those that reflect the technology packages costs OEMs would try to recover at the end purchaser, or retail, level. For that reason, we believe the two respective vehicle industry RPE values represent the most appropriate factors for this analysis. We request data

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[635] 76 FR 57106; 81 FR 73478.

[636] Heavy Duty Truck Retail Price Equivalent and Indirect Cost Multipliers, Draft Report, July 2010.

[637] Rogozhin,A., et al., Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry. International Journal of Production Economics (2009), doi:10.1016/j.ijpe.2009.11.031.

[638] Note that the report used the term ''HD Truck'' while EPA generally uses the term ''HD vehicle;'' they are equivalent when referring to this report.

to inform RPE factors for the heavy-duty industry.

3. Vehicle Technology Package RPE

Table IV–2 presents the total fleet-wide incremental technology costs estimated for the proposal relative to the reference case for the projected adoption of ZEVs in our technology package relative to the reference case on an annual basis. As previously explained in this section, the costs shown in Table IV–2 reflect marginal direct and indirect manufacturing costs of the technology package for the proposed CO_2 standards as compared to the baseline vehicle.

It is important to note that these are costs and not prices. We do not attempt to estimate how manufacturers would price their products in the technology package costs. Manufacturers may pass costs along to purchasers via price increases that reflect actual incremental costs to manufacture a ZEV when compared to a comparable ICE vehicle. However, manufacturers may also price products higher or lower than what would be necessary to account for the incremental cost difference. For instance, a manufacturer may price certain products higher than necessary and price others lower with the higher-priced products effectively subsidizing the lower-priced products. This pricing strategy may be true in any market and is not limited to the heavy-duty vehicle industry. It may be used for a variety of reasons, not solely as a response to regulatory programs.

TABLE IV–2—TOTAL FLEET-WIDE INCREMENTAL TECHNOLOGY COSTS FOR ZEVS, FOR THE PROPOSED OPTION RELATIVE TO THE REFERENCE CASE MILLIONS OF 2021 DOLLARS [a]

Calendar year	Vehicle package RPE
2027	$2,000
2028	1,800
2029	1,700
2030	2,000
2031	2,300
2032	2,000
2033	1,500
2034	1,300
2035	1,000
2036	750
2037	620
2038	410
2039	220
2040	140
2041	−40
2042	−200
2043	−360
2044	−410
2045	−550
2046	−690
2047	−820
2048	−850
2049	−970
2050	−1,100
2051	−1,100
2052	−1,200
2053	−1,300
2054	−1,400
2055	−1,500
PV, 3%	9,000
PV, 7%	10,000

[a] Values rounded to two significant digits; negative values denote lower costs, i.e., savings in expenditures.

C. Manufacturer Costs

1. Relationship to Technology Package RPE

The manufacturer costs in EPA's past HD GHG rulemaking cost analyses on an average-per-vehicle basis was only the average-per-vehicle technology package RPE described in Section II.F.5.i. However, in the cost analysis for this proposal, we are also taking into account the IRA battery tax credit in our estimates of manufacturer costs (also referred to in this section as manufacturer's RPE), as we expect the battery tax credit to reduce manufacturer costs, and in turn purchaser costs.

2. Battery Tax Credit

Table IV–3 shows the annual estimated fleet-wide battery tax credits from IRA section 13502, ''Advanced Manufacturing Production Credit,'' for the proposal relative to the reference case in 2021 dollars. These estimates were based on the detailed discussion in DRIA Chapter 2 of how we considered battery tax credits. Both BEVs and FCEVs include a battery in the powertrain system that may meet the IRA battery tax credit requirements if the applicable criteria are met. The battery tax credits begin to phase down starting in CY 2030 and expire after CY 2032.

TABLE IV–3—BATTERY TAX CREDIT IN MILLIONS OF 2021 DOLLARS FOR THE PROPOSED OPTION RELATIVE TO THE REFERENCE CASE [a]

Calendar year	Battery tax credits
2027	$340
2028	560
2029	880
2030	890
2031	650
2032	380
2033 and later	0
PV, 3%	3,300
PV, 7%	2,900

[a] Values rounded to two significant digits.

3. Manufacturer RPE

The manufacturer RPE for BEVs is calculated by subtracting the battery tax credit in Table IV–3 from the corresponding technology package RPE from Table IV–2 and the resultant manufacturer RPE is shown in Table IV–4. Table IV–4 reflects learning effects on vehicle package RPE and battery tax credits from CY 2027 through 2055. The sum of the vehicle package RPE and battery tax credits for each year is shown in the manufacturer RPE column. The difference in manufacturer RPE between the proposal and reference case is presented in Table IV–4.

TABLE IV–4—TOTAL VEHICLE PACKAGE RPE, BATTERY TAX CREDITS, AND MANUFACTURER RPE (INCLUDING BATTERY TAX CREDITS) FOR THE PROPOSED OPTION RELATIVE TO THE REFERENCE CASE, ALL REGULATORY CLASSES AND ALL FUELS, MILLIONS OF 2021 DOLLARS [a]

Calendar year	Vehicle package RPE	Battery tax credits	Manufacturer RPE
2027	$2,000	−$340	$1,600
2028	1,800	−560	1,200
2029	1,700	−880	820
2030	2,000	−890	1,100

Table IV–4—Total Vehicle Package RPE, Battery Tax Credits, and Manufacturer RPE (Including Battery Tax Credits) for the Proposed Option Relative to the Reference Case, All Regulatory Classes and All Fuels, Millions of 2021 Dollars[a]—Continued

Calendar year	Vehicle package RPE	Battery tax credits	Manufacturer RPE
2031	2,300	−650	1,700
2032	2,000	−380	1,700
2033	1,500	0	1,500
2034	1,300	0	1,300
2035	1,000	0	1,000
2036	750	0	750
2037	620	0	620
2038	410	0	410
2039	220	0	220
2040	140	0	140
2041	−40	0	−40
2042	−200	0	−200
2043	−360	0	−360
2044	−410	0	−410
2045	−550	0	−550
2046	−690	0	−690
2047	−820	0	−820
2048	−850	0	−850
2049	−970	0	−970
2050	−1,100	0	−1,100
2051	−1,100	0	−1,100
2052	−1,200	0	−1,200
2053	−1,300	0	−1,300
2054	−1,400	0	−1,400
2055	−1,500	0	−1,500
PV, 3%	9,000	−3,300	5,700
PV, 7%	10,000	−2,900	7,100

[a] Values rounded to two significant digits; negative values denote lower costs, i.e., savings in expenditures.

D. Purchaser Costs

1. Purchaser RPE

The purchaser RPE is the estimated upfront vehicle cost paid by the purchaser prior to considering the IRA vehicle tax credits. Note, as explained in Section IV.C, we do consider the IRA battery tax credit in estimating the manufacturer RPE, which in this analysis we then consider to be equivalent to the purchaser RPE because we assume full pass-through of the IRA battery tax credit from the manufacturer to the purchaser. In other words, in this analysis, the manufacturer RPE and purchaser RPE are equivalent terms. The purchaser RPEs reflect the same values as the corresponding manufacturer RPEs presented in Section IV.C.3.

2. Vehicle Purchase Tax Credit

Table IV–5 shows the annual estimated vehicle tax credit for BEV and FCEV vehicles from IRA section 13403, ‘‘Qualified Commercial Clean Vehicles,’’ for the proposal relative to the reference case, in 2021 dollars. These estimates were based on the detailed discussion in DRIA Chapter 2 of how we considered vehicle tax credits. The vehicle tax credits carry through to MY 2032 with the value diminishing over time as vehicle costs decrease due to the learning effect as shown in DRIA Chapter 2. Beginning in CY 2033, the tax credit program expires.

Table IV–5—Vehicle Tax Credit in Millions 2021 Dollars for the Proposed Option Relative to the Reference Case[a]

Calendar year	Tax credit
2027	$810
2028	670
2029	630
2030	1,100
2031	1,600
2032	1,900
2033 and later	0
PV, 3%	5,900
PV, 7%	5,000

[a] Values rounded to two significant digits.

3. Electric Vehicle Supply Equipment Costs

EVSE and associated costs are described in Chapter 2.6 of the DRIA. EVSE is needed for charging of BEVs and is not needed for FCEVs.[639] The EVSE cost estimates are assumed to include both direct and indirect costs and are sometimes referred to in this proposal as EVSE RPE costs. For these EVSE cost estimates, we assume that up to two vehicles can share one DCFC port if there is sufficient dwell time for both vehicles to meet their daily charging needs.[640] While fleet owners may also choose to share Level 2 chargers across vehicles, we are conservatively assigning one Level 2 charger per vehicle. As discussed in the DRIA, we assume that EVSE costs are incurred by purchasers, *i.e.* heavy-duty vehicle purchasers/owners. Some purchasers may be eligible for a Federal tax credit for charging equipment.[641] See DRIA

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[639] As discussed in DRIA Chapter 2.5, rather than focusing on depot hydrogen fueling infrastructure costs that would be incurred upfront, we included FCEV infrastructure costs in our per-kilogram retail price of hydrogen. Retail price of hydrogen is the total price of hydrogen when it becomes available to the end user, including the costs of production, distribution, storage, and dispensing at a fueling station. This approach is consistent with the method we use in HD TRUCS for comparable ICE vehicles, where the equivalent diesel fuel costs are included in the diesel fuel price instead of accounting for the costs of fuel stations separately.

[640] We note that for some of the vehicle types we evaluated, more than two vehicles could share a DCFC port and still meet their daily electricity consumption needs. However, we are choosing to limit DCFC sharing to two vehicles per EVSE port pending market developments and more robust dwell time estimates.

[641] IRA Section 13404, ‘‘Alternative Fuel Refueling Property Credit,’’ modifies an existing Federal tax credit available for alternative fuel refueling property, including EV charging equipment, and extends the tax credit through

Chapter 1.3.2 for a discussion of this tax credit and DRIA Chapter 2.6.5.2 for a description of how we considered it in our cost analysis. We analyzed EVSE costs in 2021 dollars on a fleet-wide basis for this analysis. The annual costs associated with EVSE in the proposal relative to the reference case are shown in Table IV–6.

We request comment on our estimated EVSE costs as well as our proposal to add EVSE costs to each vehicle's purchaser RPE costs in estimating purchaser costs.

TABLE IV–6—EVSE COSTS FOR THE PROPOSED OPTION RELATIVE TO THE REFERENCE CASE, MILLIONS 2021 DOLLARS [a]

Calendar year	EVSE costs
2027	$1,300
2028	1,600
2029	1,900
2030	2,000
2031	2,200
2032	2,600
2033	2,600
2034	2,600
2035	2,500
2036	2,500
2037	2,500
2038	2,500
2039	2,600
2040	2,600
2041	2,600
2042	2,600
2043	2,700
2044	2,700
2045	2,700
2046	2,700
2047	2,700
2048	2,700
2049	2,800
2050	2,800
2051	2,800
2052	2,900
2053	2,900
2054	2,900
2055	2,900
PV, 3%	47,000
PV, 7%	29,000

[a] Values rounded to two significant digits.

4. Purchaser Upfront Vehicle Costs

The expected upfront incremental costs to the purchaser include the purchaser RPE discussed in Section IV.D.1 less the vehicle tax credit discussed in Section IV.D.2 plus the EVSE RPE in IV.D.3. Table IV–7 shows the estimated incremental upfront purchaser costs for BEVs and FCEVs by calendar year for the proposed option relative to the reference case. Note that EVSE costs are associated with BEVs only; FCEVs do not have any associated EVSE costs.

TABLE IV–7—INCREMENTAL PURCHASER UPFRONT COSTS FOR THE PROPOSED OPTION RELATIVE TO THE REFERENCE CASE FOR IN MILLIONS 2021 DOLLARS [a]

Calendar year	Purchaser RPE	Vehicle purchase tax credit	EVSE costs	Total upfront purchaser cost
2027	$1,600	−$810	$1,300	$2,200
2028	1,200	−670	1,600	2,100
2029	820	−630	1,900	2,100
2030	1,100	−1,100	2,000	2,100
2031	1,700	−1,600	2,200	2,300
2032	1,700	−1,900	2,600	2,400
2033	1,500	0	2,600	4,100
2034	1,300	0	2,600	3,800
2035	1,000	0	2,500	3,500
2036	750	0	2,500	3,200
2037	620	0	2,500	3,100
2038	410	0	2,500	3,000
2039	220	0	2,600	2,800
2040	140	0	2,600	2,700
2041	−40	0	2,600	2,600
2042	−200	0	2,600	2,400
2043	−360	0	2,700	2,300
2044	−410	0	2,700	2,300
2045	−550	0	2,700	2,100
2046	−690	0	2,700	2,000
2047	−820	0	2,700	1,900
2048	−850	0	2,700	1,900
2049	−970	0	2,800	1,800
2050	−1,100	0	2,800	1,700
2051	−1,100	0	2,800	1,700
2052	−1,200	0	2,900	1,700
2053	−1,300	0	2,900	1,600
2054	−1,400	0	2,900	1,500
2055	−1,500	0	2,900	1,400
PV, 3%	5,700	−5,900	47,000	47,000
PV, 7%	7,100	−5,000	29,000	31,000

[a] Values rounded to two significant digits; negative values denote lower costs, *i.e.,* savings in expenditures.

2032. Beginning in 2023, this provision provides a tax credit of up to 30 percent of the cost of the qualified alternative fuel refueling property (*e.g.* HD BEV charger), up to 100,000, when located in low-income or non-urban area census tracts and certain other other requirements are met.

5. Operating Costs

We have estimated three types of operating costs associated with the proposed HD Phase 3 CO_2 emission standards and our potential projected technology pathway to comply with those proposed standards that includes BEV or FCEV powertrains. These three types of operating costs include decreased fuel costs of BEVs compared to comparable ICE vehicles, avoided diesel exhaust fluid (DEF) consumption by BEVs and FCEVs compared to comparable diesel-fueled ICE vehicles, and reduced maintenance and repair costs of BEVs and FCEVs as compared to comparable ICE vehicles. To estimate each of these costs, the results of MOVES runs, as discussed in DRIA Chapter 4, were used to estimate costs associated with fuel consumption, DEF consumption, and VMT. We have estimated the net effect on fuel costs, DEF costs, and maintenance and repair costs. We describe our approach in this Section IV.D.5.

Additional details on our methodology and estimates of operating costs per mile impacts are included in DRIA Chapter 3.4. Chapter 4 of the DRIA contains a description of the MOVES vehicle source types and regulatory classes. In short, we estimate costs in MOVES for vehicle source types that have both regulatory class populations and associated emission inventories. Also, throughout this section, LHD refers to light heavy-duty vehicles, MHD refers to medium heavy-duty vehicles, and HHD refers to heavy heavy-duty vehicles.

i. Costs Associated With Fuel Usage

To determine the total costs associated with fuel usage for MY 2027 vehicles, the fuel usage for each MOVES source type and regulatory class was multiplied by the fuel price from the AEO 2022 reference case for diesel, gasoline, and CNG prices over the first 28 years of the lifetime of the vehicle.[642] Fuel costs per gallon and kWh are discussed in DRIA Chapter 2. We used retail fuel prices since we expect that retail fuel prices are the prices paid by owners of these ICE vehicles. For electric vehicle costs, the electricity price from the AEO 2022 reference case for commercial electricity end-use prices in cents per kWh was multiplied by the fuel usage in kWh.[643] For hydrogen vehicle fuel costs, a value of $6.10/kg starting in 2027 and linearly decreasing to $4/kg in 2030 and held constant until 2055, as discussed in DRIA Chapter 2.5.3.1, was multiplied by fuel usage in kg. To calculate the average cost per mile of fuel usage for each scenario, MOVES source type and regulatory class, the fuel cost was divided by the VMT for each of the MY 2027 vehicles over the 28-year period. The estimates of fuel cost per mile for MY 2027 vehicles under the proposal are shown in Table IV–8 with 3 percent discounting and Table IV–9 with 7 percent discounting. Values shown as a dash (''-''), in Table IV–8 and Table IV–9 represent cases where a given MOVES source type and regulatory class did not use a specific fuel type for MY 2027 vehicles.[644]

TABLE IV–8—RETAIL FUEL COST PER MILE FOR MY 2027 VEHICLES DURING THE FIRST 28 YEARS FOR EACH MOVES SOURCE TYPE AND REGULATORY CLASS BY FUEL TYPE [a]

[Cents/Mile in 2021 dollars, 3% discounting]

MOVES source type	Regulatory class	Diesel	Gasoline	Electricity	CNG	Hydrogen
Other Buses	LHD45	-	37.2	23.9	-	-
	MHD67	31.3	-	29.5	-	-
	HHD8	32.4	-	30.6	40.1	-
Transit Bus	LHD45	-	37.1	14.7	-	-
	MHD67	31.5	-	18.0	-	-
	Urban Bus	32.8	-	18.4	40.1	-
School Bus	LHD45	-	27.5	10.1	-	-
	MHD67	24.4	30.4	13.1	-	-
	HHD8	25.7	-	13.8	32.5	-
Refuse Truck	MHD67	33.9	43.0	22.2	-	-
	HHD8	35.3	-	23.2	44.1	-
Single Unit Short-haul Truck	LHD45	16.7	25.7	9.0	-	-
	MHD67	25.3	32.5	13.7	-	-
	HHD8	30.4	-	16.4	38.5	-
Single Unit Long-haul Truck	LHD45	15.7	24.4	14.9	-	23.2
	MHD67	23.7	30.4	22.6	-	35.1
	HHD8	28.5	-	27.1	36.4	42.2
Combination Short-haul Truck	MHD67	34.5	-	24.8	-	-
	HHD8	36.0	-	25.9	42.9	-
Combination Long-haul Truck	MHD67	33.0	-	-	-	47.6
	HHD8	33.6	-	-	39.4	48.5

[a] Values rounded to the nearest tenth of a cent; dashes (''-'') represent cases where there are no vehicles powered by that specific fuel type in our MOVES runs for each specific source type and regulatory class of MY 2027 vehicles.

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[642] Reference Case Projection Tables, U.S. Energy Information Administration. Annual Energy Outlook 2022.

[643] U.S. Energy Information Administration. Annual Energy Outlook 2022.

[644] For example, there were no vehicles in our MOVES runs for the transit bus source type in the LHD45 regulatory class that where diesel-fueled, so the value in the table is represented as a dash (''-'').

TABLE IV–9—RETAIL FUEL COST PER MILE FOR MODEL YEAR 2027 VEHICLES DURING THE FIRST 28 YEARS FOR EACH MOVES SOURCE TYPE AND REGULATORY CLASS BY FUEL TYPE [a]

[Cents/mile in 2021 dollars, 7% discounting]

MOVES source type	Regulatory class	Diesel	Gasoline	Electricity	CNG	Hydrogen
Other Buses	LHD45	-	26.3	16.9	-	-
	MHD67	22.1	-	20.9	-	-
	HHD8	22.9	-	21.7	28.3	-
Transit Bus	LHD45	-	26.5	10.6	-	-
	MHD67	22.6	-	12.9	-	-
	Urban Bus	23.5	-	13.2	28.6	-
School Bus	LHD45	-	19.4	7.2	-	-
	MHD67	17.3	21.4	9.3	-	-
	HHD8	18.2	-	9.8	22.9	-
Refuse Truck	MHD67	24.9	31.4	16.3	-	-
	HHD8	25.9	-	17.0	32.2	-
Single Unit Short-haul Truck	LHD45	12.8	19.6	6.9	-	-
	MHD67	19.4	24.8	10.5	-	-
	HHD8	23.3	-	12.6	29.3	-
Single Unit Long-haul Truck	LHD45	12.2	18.9	11.6	-	18.3
	MHD67	18.4	23.6	17.5	-	27.8
	HHD8	22.1	-	21.0	28.2	33.3
Combination Short-haul Truck	MHD67	27.0	-	19.4	-	-
	HHD8	28.2	-	20.2	33.5	-
Combination Long-haul Truck	MHD67	24.8	-	-	-	36.4
	HHD8	25.3	-	-	29.6	37.1

[a] Values rounded to the nearest tenth of a cent; dashes ("-") represent cases where there are no vehicles powered by that specific fuel type in our MOVES runs for each specific source type and regulatory class of MY 2027 vehicles.

ii. Costs Associated With Diesel Exhaust Fluid

DEF consumption costs in heavy-duty vehicles were estimated in the HD2027 final rule.[645] We are applying the same methodology in this analysis to estimate the total costs of DEF under the proposed HD Phase 3 CO_2 standards. An example of total cost estimates of DEF for MY 2027 vehicles is provided in Table IV–10 and Table IV–11 for 3 percent and 7 percent discounting, respectively. To determine the total costs associated with DEF usage for MY 2027 vehicles, the DEF usage for each MOVES source type and regulatory class was multiplied by the DEF price over the first 28 years of the lifetime of the vehicle.[646] To calculate the average cost of DEF per mile for each MOVES Source Type and regulatory class, the total DEF cost was divided by the total VMT for each of the MY 2027 vehicles over the 28-year period. The DEF cost was computed for the reference case and proposed standard. The estimates on DEF cost per mile for the reference and proposed cases are shown in Table IV–10 for 3 percent discounting and Table IV–11 for 7 percent discounting. Several source types and regulatory classes contain no diesel-fueled ICE vehicles and therefore no DEF consumption costs. These cases are represented as zeros in Table IV–10 and Table IV–11. Table IV–10 and Table IV–11 show a reduction or no change in DEF costs per mile, which is to be expected due to an increased number of BEVs and FCEVs modeled for the proposed case compared to the reference case.

TABLE IV–10—DEF COST PER MILE FOR MODEL YEAR 2027 VEHICLES DURING THE FIRST 28 YEARS FOR EACH MOVES SOURCE TYPE AND REGULATORY CLASS ACROSS ALL FUEL TYPES [a]

[Cents/Mile in 2021 dollars, 3% discounting]

MOVES source type	Regulatory class	Cost in reference	Cost in proposal	Proposal change from reference
Other Buses	LHD45	0.00	0.00	0.00
	MHD67	1.89	1.61	−0.29
	HHD8	1.72	1.72	0.00
Transit Bus	LHD45	0.00	0.00	0.00
	MHD67	1.90	1.85	−0.05
	Urban Bus	1.74	1.74	0.00
School Bus	LHD45	0.00	0.00	0.00
	MHD67	1.37	0.96	−0.40
	HHD8	1.32	1.11	−0.20
Refuse Truck	MHD67	2.03	2.03	0.00
	HHD8	1.86	1.58	−0.28
Single Unit Short-haul Truck	LHD45	0.52	0.44	−0.08
	MHD67	1.24	1.07	−0.18
	HHD8	1.70	1.40	−0.30

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[645] 88 FR 4296, January 24, 2023.

[646] This analysis uses the DEF prices presented in the NCP Technical Support Document (see "Nonconformance Penalties for On-highway Heavy-duty Diesel Engines: Technical Support Document," EPA–420–R–12–014) with growth beyond 2042 projected at the same 1.3 percent rate as noted in the NCP TSD. Note that the DEF prices used update the NCP TSD's 2011 prices to 2021 dollars.

TABLE IV–10—DEF COST PER MILE FOR MODEL YEAR 2027 VEHICLES DURING THE FIRST 28 YEARS FOR EACH MOVES SOURCE TYPE AND REGULATORY CLASS ACROSS ALL FUEL TYPES[a]—Continued

[Cents/Mile in 2021 dollars, 3% discounting]

MOVES source type	Regulatory class	Cost in reference	Cost in proposal	Proposal change from reference
Single Unit Long-haul Truck	LHD45	0.48	0.41	−0.07
	MHD67	1.16	1.05	−0.12
	HHD8	1.59	1.43	−0.16
Combination Short-haul Truck	MHD67	2.08	1.92	−0.16
	HHD8	2.17	1.98	−0.18
Combination Long-haul Truck	MHD67	2.00	2.00	0.00
	HHD8	2.04	2.04	0.00

[a] Values rounded to the nearest hundredth of a cent; Negative values denote lower costs, *i.e.,* savings in expenditures.

TABLE IV–11—DEF COST PER MILE FOR MODEL YEAR 2027 VEHICLES DURING THE FIRST 28 YEARS FOR EACH MOVES SOURCE TYPE AND REGULATORY CLASS ACROSS ALL FUEL TYPES[a]

[Cents/mile in 2021 dollars, 7% discounting]

MOVES source type	Regulatory class	Cost in reference	Cost in proposal	Proposal change from reference
Other Buses	LHD45	0.00	0.00	0.00
	MHD67	1.32	1.12	−0.20
	HHD8	1.20	1.20	0.00
Transit Bus	LHD45	0.00	0.00	0.00
	MHD67	1.34	1.31	−0.04
	Urban Bus	1.23	1.23	0.00
School Bus	LHD45	0.00	0.00	0.00
	MHD67	0.95	0.67	−0.28
	HHD8	0.92	0.78	−0.14
Refuse Truck	MHD67	1.47	1.47	0.00
	HHD8	1.35	1.15	−0.20
Single Unit Short-haul Truck	LHD45	0.39	0.33	−0.06
	MHD67	0.94	0.81	−0.13
	HHD8	1.29	1.06	−0.23
Single Unit Long-haul Truck	LHD45	0.37	0.32	−0.06
	MHD67	0.90	0.81	−0.09
	HHD8	1.22	1.10	−0.12
Combination Short-haul Truck	MHD67	1.62	1.49	−0.12
	HHD8	1.68	1.54	−0.14
Combination Long-haul Truck	MHD67	1.50	1.50	0.00
	HHD8	1.52	1.52	0.00

[a] Values rounded to the nearest hundredth of a cent; negative values denote lower costs, *i.e.,* savings in expenditures.

iii. Costs Associated With Maintenance and Repair

We assessed the estimated maintenance and repair costs of HD BEVs and FCEVs and compared these estimates with estimated maintenance and repair costs for comparable HD ICE vehicles. The results of our analysis show that maintenance and repair costs associated with HD BEVs and FCEVs are estimated to be lower than maintenance and repair costs associated with comparable ICE vehicles. The methodology for how we calculated maintenance and repair costs were estimated is discussed in Chapter 2 and 3 of the DRIA.

For the estimate of maintenance and repair costs for diesel-fueled ICE vehicles, we relied on the research compiled by Burnham et al., 2021, in Chapter 3.5.5 of ''Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains'' and used equations found in the BEAN model.[647] [648] Burnham et al. used data from Utilimarc and ATRI to estimate maintenance and repair costs per mile for multiple heavy-duty vehicle categories over time. We selected the box truck curve to represent vocational vehicles and short-haul tractors, and the semi-tractor curve to represent long-haul tractors. We assumed that gasoline and CNG vehicles had the same maintenance and repair costs curves as diesel vehicles.

For BEVs and FCEVs, as discussed in Chapter 2 of the DRIA, the per-mile rate of brake wear is expected to be lower when compared to comparable ICE vehicles. Several literature sources propose multiplying diesel vehicle maintenance costs by a factor to estimate BEV and FCEV maintenance costs. We followed this approach and used a factor of 0.71 for BEVs and 0.75 for FCEV, based on the research in Wang et al., 2022.[649] Details of the

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[647] Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M.A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., Boloor, M. ''Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains''. Argonne National Laboratory. Chapter 3.5.5. April 1, 2021. Available at *https://publications.anl.gov/anlpubs/2021/05/167399.pdf.*

[648] Argonne National Lab, Vehicle & Mobility Systems Group, BEAN, found at: *https://vms.taps.anl.gov/tools/bean/* (accessed August 2022).

[649] Wang, G., Miller, M., and Fulton, L.'' Estimating Maintenance and Repair Costs for Battery Electric and Fuel Cell Heavy Duty Trucks,

maintenance and repair on a cost per mile basis are discussed in Chapter 3 of the DRIA.

The impacts of maintenance and repairs for MY 2027 vehicles in each MOVES source type associated with the reference and proposed cases are shown in Table IV–12 and Table IV–13 for 3- and 7-percent discount rates, respectively. The proposed case shows either no change[650] or reductions in maintenance and repair costs when compared to the reference case.

TABLE IV–12—MAINTENANCE AND REPAIR PER MILE FOR MODEL YEAR 2027 VEHICLES DURING THE FIRST 28 YEARS FOR EACH MOVES SOURCE TYPE, FOR ALL VEHICLE TYPES[a]

[Cents/mile in 2021 dollars, 3% discounting]

MOVES source type	Cost in reference	Cost in proposal	Proposal change from reference
Other Buses	80.0	74.8	−5.2
Transit Bus	78.4	75.6	−2.8
School Bus	80.1	73.9	−6.2
Refuse Truck	75.4	72.8	−2.6
Single Unit Short-haul Truck	69.2	66.2	−3.1
Single Unit Long-haul Truck	67.0	64.4	−2.5
Combination Short-haul Truck	66.1	64.6	−1.6
Combination Long-haul Truck	25.9	25.9	0.0

[a] Values rounded to the nearest tenth of a cent; negative values denote lower costs, *i.e.,* savings in expenditures.

TABLE IV–13—MAINTENANCE AND REPAIR PER MILE FOR MODEL YEAR 2027 VEHICLES DURING THE FIRST 28 YEARS FOR EACH MOVES SOURCE TYPE, FOR ALL VEHICLE TYPES[a]

[Cents/mile in 2021 dollars, 7% discounting]

MOVES source type	Cost in reference	Cost in proposal	Proposal change from reference
Other Buses	48.8	45.6	−3.2
Transit Bus	48.5	46.8	−1.7
School Bus	48.8	45.0	−3.8
Refuse Truck	48.8	47.1	−1.7
Single Unit Short-haul Truck	47.5	45.4	−2.1
Single Unit Long-haul Truck	46.8	45.1	−1.8
Combination Short-haul Truck	47.1	46.0	−1.1
Combination Long-haul Truck	17.5	17.5	0.0

[a] Values rounded to the nearest tenth of a cent; negative values denote lower costs, *i.e.,* savings in expenditures.

6. Payback

A payback period is the point in time at which savings from reduced operating expenses surpass increased upfront costs, typically estimated in years. The payback period for a new vehicle purchase is an important metric for many HD vehicle purchasers. In general, there is greater willingness to pay for new technology if that new technology ''pays back'' within an acceptable period of time. A payback period is calculated in DRIA Chapter 2.8.2 using HD TRUCS for specific use cases. Briefly, the incremental upfront costs for ZEV vehicles are estimated in contrast to comparable ICE vehicles. In these incremental upfront purchaser costs for ZEVs, IRA battery and vehicle tax credits were taken into consideration. Then the expected operating costs differences between ZEV and ICE vehicles are computed over time on an annual basis. When the operating costs savings offset the incremental upfront differences between ZEV and ICE vehicles, a breakeven point is met. The amount of time from purchase to the breakeven point is defined as the payback period. Payback periods are computed for specific vehicle types in DRIA Chapter 2.8.2. See preamble Section II.E.6 for further discussion on payback for the technology packages for the proposed standards. The calculations do not represent specific vehicle classes or specific use cases. However, the payback periods do provide a general sense, on average, of payback periods at a national level.

E. Social Costs

To compute the social costs of the proposal, we added the estimated total vehicle technology package RPE from Section IV.B.3, total operating costs from Section IV.D.5, and total EVSE RPE from Section IV.D.3. We note that the fuel costs in this subsection's social cost analysis are estimated pre-tax rather than what the purchaser would pay (*i.e.,* the retail fuel price). All of the costs are computed for the MOVES reference and proposed cases and cost impacts are presented as the difference between the proposed and reference case. Additionally, neither the battery tax credit nor the vehicle tax credit is included in the social costs analysis discussed in this subsection.

1. Total Vehicle Technology Package RPE

Table IV–14 reflects learning effects on DMC and indirect costs from 2027 through 2055. The sum of the DMC and indirect manufacturing cost for each year is shown in the ''Total Technology

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2022. Available online: *https://escholarship.org/content/qt36c08395/qt36c08395_noSplash_589098e470b036b3010eae00f3b7b618.pdf?t=r6zwjb.*

[650] There are no changes to vehicle populations for MY 2027 between the proposal and reference cases for the MOVES source type Combination Long-haul Truck, which is why the maintenance and repair cost per mile shows no change between the proposal and reference case.

Package Costs'' column and reflects the difference in total cost between the proposed and reference case in the specific calendar year.

TABLE IV–14—TOTAL TECHNOLOGY COST IMPACTS OF THE PROPOSED OPTION RELATIVE TO THE REFERENCE CASE, ALL REGULATORY CLASSES AND ALL FUELS, MILLIONS OF 2021 DOLLARS [a]

Calendar year	Direct manufacturing costs	Indirect costs	Total technology package costs
2027	$1,400	$590	$2,000
2028	1,200	520	1,800
2029	1,200	500	1,700
2030	1,400	590	2,000
2031	1,600	680	2,300
2032	1,400	600	2,000
2033	1,100	440	1,500
2034	900	380	1,300
2035	710	300	1,000
2036	530	220	750
2037	440	180	620
2038	290	120	410
2039	160	66	220
2040	95	40	140
2041	−29	−12	−40
2042	−140	−60	−200
2043	−250	−110	−360
2044	−290	−120	−410
2045	−390	−160	−550
2046	−490	−200	−690
2047	−580	−240	−820
2048	−600	−250	−850
2049	−680	−290	−970
2050	−760	−320	−1,100
2051	−770	−320	−1,100
2052	−850	−360	−1,200
2053	−930	−390	−1,300
2054	−1,000	−420	−1,400
2055	−1,100	−450	−1,500
PV, 3%	6,300	2,700	9,000
PV, 7%	7,100	3,000	10,000

[a] Values show 2 significant digits; negative values denote lower costs, *i.e.,* savings in expenditures.

2. Total EVSE RPE

Building on the analysis presented in Section IV.D.3 that discusses EVSE RPE cost per vehicle, the annual EVSE RPE was estimated by multiplying EVSE RPE on a per vehicle basis by the modeled number of BEV sales in MOVES. Table IV–15 shows the undiscounted annual EVSE RPE cost for the proposal relative to the reference case. The number of EVSE are expected to increase over time for the proposal relative to the reference case. This is due to the expected increase in BEVs requiring EVSE. Thus, the proposal shows increased EVSE cost over time.

TABLE IV–15—TOTAL EVSE RPE COST IMPACTS OF THE PROPOSED OPTION RELATIVE TO THE REFERENCE CASE, ALL REGULATORY CLASSES AND ALL FUELS, MILLIONS OF 2021 DOLLARS [a]

Calendar year	Total EVSE RPE cost impacts
2027	$1,300
2028	1,600
2029	1,900
2030	2,000
2031	2,200
2032	2,600
2033	2,600
2034	2,600
2035	2,500
2036	2,500
2037	2,500
2038	2,500
2039	2,600
2040	2,600
2041	2,600
2042	2,600
2043	2,700
2044	2,700
2045	2,700
2046	2,700
2047	2,700
2048	2,700
2049	2,800
2050	2,800
2051	2,800
2052	2,900
2053	2,900
2054	2,900
2055	2,900
PV, 3%	47,000
PV, 7%	29,000

3. Total Operating Costs

Annual fuel costs across the national fleet for each fuel type were computed for the proposal and reference cases by multiplying the amount of fuel consumed for each vehicle modeled in MOVES by the cost of each fuel type. Table IV–16 shows the undiscounted annual fuel savings for the proposal relative to the reference case for each fuel type. Using projected fuel prices from AEO and the estimated hydrogen prices as discussed in Section IV.D.5.i, the total, national fleet-wide cost of electricity and hydrogen consumption increase over time while the costs for diesel, gasoline, and CNG consumption decrease over time, as shown on an annual basis in Table IV–17. This is due to the expected increase in BEVs and FCEVs resulting in fewer diesel, gasoline, and CNG vehicles in the proposed case compared to the reference case. The net effect of the proposal shows increased operating cost savings over time.

TABLE IV–16—ANNUAL UNDISCOUNTED PRE-TAX FUEL COSTS FOR THE PROPOSAL RELATIVE TO THE REFERENCE CASE, MILLIONS OF 2021 DOLLARS [a]

Calendar year	Diesel	Gasoline	CNG	Electricity	Hydrogen	Sum
2027	−$370	−$160	−$4	$390	$0	−$150
2028	−810	−360	−8	840	0	−340
2029	−1,300	−590	−12	1,400	0	−580
2030	−2,300	−870	−24	1,900	520	−710
2031	−3,800	−1,200	−39	2,500	1,700	−710
2032	−5,600	−1,600	−59	3,200	3,300	−710
2033	−7,400	−2,100	−78	3,900	4,900	−680
2034	−9,100	−2,500	−97	4,600	6,500	−630
2035	−11,000	−2,900	−120	5,200	8,100	−610
2036	−12,000	−3,300	−130	5,700	9,600	−640
2037	−14,000	−3,800	−150	6,200	11,000	−710
2038	−15,000	−4,200	−170	6,600	12,000	−810
2039	−17,000	−4,600	−190	7,100	14,000	−780
2040	−18,000	−5,000	−220	7,500	15,000	−940
2041	−19,000	−5,400	−240	7,800	16,000	−1,100
2042	−20,000	−5,800	−260	8,200	17,000	−1,100
2043	−21,000	−6,200	−290	8,500	18,000	−1,400
2044	−22,000	−6,600	−320	8,700	19,000	−1,900
2045	−23,000	−7,000	−350	8,900	19,000	−2,200
2046	−24,000	−7,400	−380	9,200	20,000	−2,600
2047	−24,000	−7,800	−410	9,300	20,000	−2,800
2048	−25,000	−8,000	−440	9,500	21,000	−2,900
2049	−25,000	−8,400	−480	9,700	21,000	−3,000
2050	−25,000	−8,700	−520	9,800	21,000	−3,200
2051	−26,000	−9,100	−570	10,000	22,000	−3,400
2052	−26,000	−9,400	−610	10,000	22,000	−3,600
2053	−26,000	−9,700	−670	10,000	22,000	−3,800
2054	−26,000	−10,000	−720	10,000	23,000	−4,000
2055	−26,000	−10,000	−780	10,000	23,000	−4,300

[a] Values rounded to two significant digits; negative values denote lower costs, *i.e.,* savings in expenditures.

Annual DEF costs for diesel vehicles were computed for the proposal and reference cases by multiplying the modeled amount of DEF consumed by the cost DEF. Table IV–17 shows the annual savings associated with less DEF consumption in the proposal relative to the reference case; note that non-diesel vehicles are shown for completeness with no savings since those vehicles do not consume DEF.

TABLE IV–17—ANNUAL UNDISCOUNTED DEF COSTS FOR THE PROPOSAL RELATIVE TO THE REFERENCE CASE, MILLIONS OF 2021 DOLLARS [a]

Calendar year	Diesel	Gasoline, CNG, electric, hydrogen vehicles	Sum
2027	−$27	$0	−$27
2028	−58	0	−58
2029	−97	0	−97
2030	−160	0	−160
2031	−270	0	−270
2032	−410	0	−410
2033	−540	0	−540
2034	−680	0	−680
2035	−810	0	−810
2036	−930	0	−930
2037	−1,100	0	−1,100
2038	−1,200	0	−1,200
2039	−1,300	0	−1,300
2040	−1,400	0	−1,400
2041	−1,500	0	−1,500

TABLE IV–17—ANNUAL UNDISCOUNTED DEF COSTS FOR THE PROPOSAL RELATIVE TO THE REFERENCE CASE, MILLIONS OF 2021 DOLLARS [a]—Continued

Calendar year	Diesel	Gasoline, CNG, electric, hydrogen vehicles	Sum
2042	−1,600	0	−1,600
2043	−1,700	0	−1,700
2044	−1,700	0	−1,700
2045	−1,800	0	−1,800
2046	−1,900	0	−1,900
2047	−1,900	0	−1,900
2048	−2,000	0	−2,000
2049	−2,000	0	−2,000
2050	−2,100	0	−2,100
2051	−2,100	0	−2,100
2052	−2,200	0	−2,200
2053	−2,200	0	−2,200
2054	−2,300	0	−2,300
2055	−2,300	0	−2,300

[a] Values rounded to two significant digits; negative values denote lower costs, *i.e.,* savings in expenditures.

Annual maintenance and repair costs were computed on an annual basis for all vehicles modeled in MOVES based on the total annual VMT, vehicle type and vehicle age as discussed in Section 5 and DRIA Chapter 2 and 3. Table IV–18 presents the maintenance and repair costs associated with the proposal. The maintenance and repair costs are attributable to changes in new BEV, FCEV, and ICE vehicle sales and populations. EPA has not projected any changes to the maintenance and repair costs on a per mile basis for each vehicle powertrain type between the proposal and reference case, but as more HD ZEVs enter the HD fleet, the total maintenance and repair costs for the fleet of those vehicles correspondingly increases. The opposite is true for diesel, gasoline, and CNG vehicles as there become fewer of these vehicles in the fleet such that the total maintenance and repair costs for the fleet of those vehicles decreases as more HD ZEVs enter the HD fleet.

TABLE IV–18—ANNUAL UNDISCOUNTED MAINTENANCE & REPAIR COSTS FOR THE PROPOSAL RELATIVE TO THE REFERENCE CASE, MILLIONS OF 2021 DOLLARS [a]

Calendar year	Diesel	Gasoline	CNG	Electricity	Hydrogen	Sum
2027	−$370	−$150	−$3	$380	$0	−$150
2028	−940	−400	−7	950	0	−390
2029	−1,700	−740	−12	1,800	0	−720
2030	−2,900	−1,200	−22	2,800	140	−1,200
2031	−4,700	−1,800	−36	4,100	530	−1,900
2032	−7,000	−2,600	−56	5,700	1,100	−2,700
2033	−9,600	−3,400	−78	7,500	1,900	−3,700
2034	−12,000	−4,400	−100	9,500	2,700	−4,800
2035	−15,000	−5,500	−130	11,000	3,700	−5,900
2036	−19,000	−6,700	−160	14,000	4,800	−7,100
2037	−22,000	−7,900	−190	16,000	5,800	−8,400
2038	−25,000	−9,100	−220	18,000	6,900	−9,600
2039	−28,000	−10,000	−260	20,000	8,100	−11,000
2040	−31,000	−12,000	−300	22,000	9,200	−12,000
2041	−34,000	−13,000	−330	24,000	10,000	−13,000
2042	−37,000	−14,000	−380	26,000	11,000	−14,000
2043	−39,000	−15,000	−420	27,000	12,000	−15,000
2044	−41,000	−17,000	−460	29,000	13,000	−16,000
2045	−43,000	−18,000	−510	31,000	14,000	−17,000
2046	−45,000	−19,000	−560	32,000	15,000	−18,000
2047	−47,000	−20,000	−620	34,000	15,000	−19,000
2048	−48,000	−21,000	−670	35,000	16,000	−19,000
2049	−49,000	−22,000	−740	36,000	16,000	−20,000
2050	−51,000	−24,000	−800	38,000	17,000	−21,000
2051	−52,000	−25,000	−880	39,000	17,000	−22,000
2052	−53,000	−26,000	−960	40,000	17,000	−22,000
2053	−54,000	−27,000	−1,000	42,000	18,000	−23,000
2054	−55,000	−28,000	−1,100	43,000	18,000	−24,000
2055	−56,000	−30,000	−1,200	44,000	19,000	−24,000

[a] Values rounded to two significant digits; negative values denote lower costs, *i.e.,* savings in expenditures.

4. Total Social Costs

Adding together the cost elements outlined in Sections IV.E.1, IV.E.2, and IV.E.30, we estimated the total social costs associated with the proposed CO_2 standards; these total social costs associated with the proposal relative to the reference case are shown in Table IV–19. Table IV–19 presents costs in 2021 dollars in undiscounted annual values along with net present values at both 3- and 7-percent discount rates with values discounted to the 2027 calendar year. Additionally, neither the battery tax credit nor the vehicle tax credit is included in the social costs analysis discussed in this subsection.

As shown in Table IV–19, starting in 2033, our analysis demonstrates that total program costs under the proposal scenario are lower than the total program costs under the reference case without the standard.

TABLE IV–19—TOTAL TECHNOLOGY PACKAGE, OPERATING COST, AND EVSE COST IMPACTS OF THE PROPOSED OPTION RELATIVE TO THE REFERENCE CASE, ALL REGULATORY CLASSES AND ALL FUELS, MILLIONS OF 2021 DOLLARS [a]

Calendar year	Total technology package costs	Total operating costs	Total EVSE costs	Sum
2027	$2,000	−$330	$1,300	$3,000
2028	1,800	−790	1,600	2,500
2029	1,700	−1,400	1,900	2,200
2030	2,000	−2,100	2,000	1,900
2031	2,300	−2,800	2,200	1,700
2032	2,000	−3,800	2,600	860
2033	1,500	−4,900	2,600	−820
2034	1,300	−6,100	2,600	−2,200
2035	1,000	−7,400	2,500	−3,800
2036	750	−8,700	2,500	−5,500
2037	620	−10,000	2,500	−7,000
2038	410	−12,000	2,500	−8,700
2039	220	−13,000	2,600	−10,000
2040	140	−14,000	2,600	−12,000
2041	−40	−16,000	2,600	−13,000
2042	−200	−17,000	2,600	−15,000
2043	−360	−18,000	2,700	−16,000
2044	−410	−20,000	2,700	−18,000
2045	−550	−21,000	2,700	−19,000
2046	−690	−22,000	2,700	−20,000
2047	−820	−23,000	2,700	−22,000
2048	−850	−24,000	2,700	−22,000
2049	−970	−25,000	2,800	−23,000
2050	−1,100	−26,000	2,800	−24,000
2051	−1,100	−27,000	2,800	−25,000
2052	−1,200	−28,000	2,900	−26,000
2053	−1,300	−29,000	2,900	−27,000
2054	−1,400	−30,000	2,900	−28,000
2055	−1,500	−31,000	2,900	−29,000
PV, 3%	9,000	−250,000	47,000	−190,000
PV, 7%	10,000	−120,000	29,000	−85,000
Annualized, 3%	470	−13,000	2,500	−10,000
Annualized, 7%	820	−10,000	2,300	−6,900

[a] Values rounded to two significant digits; negative values denote lower costs, *i.e.,* savings in expenditures.

V. Estimated Emission Impacts From the Proposed Program

We expect the proposed CO_2 standards would result in downstream emission reductions of GHGs from heavy-duty vehicles. Downstream emissions processes are those that come directly from a vehicle, such as tailpipe exhaust, crankcase exhaust, evaporative emissions, and refueling emissions. While we are not proposing standards to address criteria pollutants or air toxics, we expect the proposed standards would also result in reductions of downstream emissions of both criteria pollutants and air toxics. We expect these anticipated emission reductions would be achieved through increased adoption of heavy-duty battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) and by additional improvements to ICE vehicles. The emissions modeling that we present in this section characterizes the emissions impacts of the technology package described in Section II of the preamble. As we note there, manufacturers may elect to comply using a different combination of HD vehicle and engine technologies than we modeled.

To estimate the downstream emission reductions from the proposed standards, we used an updated version of EPA's Motor Vehicle Emission Simulator (MOVES) model, MOVES3.R3. This version already included the impacts of the HD GHG Phase 2 program, and also includes several changes related specifically to heavy-duty vehicle emissions (*e.g.,* updates to incorporate the HD2027 final rule) and activity (*e.g.,* updates to vehicle population and miles traveled) as well as new capabilities to model heavy-duty vehicles with electric powertrains.[651] These model updates are summarized in Chapter 4.2 of the DRIA and described in detail in the technical reports that are available in the docket for this proposed rulemaking.

With the increased adoption of heavy-duty BEVs and FCEVs (together referred to as ZEVs), we expect the proposed standards to impact upstream emissions of GHGs and other pollutants. Upstream emissions sources are those that occur

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[651] Memo to Docket. ''EPA's Motor Vehicle Emission Simulator (MOVES) model, MOVES3.R3.'' Docket EPA–HQ–OAR–2022–0985.

before tailpipe emissions from vehicles, such as from electricity generation for charging BEVs, the production of hydrogen used to fuel FCEVs, and emissions generated during petroleum-based fuel production and distribution. We estimated the impacts of the proposed standards on emissions from electricity generation units (EGUs). We also estimated the impacts on refinery emissions of non-GHGs for calendar year 2055.[652] We did not estimate the impacts on emissions related to crude production or extraction or the transportation of crude or refined fuels.

To estimate upstream EGU emission impacts from the proposed standards, we used the Integrated Planning Model (IPM). IPM is a linear programming model that accounts for variables and information such as energy demand, planned EGU retirements, and planned rules to forecast EGU-level energy production and configurations. The IPM runs we performed to estimate EGU emissions were based on preliminary reference and control scenarios, and the IPM run for the control scenario did not account for the IRA. Therefore, we developed a methodology, using output of three IPM runs, to estimate the increase in EGU emissions from the proposal and alternative, adjusted for the IRA. The first represents the EGU inventory absent both the proposal and the Inflation Reduction Act (IRA),[653] the second represents the inventory absent the proposal but includes the IRA,[654] and the third includes impacts from a preliminary version of the proposal we developed earlier in the regulatory development process but not the IRA. Together, they help us estimate the impact of the proposed standards on EGU emissions, accounting for the IRA. More details on IPM and the specific version used in this proposal can be found in the Chapter 4.3.3 of the DRIA.

To estimate upstream refinery impacts from the proposed standards, we adjusted an existing refinery inventory that included $PM_{2.5}$, NO_X, SO_2 and VOC emissions for the year 2055. The adjustment factors are based on liquid fuel demand projections for the reference, proposal, and alternative cases. In this analysis, we assumed refinery activity decreases with decreased demand for liquid fuel from heavy-duty vehicles. More details on the refinery impacts estimated for this proposal can be found in Chapters 4.3.3 and 4.6 of the DRIA.

A. Model Inputs

1. MOVES Inputs

In the analysis to support this proposal, we evaluated the proposed standards relative to a reference case using MOVES. MOVES defines vehicles using a combination of source type and regulatory class, where source type roughly defines a vehicle's vocation or usage pattern, and regulatory class defines a vehicle's weight class. Table V–1 defines MOVES medium- and heavy-duty source types.

TABLE V–1—MOVES SOURCE TYPE DEFINITIONS

sourceTypeID	Source type description
31	Passenger Truck.
32	Light Commercial Truck.
41	Other Bus.
42	Transit Bus.
43	School Bus.
51	Refuse Truck.
52	Single Unit Short-haul Truck.
53	Single Unit Long-haul Truck.
54	Motor Home.
61	Combination Short-haul Truck.
62	Combination Long-haul Truck.

In modeling the heavy-duty ZEV populations in the reference case, a scenario that represents the United States without the proposed rulemaking, we considered several different factors related to purchaser acceptance of new technologies as discussed in DRIA Chapter 2, along with three factors described in Section I.C. First, the market has evolved such that early HD ZEV models are in use today for some applications and HD ZEVs are expected to expand to many more applications, as discussed in Section II.D and DRIA Chapters 1.5 and 2. Additionally, manufacturers have announced plans to rapidly increase their investments in ZEV technologies over the next decade. Second, the IRA and the BIL provide many monetary incentives for the production and purchase of ZEVs in the heavy-duty market, as well as incentives for electric vehicle charging infrastructure. Third, there have been multiple actions by states to accelerate the adoption of heavy-duty ZEVs, such as (1) a multi-state Memorandum of Understanding for the support of heavy-duty ZEV adoption;[655] and (2) the State of California's ACT program, which has also been adopted by other states and includes a manufacturer requirement for zero-emission truck sales.[656] [657]

We also reviewed the literature to evaluate future HD ZEV projections from others. We found that the literature had varied projections for HD ZEV adoption absent this proposed rulemaking. For instance, the International Council for Clean Transportation (ICCT) conducted an analysis in early 2022, before IRA, and projected a variety of scenarios. They specifically projected eight percent HD ZEV sales in 2030 when only considering current policies and 11 percent in 2030 when considering the multi-state MOUs.[658] The National Renewable Energy Laboratory (NREL) conducted an analysis in early 2022, also prior to the IRA, that projected 42 percent HD ZEV sales by 2030 and 98 percent sales by 2040, along with 100 percent of bus sales being ZEVs by 2030.[659] The NREL analysis assumed economics alone drive adoption (*i.e.,* total cost of ownership), and therefore they did not consider non-financial factors such ZEV product research and development timelines, ZEV manufacturing time lines, the availability of ZEV models, manufacturing or infrastructure constraints, driver preferences, and

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[652] As discussed in Chapter 4.3.3.3 of the DRIA, our methodology for estimating refinery emissions is limited to one analysis year (2055) and only certain non-GHG pollutants (NO_X, $PM_{2.5}$, VOC, and SO_2).

[653] All inputs, outputs, and full documentation of EPA's IPM v6 Summer 2022 Reference Case and the associated NEEDS version is available on the power sector modeling website (*https://www.epa.gov/power-sector-modeling/documentation-pre-ira-2022-reference-case*).

[654] We expect IRA incentives, particularly sections 45X, 45Y, and 48E of the Internal Revenue Code (*i.e.,* Title 26) added by sections 13502 (Advanced Manufacturing Production Credit), 13701 (Clean Electricity Production Credit), and 13702 (Clean Electricity Investment Credit), respectively, to contribute significantly to increases in renewables in the future power generation mix.

[655] NESCAUM MOU, available at *https://www.nescaum.org/documents/mhdv-zev-mou-20220329.pdf.*

[656] EPA granted the ACT rule waiver requested by California under CAA section 209(b) on March 30, 2023. When we developed the reference case, the ACT had been adopted by five states under CAA section 177: Oregon, Washington, New York, New Jersey, and Massachusetts. Oregon and Washington adopted ACT as-is, whereas New York, New Jersey, and Massachusetts adopted ACT on a one-year delay.

[657] In December 2022, Vermont also adopted ACT under CAA section 177 effective beginning with MY 2026. Due to the timing of Vermont's adoption of ACT relative to the timing of the analysis conducted for this proposal, Vermont's adoption of ACT is not included in the analysis for our proposal; however, Vermont's adoption of ACT provides additional support for the ZEV levels in our reference case. See *https://dec.vermont.gov/sites/dec/files/aqc/laws-regs/documents/Chapter_40_LEV_ZEV_rule_adoped.pdf.*

[658] Buysee, Claire, et al. ''Racing to Zero: The Ambition We Need for Zero-Emission Heavy-Duty Vehicles in the United States.'' April 2022. Available online: *https://theicct.org/racing-to-zero-hdv-us-apr22/* ICCT.

[659] Ledna, Catherine, et al. ''Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis.'' March 2022. Slide 25. Available online: *https://www.nrel.gov/docs/fy22osti/82081.pdf.*

other factors. ACT Research also conducted an analysis prior to IRA and projected HD ZEV sales of 24 pecent in 2024, 26 percent in 2030, and 34 percent in 2031.[660] EDF and ERM conducted a follow-up analysis of their HD ZEV sales projections after the IRA passed in 2022.[661] They project several scenarios which range between 11 and 42 percent HD ZEV sales in 2029 when including long-haul tractors. The EDF/ERM analysis found that IRA will help accelerate ZEV adoption due to the purchasing incentives, which drives HD ZEVs to reach cost parity at least five years sooner than without the IRA incentives. The ACT Research, ICCT, and EDF/ERM projections, similar to the 2022 NREL study, also did not consider several important real-world factors which would in general be expected to slow down or reduce ZEV sales.

To estimate the adoption of HD ZEVs in the reference case for this proposal, we analyzed a national level of ZEV sales based on volumes expected from the ACT rule in California and other states that have adopted ACT.[662] [663] We used those volumes as the numeric basis for the number of ZEVs in the MY 2024 and later timeframe. EPA granted the ACT rule waiver requested by California under CAA section 209(b) on March 30, 2023, and we expect the market, at a national level, had already been responding to the ACT requirements, in addition to the market forces discussed earlier. It is, therefore, reasonable to use the ZEV sales volume that could be expected from ACT in the reference case as an overall projection for where the national ZEV sales volumes may be in the absence of this EPA action. Table V–2 shows the national adoption of heavy-duty ZEVs we modeled in the reference case. Additional details regarding the modeling of the reference case can be found in Chapter 4.3 of the DRIA.

TABLE V–2—NATIONAL HEAVY-DUTY ZEV ADOPTION IN THE REFERENCE CASE

Model year	Class 4–8 vocational vehicle group [a] source types 41–54 (percent)	Class 7–8 tractors group source types 61, 62 (percent)
2024	1.1	0.3
2025	2.0	0.7
2026	2.4	1.0
2027	3.4	1.4
2028	5.1	1.9
2029	7.1	2.5
2030	9.1	3.0
2031	10.5	3.5
2032	11.4	4.1
2033	12.4	4.3
2034	13.4	4.3
2035	14.4	4.3
2036 and beyond	14.8	4.3

[a] The ACT program includes ZEV adoption rates for a Class 2b–3 Vocational Vehicle Group, which we also included in our reference case modeling. However, we did not model the proposal as increasing ZEV adoption in this vehicle category so they are not presented here. Class 2b–3 Vocational Vehicle Group ZEV adoption rates can be found in Appendix 4A of the DRIA.

We note that our reference case projection of ZEV adoption in this proposal is conservative when compared to the studies from NREL, ICCT, ACT Research, and EDF/ERM. Therefore, we may be projecting emission reductions due to the proposed standards that are greater than could be expected using a reference case that reflects higher levels of ZEV adoption in the HD market absent our rule. At the same time, our use of this reference case would also be conservative in terms of costs of compliance, which would be overestimated if the market would acheive higher levels of ZEV adoption in the absence of our proposed standards. We may revisit our reference case in the final rule analysis. For example, given that EPA granted the California Air Resources Board's request for a waiver for the ACT Regulation on March 30, 2023, which was not in a time frame for EPA to consider for this proposal an alternative approach for the reference case, we may make revisions for the final rule to explicitly reflect the waiver decision. In addition, while the approach we have used to quantify the national ZEV volumes in the reference case considers the impacts of the IRA and the BIL, it does not explicitly model them. Therefore, we invite stakeholders to comment and provide additional information on our approach to modeling the reference case. Commenters may also provide input on other data or modeling approaches that EPA should consider when estimating the reference case in the final rulemaking, including but not limited to the reports summarized in this section. We invite stakeholders to comment and provide additional information on our approach to modeling the reference case. Commenters may also provide input on other data or modeling approaches that EPA should consider when estimating the reference case in the final rulemaking, including but not limited to the reports summarized in this section.

For the purposes of the modeling analysis, we assume the proposed CO_2 emission standards would be met by technology packages that reflect both ICE vehicles and an increased level of ZEV adoption. The technology packages we are using for the ICE vehicles are built into the MOVES versions we are using for the analysis. Future HD ZEV populations in MOVES for the proposal and alternative scenarios were estimated using HD TRUCS based on the technology assessment for BEVs and FCEVs discussed in DRIA Chapter 2. Table V–3 shows the ZEV adoption rates by vehicle type used in modeling the control case for the proposal in MOVES. ZEV adoption rates for the alternative are discussed in Section IX. Further discussion of the ZEV adoption rates we modeled can be found in DRIA Chapter 4.3.

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[660] Lockridge, Deborah. "ACT: Third of Class 4–8 Vehicles to be Battery-Electric in 10 Years." June 2021. Available online: *https://www.truckinginfo.com/10144947/act-third-of-class-4-8-vehicles-to-be-battery-electric-in-10-years.*

[661] Robo, Ellen and Dave Seamonds. Technical Memo to Environmental Defense Fund: Investment Reduction Act Supplemental Assessment: Analysis of Alternative Medium- and Heavy-Duty Zero-Emission Vehicle Business-As-Usual Scenarios. ERM. August 19, 2022. Page 9. Available online: *https://www.erm.com/contentassets/154d08e0d0674752925cd82c66b3e2b1/edf-zev-baseline-technical-memo-addendum.pdf.*

[662] California Air Resources Board, Final Regulation Order—Advanced Clean Trucks Regulation. Filed March 15, 2021. Available at: *https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf.* Final Advanced Clean Truck Amendments, Oregon adopted ACT on 11/17/2021: *https://www.oregon.gov/deq/rulemaking/Pages/ctr2021.aspx.* Washington adopted ACT on 11/29/2021: *https://ecology.wa.gov/Regulations-Permits/Laws-rules-rulemaking/Rulemaking/WAC-173-423-400.* New York adopted ACT on 12/29/2021: *https://www.dec.ny.gov/regulations/26402.html.* New Jersey adopted ACT on 12/20/2021: *https://www.nj.gov/dep/rules/adoptions.html.* Massachusetts adopted ACT on 12/30/2021: *https://www.mass.gov/regulations/310-CMR-700-air-pollution-control#proposed-amendments-public-comment.*

[663] In December 2022, Vermont also adopted ACT under CAA section 177 effective beginning with MY 2026. Due to the timing of Vermont's adoption of ACT relative to the timing of the analysis conducted for this proposal, Vermont's adoption of ACT is not included in the analysis for our proposal; however, Vermont's adoption of ACT provides additional support for the ZEV levels in our reference case. See *https://dec.vermont.gov/sites/dec/files/aqc/laws-regs/documents/Chapter_40_LEV_ZEV_rule_adopted.pdf.*

TABLE V–3—HD ZEV ADOPTION RATES IN THE CONTROL CASE USED TO MODEL THE PROPOSED STANDARDS

Model year	Vocational source types 41–54 (percent)	Short-haul tractors source type 61 (percent)	Long-haul tractors [a] source Type 62 (percent)
MY 2027	20	10	0.3
MY 2028	25	12	0.7
MY 2029	30	15	1.0
MY 2030	35	20	10
MY 2031	40	30	20
MY 2032 and later	50	35	25

[a] For sleeper cab tractors, which are represented by long-haul tractors (source type 62) in MOVES, we are not proposing revisions to MY 2027 standards or new standards for MYs 2028 or 2029. ZEV adoption for this source type in these model years was set to be equal to the reference case.

2. IPM Inputs

We used IPM to estimate the EGU emissions associated with the additional energy demand from increased HD ZEV adoption. We do not have IPM output from runs directly corresponding to the reference case and proposal, so we approximated the EGU emission impacts of the proposal based on IPM runs that did not specifically model that scenario. The details of this methodology, including its simplifying assumptions and limitations, can be found in Chapter 4.3.3 of the draft RIA.

To account for the upstream emissions from the production of hydrogen used to fuel FCEVs, we made a simplifying assumption that all hydrogen used for FCEVs is produced via grid electrolysis of water and can therefore be entirely represented as additional demand to EGUs and modeled using IPM.[664] We developed a scaling factor to account for the amount of hydrogen that would need to be produced to meet the FCEV energy demand calculated by MOVES. More details on the derivation of the scaling factors can be found in Chapter 4.3 of the draft RIA. We invite stakeholders to comment and provide additional information on our approach to modeling the emissions impact of hydrogen production. Commenters may also provide input on other data or modeling approaches that EPA should consider when estimating emissions from hydrogen production in the final rulemaking.

B. Estimated Emission Impacts From the Proposed Standards

This NPRM includes proposed CO_2 emission standards for MYs 2027 through 2032. Because we anticipate an increase in the use of heavy-duty ZEVs to meet the proposed emission standards, and ZEVs do not produce any tailpipe emissions, we expect downstream GHG emissions reductions as well as reductions in emissions of criteria pollutants and air toxics. As described in Section V.A, we modeled the proposed standards in MOVES3.R3 by increasing the adoption of heavy-duty BEVs and FCEVs relative to the reference case, which means the primary driving factor behind the projected emission reductions is the displacement of ICE vehicles with ZEVs. The downstream emissions are presented in Section V.B.1.

We also expect the increased adoption of HD ZEVs to increase emissions from EGUs and decrease emissions from refineries. Section V.B.2 presents these upstream emissions impacts, Section V.B.3 presents the net emission impacts of the proposed standards, and the downstream and upstream impacts of the alternative are discussed in Section IX.

Because all our modeling is done for a full national domain, all emissions impacts cover the full national inventory. Emissions impacts in other domains, such as particular regions or localities in the United States, are likely to differ from the impacts presented here.

1. Estimated Impacts on Downstream Emissions

Our estimates of the downstream emission reductions of GHGs that would result from the proposed standards, relative to the reference case emission inventory without the proposed standards, are presented in Table V–4 for calendar years 2035, 2045, and 2055. Total GHG emissions, or CO_2 equivalent (CO_2e), are calculated by summing all GHG emissions multiplied by their 100-year Global Warming Potentials (GWP).[665]

TABLE V–4—ANNUAL DOWNSTREAM HEAVY-DUTY GHG EMISSION REDUCTIONS FROM THE PROPOSED STANDARDS IN CALENDAR YEARS (CY) 2035, 2045, AND 2055

Pollutant	100-year GWP	CY 2035 reductions		CY 2045 reductions		CY 2055 reductions	
		Million metric tons	Percent	Million metric tons	Percent	Million metric tons	Percent
Carbon Dioxide (CO_2)	1	51	13	102	26	125	30

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[664] Hydrogen in the U.S. today is primarily produced via steam methane reforming (SMR) largely as part of petroleum refining and ammonia production. Given the BIL and the IRA provisions that meaningfully incentivize reducing the emissions and carbon intensity of hydrogen production, as well as new transportation and other demand drivers and potential future regulation, it is anticipated there will be a shift in how hydrogen is produced. Considering this and because electrolysis is a key mature technology for hydrogen production, our analysis includes the simplifying assumption that increased levels of hydrogen to fuel FCEVs will be produced using grid electrolysis. We recognize that the relative emissions impact of hydrogen production via SMR versus grid electrolysis depends on how electricity is produced, which varies significantly by region across the country. We also recognize that electrolysis powered by electricity from the grid on average in the U.S. may overestimate the upstream emissions impacts that are attributable to HD FCEVs in our analysis. See DRIA Chapter 4.3.3 for additional discussion.

[665] The GWP values used by MOVES are values used in the 2007 IPCC Fourth Assessment Report (AR4). The Intergovernmental Panel on Climate Change, *Climate Change 2007: Impacts, Adaptation and Vulnerability. https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf.*

TABLE V–4—ANNUAL DOWNSTREAM HEAVY-DUTY GHG EMISSION REDUCTIONS FROM THE PROPOSED STANDARDS IN CALENDAR YEARS (CY) 2035, 2045, AND 2055—Continued

Pollutant	100-year GWP	CY 2035 reductions		CY 2045 reductions		CY 2055 reductions	
		Million metric tons	Percent	Million metric tons	Percent	Million metric tons	Percent
Methane (CH_4)	25	0.004	8	0.015	24	0.032	31
Nitrous Oxide (N_2O)	298	0.007	12	0.013	24	0.015	28
CO_2 Equivalent (CO_2e)		53	13	106	26	130	30

In 2055, we estimate that the proposal would reduce downstream emissions of CO_2 by 30 percent, methane by 31 percent, and nitrous oxide by 28 percent, resulting in a reduction of 30 percent for total CO_2 equivalent emissions. Table V–4 also shows that most of the GHG emission reductions would be from CO_2, which would represent approximately 96 percent of all heavy-duty GHG emission reductions from the proposed standards.

The warming impacts of GHGs are cumulative. Table V–5 presents the cumulative GHG reductions that would result from the proposed standards in 2055, in billion metric tons (BMT).

TABLE V–5—CUMULATIVE 2027–2055 DOWNSTREAM HEAVY-DUTY GHG EMISSION REDUCTIONS FROM THE PROPOSED STANDARDS

Pollutant	Reduction in BMT	Percent reduction
Carbon Dioxide (CO_2)	2.2	18
Methane (CH_4)	0.00035	17
Nitrous Oxide (N_2O)	0.00028	17
CO_2 Equivalent (CO_2e)	2.3	18

Cumulative emission reductions increase over time from 2027 through 2055, as more HD ZEVs meeting the proposed standards enter the fleet. This is discussed in more detail in Chapter 4.4.3 of the draft RIA.

We expect the proposed CO_2 emission standards will lead to an increase in HD ZEVs, which will result in reductions of non-GHG pollutants. Table V–6 presents our estimates of the downstream emission reductions of criteria pollutants and air toxics from heavy-duty vehicles that would result from the proposed standards in calendar years 2035, 2045, and 2055.

TABLE V–6—ANNUAL DOWNSTREAM HEAVY-DUTY EMISSION REDUCTIONS FROM THE PROPOSED STANDARDS IN CALENDAR YEARS (CY) 2035, 2045, AND 2055 FOR CRITERIA POLLUTANTS AND AIR TOXICS

Pollutant	CY 2035 reductions		CY 2045 reductions		CY 2055 reductions	
	U.S. Tons	Percent	U.S. Tons	Percent	U.S. Tons	Percent
Nitrogen Oxides (NO_X)	16,232	4	56,191	21	70,838	28
Primary Exhaust $PM_{2.5}$	271	6	690	30	967	39
Volatile Organic Compounds (VOC)	6,016	11	14,219	28	20,775	37
Sulfur Dioxide (SO_2)	204	13	414	27	518	31
Carbon Monoxide (CO)	98,889	11	244,649	28	349,704	35
1,3-Butadiene	19	22	48	46	68	51
Acetaldehyde	123	11	298	30	454	35
Benzene	109	17	281	41	410	49
Formaldehyde	83	8	217	27	361	33
Naphthalene[a]	6	10	16	38	21	45
Ethylbenzene	70	11	175	30	266	41

[a] Naphthalene includes both gas and particle phase emissions.

In 2055, we estimate the proposal would reduce heavy-duty vehicle emissions of NO_X by 28 percent, $PM_{2.5}$ by 39 percent, VOC by 37 percent, and SO_2 by 31 percent. Reductions in air toxics range from 33 percent for formaldehyde to 51 percent for 1,3-butadiene.

Chapter 4.4 of the draft RIA contains more details on downstream emission reductions by vehicle type, fuel type, and emission process, as well as year-over-year impacts from 2027 through 2055.

2. Estimated Impacts on Upstream Emissions

Our estimates of the additional CO_2 emissions from EGUs due to the proposed standards, relative to the reference case, are presented in Table V–7 for calendar years 2035, 2045, and 2055, in million metric tons (MMT).

TABLE V–7—ANNUAL CO_2 EMISSION INCREASES FROM EGUS FROM THE PROPOSED STANDARDS IN CALENDAR YEARS (CY) 2035, 2045, AND 2055

Pollutant	Additional EGU emissions (mmt)		
	CY 2035	CY 2045	CY 2055
Carbon Dioxide (CO_2)	20	16	11

In 2055, we estimate the proposal would increase EGU emissions of CO_2 by 11 million metric tons, compared to 20 million metric tons in 2035. The EGU impacts decrease over time because of changes in the projected power generation mix as electricity generation uses less fossil fuels. This is discussed in more detail in Chapter 4.5 of the DRIA. In total, we estimate the proposal will lead, cumulatively, to 0.4 BMT of additional CO_2 emissions from EGUs from 2027 to 2055.

Table V–8 shows the estimated impact of the proposed standards on EGU emissions for some criteria pollutants.

TABLE V–8—ANNUAL CRITERIA POLLUTANT EMISSION INCREASES FROM EGUS FROM THE PROPOSED STANDARDS IN CALENDAR YEARS (CYS) 2035, 2045, AND 2055

Pollutant	Additional EGU emissions (U.S. tons)		
	CY 2035	CY 2045	CY 2055
Nitrogen Oxides (NO_X)	2,821	2,226	787
Primary $PM_{2.5}$	1,216	1,043	751
Volatile Organic Compounds (VOC)	629	772	754
Sulfur Dioxide (SO_2)	9,937	2,552	912

Chapter 4.5 of the DRIA contains more detail and discussion of the impacts of the proposed CO_2 emission standards on EGU emissions, including year-over-year impacts from 2027 through 2055.

In addition to EGU emissions impacts, we also estimated impacts on select criteria pollutant emissions from refineries for calendar year 2055. This analysis assumes that the reduction in demand for liquid fuels would lead to reduced activity and emissions at refineries. The results are presented in Table V–9. Additional detail on the refinery analysis is available in Chapters 4.3.3 and 4.5 of the DRIA.

TABLE V–9—CRITERIA POLLUTANT EMISSION REDUCTIONS FROM REFINERIES FROM THE PROPOSED STANDARDS IN 2055

Pollutant	CY 2055 refinery emission reductions (U.S. tons)
NO_X	1,785
$PM_{2.5}$	436
VOC	1,227
SO_2	642

3. Estimated Impacts on Combined Downstream and Upstream Emissions

While we present a net emissions impact of the proposed CO_2 emission standards, it is important to note that some upstream emission sources are not included in the analysis. Although we expect the proposed CO_2 standards to reduce demand for refined fuels, we did not quantify emissions changes associated with producing or extracting crude or transporting crude or refined fuels. Also, because our analysis of refinery emissions only included select criteria pollutants, refinery emission impacts are not included in GHG emission impacts. Therefore, this analysis likely underestimates the net emissions reductions that may result from the proposal. As discussed in Section II.G, EPA considered these net impacts as supportive of the proposed standards.

Table V–10 shows a summary of our modeled downstream, upstream, and net CO_2 emission impacts of the proposed standards relative to the reference case (*i.e.,* the emissions inventory without the proposed standards), in million metric tons, for calendar years 2035, 2045, and 2055.

TABLE V–10—ANNUAL NET IMPACTS[a] ON CO_2 EMISSIONS FROM THE PROPOSED CO_2 EMISSION STANDARDS IN CALENDAR YEARS (CYS) 2035, 2045, AND 2055

Pollutant	CY 2035 impacts (MMT)			CY 2045 impacts (MMT)			CY 2055 impacts (MMT)		
	Downstream	EGU	Net	Downstream	EGU	Net	Downstream	EGU	Net
CO_2	−51	20	−31	−102	16	−86	−125	11	−114

[a] We present emissions reductions as negative numbers and emission increases as positive numbers.

In 2055, we estimate the proposal would result in a net decrease of 114 million metric tons in CO_2 emissions. The net decreases become larger between 2035 and 2055 as the HD fleet turns over and the power grid uses less fossil fuels.

The warming impacts of GHGs are cumulative. In Table V–11, we present the cumulative net CO_2 emissions impact that we expect would result from the proposed standards, accounting for downstream emission reductions and EGU emission increases. Overall, we estimate the proposal would result in a net reduction of 1.8 billion metric tons of CO_2 emissions from 2027 to 2055.

TABLE V–11—CUMULATIVE 2027–2055 NET CO_2 EMISSION IMPACTS [a] (IN BMT) REFLECTING THE PROPOSED CO_2 EMISSION STANDARDS

Pollutant	Downstream	EGU	Net
Carbon Dioxide (CO_2)	−2.2	0.4	−1.8

[a] We present emissions reductions as negative numbers and emission increases as positive numbers.

Table V–12 contains a summary of the modeled net impacts of the proposed CO_2 emission standards on criteria pollutant emissions considering downstream and EGUs, relative to the reference case (*i.e.,* without the proposed standards), for calendar years 2035 and 2045. Table V–13 contains a similar summary for calendar year 2055 that includes estimates of net impacts of refinery, EGU, and downstream emissions.

TABLE V–12—ANNUAL NET IMPACTS [a] ON CRITERIA POLLUTANT EMISSIONS FROM THE PROPOSED CO_2 EMISSION STANDARDS IN CALENDAR YEARS (CYS) 2035 AND 2045

Pollutant	CY 2035 impacts (U.S. tons)			CY 2045 impacts (U.S. tons)		
	Downstream	EGU	Net	Downstream	EGU	Net
NO_X	−16,232	2,821	−13,411	−56,191	2,226	−53,966
$PM_{2.5}$	−271	1,216	945	−690	1,043	352
VOC	−6,016	629	−5,387	−14,219	772	−13,447
SO_2	−204	9,937	9,732	−414	2,552	2,138

[a] We present emissions reductions as negative numbers and emission increases as positive numbers.

TABLE V–13—NET IMPACTS [a] ON CRITERIA POLLUTANT EMISSIONS FROM THE PROPOSED CO_2 EMISSION STANDARDS IN CY 2055

Pollutant	CY 2055 impacts (U.S. tons)			
	Downstream	EGU	Refinery	Net
NO_X	−70,838	787	−1,785	−71,836
$PM_{2.5}$	−967	751	−436	−652
VOC	−20,775	754	−1,227	−21,248
SO_2	−518	912	−642	−248

[a] We present emissions reductions as negative numbers and emission increases as positive numbers.

By 2055, when considering downstream, EGU, and refinery emissions, we estimate a net decrease in emissions from all pollutants that we modeled for all emissions sources (*i.e.,* NO_X, $PM_{2.5}$, VOC, and SO_2). In earlier years, when considering only downstream and EGU emissions, we estimate net decreases of NO_X and VOC emissions, but net increases of $PM_{2.5}$ and SO_2 emissions. These increases become smaller over time.

Overall, we estimate that the proposal will lead to net reductions in emissions of most pollutants because downstream emission reductions tend to outpace EGU emission increases. We estimate that reductions will start small and increase from 2027 through 2055. It is possible there are increases in emissions of $PM_{2.5}$ and SO_2 in the nearer term as the electricity generation mix still relies on a relatively higher proportion of fossil fuels. While we do not have refinery emission impacts estimated for all calendar years, it is possible that refinery emission reductions combined with downstream emission reductions also outpace EGU emission increases. In 2055, for example, we estimate that refinery and downstream emission reductions exceed EGU emission increases of SO_2.

VI. Climate, Health, Air Quality, Environmental Justice, and Economic Impacts

In this section, we discuss the impacts of the NPRM on climate change, health and environmental effects, environmental justice, and oil and electricity consumption. We also discuss our approaches to analyzing the impact of this proposal on the heavy-duty vehicle market and employment.

A. Climate Change Impacts

Extensive information on climate change impacts is available in the scientific assessments that are briefly described in this section, as well as in the technical and scientific information supporting them. One of those documents is the EPA's 2009 Endangerment and Cause or Contribute Findings for GHGs Under section 202(a) of the CAA (74 FR 66496; December 15, 2009).[666] In the 2009 Endangerment Findings, the Administrator found under section 202(a) of the CAA that elevated atmospheric concentrations of six key well-mixed GHGs—CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—''may reasonably be anticipated to endanger the public health and welfare of current and future generations'' (74 FR 66523; December 15, 2009), and the science and observed changes have confirmed and strengthened the understanding and concerns regarding the climate risks considered in the Finding. The 2009 Endangerment Findings, together with

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[666] In describing these 2009 Findings in this proposal, the EPA is neither reopening nor revisiting them.

the extensive scientific and technical evidence in the supporting record, documented that climate change caused by human emissions of GHGs threatens the public health of the U.S. population.

The most recent information demonstrates that the climate is continuing to change in response to the human-induced buildup of GHGs in the atmosphere. Recent scientific assessments show that atmospheric concentrations of GHGs have risen to a level that has no precedent in human history and that they continue to climb, primarily because of both historic and current anthropogenic emissions, and that these elevated concentrations endanger our health by affecting our food and water sources, the air we breathe, the weather we experience, and our interactions with the natural and built environments.

Global average temperature has increased by about 1.1 degrees Celsius (°C) (2.0 degrees Fahrenheit (°F)) in the 2011–2020 decade relative to 1850–1900.[667] The IPCC determined with medium confidence that this past decade was warmer than any multi-century period in at least the past 100,000 years.[668] Global average sea level has risen by about 8 inches (about 21 centimeters (cm)) from 1901 to 2018, with the rate from 2006 to 2018 (0.15 inches/year or 3.7 millimeters (mm)/year) almost twice the rate over the 1971 to 2006 period, and three times the rate of the 1901 to 2018 period.[669] The rate of sea level rise during the 20th Century was higher than in any other century in at least the last 2,800 years.[670] The CO_2 being absorbed by the ocean has resulted in changes in ocean chemistry due to acidification of a magnitude not seen in 65 million years,[671] putting many marine species—particularly calcifying species—at risk. Human-induced climate change has led to heatwaves and heavy precipitation becoming more frequent and more intense, along with increases in agricultural and ecological droughts[672] in many regions.[673] The NCA4 found that it is very likely (greater than 90 percent likelihood) that by mid-century, the Arctic Ocean will be almost entirely free of sea ice by late summer for the first time in about 2 million years.[674] Coral reefs will be at risk for almost complete (99 percent) losses with 1 °C (1.8 °F) of additional warming from today (2 °C or 3.6 °F since preindustrial). At this temperature, between 8 and 18 percent of animal, plant, and insect species could lose over half of the geographic area with suitable climate for their survival, and 7 to 10 percent of rangeland livestock would be projected to be lost.[675] The IPCC similarly found that climate change has caused substantial damages and increasingly irreversible losses in terrestrial, freshwater, and coastal and open ocean marine ecosystems.[676]

Scientific assessments also demonstrate that even modest additional amounts of warming may lead to a climate different from anything humans have ever experienced. Every additional increment of temperature comes with consequences. For example, the half-degree of warming from 1.5 to 2 °C (0.9 °F of warming from 2.7 °F to 3.6 °F) above preindustrial temperatures is projected on a global scale to expose 420 million more people to frequent extreme heatwaves, and 62 million more people to frequent exceptional heatwaves (where heatwaves are defined based on a heat wave magnitude index which takes into account duration and intensity—using this index, the 2003 French heat wave that led to almost 15,000 deaths would be classified as an ''extreme heatwave'' and the 2010 Russian heatwave which led to thousands of deaths and extensive wildfires would be classified as ''exceptional''). Every additional degree will intensify extreme precipitation events by about 7 percent. The peak winds of the most intense tropical cyclones (hurricanes) are projected to increase with warming. In addition to a higher intensity, the IPCC found that precipitation and frequency of rapid intensification of these storms has already increased, while the movement speed has decreased, and elevated sea levels have increased coastal flooding, all of which make these tropical cyclones more damaging.[677]

The NCA4 recognized that climate change can increase risks to national security, both through direct impacts on military infrastructure, but also by affecting factors such as food and water availability that can exacerbate conflict outside U.S. borders. Droughts, floods, storm surges, wildfires, and other extreme events stress nations and people through loss of life, displacement of populations, and impacts on livelihoods.[678] Risks to food security would increase from ''medium'' to ''high'' for several lower income regions in the Sahel, southern Africa, the Mediterranean, central Europe, and the Amazon. In addition to food security issues, this temperature increase would have implications for human health in terms of increasing ozone pollution, heatwaves, and vector-borne diseases (for example, expanding the range of the mosquitoes which carry dengue fever, chikungunya, yellow fever, and the Zika virus; or the ticks that carry Lyme disease or Rocky Mountain Spotted Fever).[679]

The NCA4 also evaluated a number of impacts specific to the United States. Severe drought and outbreaks of insects like the mountain pine beetle have killed hundreds of millions of trees in the western United States. Wildfires have burned more than 3.7 million acres in 14 of the 17 years between 2000 and 2016, and Federal wildfire suppression costs were about a billion dollars annually.[680] The National Interagency Fire Center has documented U.S. wildfires since 1983; the 10 years with the largest acreage burned have all occurred since 2004.[681] Wildfire smoke degrades air quality, increasing health

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[667] IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Pe´an, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press.

[668] *Ibid.*

[669] *Ibid.*

[670] USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

[671] IPCC, 2018: Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Portner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Pe´an, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].

[672] These are drought measures based on soil moisture.

[673] IPCC, 2021.

[674] USGCRP, 2021.

[675] IPCC, 2018.

[676] IPCC, 2022: Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.

[677] IPCC, 2021.

[678] USGCRP, 2018.

[679] IPCC, 2018.

[680] USGCRP, 2018.

[681] NIFC (National Interagency Fire Center). 2022. Total wildland fires and acres (1983–2020). Accessed November 2022. *https://www.nifc.gov/sites/default/files/document-media/TotalFires.pdf.*

risks. More frequent and severe wildfires due to climate change would further diminish air quality, increase incidences of respiratory illness, impair visibility, and disrupt outdoor activities, sometimes thousands of miles from the location of the fire.[682]

While GHGs collectively are not the only factor that controls climate, it is illustrative that 3 million years ago (the last time CO_2 concentrations were this high) Greenland was not yet completely covered by ice and still supported forests, while 23 million years ago (the last time concentrations were above 450 ppm) the West Antarctic ice sheet was not yet developed, indicating the possibility that high GHG concentrations could lead to a world that looks very different from today and from the conditions in which human civilization has developed. If the Greenland and Antarctic ice sheets were to melt substantially, sea levels would rise dramatically—the IPCC estimated that during the next 2,000 years, sea level will rise by 7 to 10 feet even if warming is limited to 1.5 °C (2.7 °F), from 7 to 20 feet if limited to 2 °C (3.6 °F), and by 60 to 70 feet if warming is allowed to reach 5 °C (9 °F) above preindustrial levels.[683] For context, almost all of the city of Miami is less than 25 feet above sea level, and the NCA4 stated that 13 million Americans would be at risk of migration due to 6 feet of sea level rise. Meanwhile, sea level rise has amplified coastal flooding and erosion impacts, requiring the installation of costly pump stations, flooding streets, and increasing storm surge damages. Tens of billions of dollars of U.S. real estate could be below sea level by 2050 under some scenarios. Increased frequency and duration of drought will reduce agricultural productivity in some regions, accelerate depletion of water supplies for irrigation, and expand the distribution and incidence of pests and diseases for crops and livestock.

Transportation is the largest U.S. source of GHG emissions, representing 27 percent of total GHG emissions. Within the transportation sector, heavy-duty vehicles are the second largest contributor to GHG emissions and are responsible for 25 percent of GHG emissions in the sector. The reduction in GHG emissions from the standards in this proposal, quantified in Section V of this preamble, would contribute toward the goal of holding the increase in the global average temperature to well below 2 °C above pre-industrial levels, and subsequently reduce the probability of severe climate change-related impacts including heat waves, drought, sea level rise, extreme climate and weather events, coastal flooding, and wildfires.[684] Section VI.D.1 of this preamble discusses impacts of GHG emissions on individuals living in socially and economically vulnerable communities. While EPA did not conduct modeling to specifically quantify changes in climate impacts resulting from this rule in terms of avoided temperature change or sea-level rise, we did quantify climate benefits by monetizing the emission reductions through the application of the social cost of greenhouse gases (SC–GHGs), as described in Section VII.A of this preamble.

B. Health and Environmental Effects Associated With Exposure to Non-GHG Pollutants

The non-GHG emissions that would be impacted by the proposed rule contribute, directly or via secondary formation, to concentrations of pollutants in the air which affect human and environmental health. These pollutants include particulate matter, ozone, nitrogen oxides, sulfur oxides, carbon monoxide and air toxics.

1. Background on Criteria and Air Toxics Pollutants Impacted by This Proposal

i. Particulate Matter

Particulate matter (PM) is a complex mixture of solid particles and liquid droplets distributed among numerous atmospheric gases which interact with solid and liquid phases. Particles in the atmosphere range in size from less than 0.01 to more than 10 micrometers (μm) in diameter.[685] Atmospheric particles can be grouped into several classes according to their aerodynamic diameter and physical sizes. Generally, the three broad classes of particles include ultrafine particles (UFPs, generally considered as particles with a diameter less than or equal to 0.1 μm [typically based on physical size, thermal diffusivity, or electrical mobility]), ''fine'' particles ($PM_{2.5}$; particles with a nominal mean aerodynamic diameter less than or equal to 2.5 μm), and ''thoracic'' particles (PM_{10}; particles with a nominal mean aerodynamic diameter less than or equal to 10 μm). Particles that fall within the size range between $PM_{2.5}$ and PM_{10}, are referred to as ''thoracic coarse particles'' ($PM_{10-2.5}$, particles with a nominal mean aerodynamic diameter greater than 2.5 μm and less than or equal to 10 μm). EPA currently has NAAQS for $PM_{2.5}$ and PM_{10}.[686]

Most particles are found in the lower troposphere, where they can have residence times ranging from a few hours to weeks. Particles are removed from the atmosphere by wet deposition, such as when they are carried by rain or snow, or by dry deposition, when particles settle out of suspension due to gravity. Atmospheric lifetimes are generally longest for $PM_{2.5}$, which often remains in the atmosphere for days to weeks before being removed by wet or dry deposition.[687] In contrast, atmospheric lifetimes for UFP and $PM_{10-2.5}$ are shorter. Within hours, UFP can undergo coagulation and condensation that lead to formation of larger particles in the accumulation mode or can be removed from the atmosphere by evaporation, deposition, or reactions with other atmospheric components. $PM_{10-2.5}$ are also generally removed from the atmosphere within hours, through wet or dry deposition.[688]

Particulate matter consists of both primary and secondary particles. Primary particles are emitted directly from sources, such as combustion-related activities (*e.g.,* industrial activities, motor vehicle operation, biomass burning), while secondary particles are formed through atmospheric chemical reactions of gaseous precursors (*e.g.,* sulfur oxides (SO_X), nitrogen oxides (NO_X) and volatile organic compounds (VOCs)).

ii. Ozone

Ground-level ozone pollution forms in areas with high concentrations of ambient NO_X and VOCs when solar radiation is strong. Major U.S. sources of NO_X are highway and nonroad motor vehicles, engines, power plants and other industrial sources, with natural sources, such as soil, vegetation, and lightning, serving as smaller sources.

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[682] USGCRP, 2018.

[683] IPCC, 2021.

[684] Paris Agreement FCCC/CP/2015/10/Add.1 *https://unfccc.int/documents/9097.*

[685] U.S. EPA. Policy Assessment (PA) for the Review of the National Ambient Air Quality Standards for Particulate Matter (Final Report, 2020). U.S. Environmental Protection Agency, Washington, DC, EPA/452/R–20/002, 2020.

[686] Regulatory definitions of PM size fractions, and information on reference and equivalent methods for measuring PM in ambient air, are provided in 40 CFR parts 50, 53, and 58. With regard to NAAQS which provide protection against health and welfare effects, the 24-hour PM_{10} standard provides protection against effects associated with short-term exposure to thoracic coarse particles (*i.e.,* $PM_{10-2.5}$).

[687] U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019. Table 2–1.

[688] U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019. Table 2–1.

Vegetation is the dominant source of VOCs in the United States. Volatile consumer and commercial products, such as propellants and solvents, highway and nonroad vehicles, engines, fires, and industrial sources also contribute to the atmospheric burden of VOCs at ground-level.

The processes underlying ozone formation, transport, and accumulation are complex. Ground-level ozone is produced and destroyed by an interwoven network of free radical reactions involving the hydroxyl radical (OH), NO, NO_2, and complex reaction intermediates derived from VOCs. Many of these reactions are sensitive to temperature and available sunlight. High ozone events most often occur when ambient temperatures and sunlight intensities remain high for several days under stagnant conditions. Ozone and its precursors can also be transported hundreds of miles downwind, which can lead to elevated ozone levels in areas with otherwise low VOC or NO_X emissions. As an air mass moves and is exposed to changing ambient concentrations of NO_X and VOCs, the ozone photochemical regime (relative sensitivity of ozone formation to NO_X and VOC emissions) can change.

When ambient VOC concentrations are high, comparatively small amounts of NO_X catalyze rapid ozone formation. Without available NO_X, ground-level ozone production is severely limited, and VOC reductions would have little impact on ozone concentrations. Photochemistry under these conditions is said to be ''NO_X-limited.'' When NO_X levels are sufficiently high, faster NO_2 oxidation consumes more radicals, dampening ozone production. Under these ''VOC-limited'' conditions (also referred to as '' NO_X-saturated'' conditions), VOC reductions are effective in reducing ozone, and NO_X can react directly with ozone, resulting in suppressed ozone concentrations near NO_X emission sources. Under these NO_X-saturated conditions, NO_X reductions can increase local ozone under certain circumstances, but overall ozone production (considering downwind formation) decreases and, even in VOC-limited areas, NO_X reductions are not expected to increase ozone levels if the NO_X reductions are sufficiently large—large enough for photochemistry to become NO_X-limited.

iii. Nitrogen Oxides

Oxides of nitrogen (NO_X) refers to nitric oxide (NO) and nitrogen dioxide (NO_2). Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature. NO_X is a major contributor to secondary $PM_{2.5}$ formation, and NO_X along with VOCs are the two major precursors of ozone.

iv. Sulfur Oxides

Sulfur dioxide (SO_2), a member of the sulfur oxide (SO_X) family of gases, is formed from burning fuels containing sulfur (*e.g.,* coal or oil), extracting gasoline from oil, or extracting metals from ore. SO_2 and its gas phase oxidation products can dissolve in water droplets and further oxidize to form sulfuric acid which reacts with ammonia to form sulfates, which are important components of ambient PM.

v. Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless gas emitted from combustion processes. Nationally, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources.[689]

vi. Diesel Exhaust

Diesel exhaust is a complex mixture composed of particulate matter, carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, nitrogen compounds, sulfur compounds and numerous low-molecular-weight hydrocarbons. A number of these gaseous hydrocarbon components are individually known to be toxic, including aldehydes, benzene and 1,3-butadiene. The diesel particulate matter present in diesel exhaust consists mostly of fine particles (less than 2.5 µm), of which a significant fraction is ultrafine particles (less than 0.1 µm). These particles have a large surface area which makes them an excellent medium for adsorbing organics, and their small size makes them highly respirable. Many of the organic compounds present in the gases and on the particles, such as polycyclic organic matter, are individually known to have mutagenic and carcinogenic properties.

Diesel exhaust varies significantly in chemical composition and particle sizes between different engine types (heavy-duty, light-duty), engine operating conditions (idle, acceleration, deceleration), and fuel formulations (high/low sulfur fuel). Also, there are emissions differences between on-road and nonroad engines because the nonroad engines are generally of older technology. After being emitted in the engine exhaust, diesel exhaust undergoes dilution as well as chemical and physical changes in the atmosphere. The lifetimes of the components present in diesel exhaust range from seconds to days.

vii. Air Toxics

The most recent available data indicate that millions of Americans live in areas where air toxics pose potential health concerns.[690] [691] The levels of air toxics to which people are exposed vary depending on where people live and work and the kinds of activities in which they engage, as discussed in detail in EPA's 2007 Mobile Source Air Toxics Rule.[692] According to EPA's Air Toxics Screening Assessment (AirToxScreen) for 2018, mobile sources were responsible for 40 percent of outdoor anthropogenic toxic emissions and were the largest contributor to national average cancer and noncancer risk from directly emitted pollutants.[693] [694] Mobile sources are also significant contributors to precursor emissions which react to form air toxics.[695] Formaldehyde is the largest contributor to cancer risk of all 71 pollutants quantitatively assessed in the 2018 AirToxScreen. Mobile sources were responsible for 26 percent of primary anthropogenic emissions of this pollutant in 2018 and are significant contributors to formaldehyde precursor emissions. Benzene is also a large contributor to cancer risk, and mobile sources account for about 60 percent of average exposure to ambient concentrations.

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[689] U.S. EPA, (2010). Integrated Science Assessment for Carbon Monoxide (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–09/019F, 2010. *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686.* See Section 2.1.

[690] Air toxics are pollutants known to cause or suspected of causing cancer or other serious health effects. Air toxics are also known as toxic air pollutants or hazardous air pollutants. *https://www.epa.gov/AirToxScreen/airtoxscreen-glossary-terms#air-toxics.*

[691] U.S. EPA (2022) Technical Support Document EPA Air Toxics Screening Assessment. 2017AirToxScreen TSD. *https://www.epa.gov/system/files/documents/2022-03/airtoxscreen_2017tsd.pdf.*

[692] U.S. Environmental Protection Agency (2007). Control of Hazardous Air Pollutants from Mobile Sources; Final Rule. 72 FR 8434, February 26, 2007.

[693] U.S. EPA. (2022) 2018 Air Toxics Screening Assessment. *https://www.epa.gov/AirToxScreen/2018-airtoxscreen-assessment-results.*

[694] AirToxScreen also includes estimates of risk attributable to background concentrations, which includes contributions from long-range transport, persistent air toxics, and natural sources; as well as secondary concentrations, where toxics are formed via secondary formation. Mobile sources substantially contribute to long-range transport and secondarily formed air toxics.

[695] Rich Cook, Sharon Phillips, Madeleine Strum, Alison Eyth & James Thurman (2020): Contribution of mobile sources to secondary formation of carbonyl compounds, Journal of the Air & Waste Management Association, DOI: 10.1080/10962247.2020.1813839.

2. Health Effects Associated With Exposure to Non-GHG Pollutants

Emissions sources impacted by this proposal emit pollutants that contribute to ambient concentrations of non-GHG pollutants. This section of the preamble discusses the health effects associated with exposure to these pollutants.

Additionally, because children have increased vulnerability and susceptibility for adverse health effects related to air pollution exposures, EPA's findings regarding adverse effects for children related to exposure to pollutants that are impacted by this rule are noted in this section. The increased vulnerability and susceptibility of children to air pollution exposures may arise because infants and children generally breathe more relative to their size than adults, and consequently they may be exposed to relatively higher amounts of air pollution.[696] Children also tend to breathe through their mouths more than adults, and their nasal passages are less effective at removing pollutants, which leads to greater lung deposition of some pollutants such as PM.[697] [698] Furthermore, air pollutants may pose health risks specific to children because children's bodies are still developing.[699] For example, during periods of rapid growth such as fetal development, infancy and puberty, their developing systems and organs may be more easily harmed.[700] [701] EPA produces the report titled ''America's Children and the Environment,'' which presents national trends on air pollution and other contaminants and environmental health of children.[702]

i. Particulate Matter

Scientific evidence spanning animal toxicological, controlled human exposure, and epidemiologic studies shows that exposure to ambient PM is associated with a broad range of health effects. These health effects are discussed in detail in the Integrated Science Assessment for Particulate Matter, which was finalized in December 2019 (2019 PM ISA), with a more targeted evaluation of studies published since the literature cutoff date of the 2019 PM ISA in the Supplement to the Integrated Science Assessment for PM (Supplement).[703] [704] The PM ISA characterizes the causal nature of relationships between PM exposure and broad health categories (*e.g.,* cardiovascular effects, respiratory effects, etc.) using a weight-of-evidence approach.[705] Within this characterization, the PM ISA summarizes the health effects evidence for short-term (*i.e.,* hours up to one month) and long-term (*i.e.,* one month to years) exposures to $PM_{2.5}$, $PM_{10-2.5}$, and ultrafine particles and concludes that exposures to ambient $PM_{2.5}$ are associated with a number of adverse health effects. The discussion in this Section VI.B.2.i highlights the PM ISA's conclusions and summarizes additional information from the Supplement where appropriate, pertaining to the health effects evidence for both short- and long-term PM exposures. Further discussion of PM-related health effects can also be found in the 2022 Policy Assessment for the review of the PM NAAQS.[706]

EPA has concluded that recent evidence in combination with evidence evaluated in the 2009 PM ISA supports a ''causal relationship'' between both long- and short-term exposures to $PM_{2.5}$ and premature mortality and cardiovascular effects and a ''likely to be causal relationship'' between long- and short-term $PM_{2.5}$ exposures and respiratory effects.[707] Additionally, recent experimental and epidemiologic studies provide evidence supporting a ''likely to be causal relationship'' between long-term $PM_{2.5}$ exposure and nervous system effects and between long-term $PM_{2.5}$ exposure and cancer. Because of remaining uncertainties and limitations in the evidence base, EPA determined a ''suggestive of, but not sufficient to infer, a causal relationship'' for long-term $PM_{2.5}$ exposure and reproductive and developmental effects (*i.e.,* male/female reproduction and fertility; pregnancy and birth outcomes), long- and short-term exposures and metabolic effects, and short-term exposure and nervous system effects.

As discussed extensively in the 2019 PM ISA and the Supplement, recent studies continue to support a ''causal relationship'' between short- and long-term $PM_{2.5}$ exposures and mortality.[708] [709] For short-term $PM_{2.5}$ exposure, multi-city studies, in combination with single- and multi-city studies evaluated in the 2009 PM ISA, provide evidence of consistent, positive associations across studies conducted in different geographic locations, populations with different demographic characteristics, and studies using different exposure assignment techniques. Additionally, the consistent and coherent evidence across scientific disciplines for cardiovascular morbidity, particularly ischemic events and heart failure, and to a lesser degree for respiratory morbidity, including exacerbations of chronic obstructive pulmonary disease (COPD) and asthma,

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[696] EPA (2009) Metabolically-derived ventilation rates: A revised approach based upon oxygen consumption rates. Washington, DC: Office of Research and Development. EPA/600/R–06/129F. *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=202543.*

[697] U.S. EPA Integrated Science Assessment for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019. Chapter 4 ''Overall Conclusions'' p. 4–1.

[698] Foos, B.; Marty, M.; Schwartz, J.; Bennet, W.; Moya, J.; Jarabek, A.M.; Salmon, A.G. (2008) Focusing on children's inhalation dosimetry and health effects for risk assessment: An introduction. J Toxicol Environ Health 71A: 149–165.

[699] Children's environmental health includes conception, infancy, early childhood and through adolescence until 21 years of age as described in the EPA Memorandum: Issuance of EPA's 2021 Policy on Children's Health. October 5, 2021. Available at *https://www.epa.gov/system/files/documents/2021-10/2021-policy-on-childrens-health.pdf.*

[700] EPA (2006) A Framework for Assessing Health Risks of Environmental Exposures to Children. EPA, Washington, DC, EPA/600/R–05/093F, 2006.

[701] U.S. Environmental Protection Agency. (2005). Supplemental guidance for assessing susceptibility from early-life exposure to carcinogens. Washington, DC: Risk Assessment Forum. EPA/630/R–03/003F. *https://www3.epa.gov/airtoxics/childrens_supplement_final.pdf.*

[702] U.S. EPA. America's Children and the Environment. Available at: *https://www.epa.gov/americaschildrenenvironment.*

[703] U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019.

[704] U.S. EPA. Supplement to the 2019 Integrated Science Assessment for Particulate Matter (Final Report, 2022). U.S. Environmental Protection Agency, Washington, DC, EPA/635/R–22/028, 2022.

[705] The causal framework draws upon the assessment and integration of evidence from across scientific disciplines, spanning atmospheric chemistry, exposure, dosimetry and health effects studies (*i.e.,* epidemiologic, controlled human exposure, and animal toxicological studies), and assess the related uncertainties and limitations that ultimately influence our understanding of the evidence. This framework employs a five-level hierarchy that classifies the overall weight-of-evidence with respect to the causal nature of relationships between criteria pollutant exposures and health and welfare effects using the following categorizations: causal relationship; likely to be causal relationship; suggestive of, but not sufficient to infer, a causal relationship; inadequate to infer the presence or absence of a causal relationship; and not likely to be a causal relationship (U.S. EPA. (2019). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, Section P. 3.2.3).

[706] U.S. EPA. Policy Assessment (PA) for the Reconsideration of the National Ambient Air Quality Standards for Particulate Matter (Final Report, 2022). U.S. Environmental Protection Agency, Washington, DC, EPA–452/R–22–004, 2022.

[707] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–08/139F.

[708] U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019.

[709] U.S. EPA. Supplement to the 2019 Integrated Science Assessment for Particulate Matter (Final Report, 2022). U.S. Environmental Protection Agency, Washington, DC, EPA/635/R–22/028, 2022.

provide biological plausibility for cause-specific mortality and ultimately total mortality. Recent epidemiologic studies evaluated in the Supplement, including studies that employed alternative methods for confounder control, provide additional support to the evidence base that contributed to the 2019 PM ISA conclusion for short-term $PM_{2.5}$ exposure and mortality.

The 2019 PM ISA concluded a ''causal relationship'' between long-term $PM_{2.5}$ exposure and mortality. In addition to reanalyses and extensions of the American Cancer Society (ACS) and Harvard Six Cities (HSC) cohorts, multiple new cohort studies conducted in the United States and Canada consisting of people employed in a specific job (*e.g.,* teacher, nurse), and that apply different exposure assignment techniques, provide evidence of positive associations between long-term $PM_{2.5}$ exposure and mortality. Biological plausibility for mortality due to long-term $PM_{2.5}$ exposure is provided by the coherence of effects across scientific disciplines for cardiovascular morbidity, particularly for coronary heart disease, stroke, and atherosclerosis, and for respiratory morbidity, particularly for the development of COPD. Additionally, recent studies provide evidence indicating that as long-term $PM_{2.5}$ concentrations decrease there is an increase in life expectancy. Recent cohort studies evaluated in the Supplement, as well as epidemiologic studies that conducted accountability analyses or employed alternative methods for confounder controls, support and extend the evidence base that contributed to the 2019 PM ISA conclusion for long-term $PM_{2.5}$ exposure and mortality.

A large body of studies examining both short- and long-term $PM_{2.5}$ exposure and cardiovascular effects builds on the evidence base evaluated in the 2009 PM ISA. The strongest evidence for cardiovascular effects in response to short-term $PM_{2.5}$ exposures is for ischemic heart disease and heart failure. The evidence for short-term $PM_{2.5}$ exposure and cardiovascular effects is coherent across scientific disciplines and supports a continuum of effects ranging from subtle changes in indicators of cardiovascular health to serious clinical events, such as increased emergency department visits and hospital admissions due to cardiovascular disease and cardiovascular mortality. For long-term $PM_{2.5}$ exposure, there is strong and consistent epidemiologic evidence of a relationship with cardiovascular mortality. This evidence is supported by epidemiologic and animal toxicological studies demonstrating a range of cardiovascular effects including coronary heart disease, stroke, impaired heart function, and subclinical markers (*e.g.,* coronary artery calcification, atherosclerotic plaque progression), which collectively provide coherence and biological plausibility. Recent epidemiologic studies evaluated in the Supplement, as well as studies that conducted accountability analyses or employed alternative methods for confounder control, support and extend the evidence base that contributed to the 2019 PM ISA conclusion for both short- and long-term $PM_{2.5}$ exposure and cardiovascular effects.

Studies evaluated in the 2019 PM ISA continue to provide evidence of a ''likely to be causal relationship'' between both short- and long-term $PM_{2.5}$ exposure and respiratory effects. Epidemiologic studies provide consistent evidence of a relationship between short-term $PM_{2.5}$ exposure and asthma exacerbation in children and COPD exacerbation in adults as indicated by increases in emergency department visits and hospital admissions, which is supported by animal toxicological studies indicating worsening allergic airways disease and subclinical effects related to COPD. Epidemiologic studies also provide evidence of a relationship between short-term $PM_{2.5}$ exposure and respiratory mortality. However, there is inconsistent evidence of respiratory effects, specifically lung function declines and pulmonary inflammation, in controlled human exposure studies. With respect to long term $PM_{2.5}$ exposure, epidemiologic studies conducted in the United States and abroad provide evidence of a relationship with respiratory effects, including consistent changes in lung function and lung function growth rate, increased asthma incidence, asthma prevalence, and wheeze in children; acceleration of lung function decline in adults; and respiratory mortality. The epidemiologic evidence is supported by animal toxicological studies, which provide coherence and biological plausibility for a range of effects including impaired lung development, decrements in lung function growth, and asthma development.

Since the 2009 PM ISA, a growing body of scientific evidence examined the relationship between long-term $PM_{2.5}$ exposure and nervous system effects, resulting for the first time in a causality determination for this health effects category of a ''likely to be causal relationship.'' The strongest evidence for effects on the nervous system comes from epidemiologic studies that consistently report cognitive decrements and reductions in brain volume in adults. The effects observed in epidemiologic studies in adults are supported by animal toxicological studies demonstrating effects on the brain of adult animals including inflammation, morphologic changes, and neurodegeneration of specific regions of the brain. There is more limited evidence for neurodevelopmental effects in children, with some studies reporting positive associations with autism spectrum disorder and others providing limited evidence of an association with cognitive function. While there is some evidence from animal toxicological studies indicating effects on the brain (*i.e.,* inflammatory and morphological changes) to support a biologically plausible pathway for neurodevelopmental effects, epidemiologic studies are limited due to their lack of control for potential confounding by copollutants, the small number of studies conducted, and uncertainty regarding critical exposure windows.

Building off the decades of research demonstrating mutagenicity, DNA damage, and other endpoints related to genotoxicity due to whole PM exposures, recent experimental and epidemiologic studies focusing specifically on $PM_{2.5}$ provide evidence of a relationship between long-term $PM_{2.5}$ exposure and cancer. Epidemiologic studies examining long-term $PM_{2.5}$ exposure and lung cancer incidence and mortality provide evidence of generally positive associations in cohort studies spanning different populations, locations, and exposure assignment techniques. Additionally, there is evidence of positive associations with lung cancer incidence and mortality in analyses limited to never smokers. The epidemiologic evidence is supported by both experimental and epidemiologic evidence of genotoxicity, epigenetic effects, carcinogenic potential, and that $PM_{2.5}$ exhibits several characteristics of carcinogens, which collectively provides biological plausibility for cancer development and resulted in the conclusion of a ''likely to be causal relationship.''

For the additional health effects categories evaluated for $PM_{2.5}$ in the 2019 PM ISA, experimental and epidemiologic studies provide limited and/or inconsistent evidence of a relationship with $PM_{2.5}$ exposure. As a result, the 2019 PM ISA concluded that the evidence is ''suggestive of, but not sufficient to infer a causal relationship'' for short-term $PM_{2.5}$ exposure and metabolic effects and nervous system effects and for long-term $PM_{2.5}$ exposures and metabolic effects as well as reproductive and developmental effects.

In addition to evaluating the health effects attributed to short- and long-term exposure to $PM_{2.5}$, the 2019 PM ISA also conducted an extensive evaluation as to whether specific components or sources of $PM_{2.5}$ are more strongly related with health effects than $PM_{2.5}$ mass. An evaluation of those studies resulted in the 2019 PM ISA concluding that ''many $PM_{2.5}$ components and sources are associated with many health effects, and the evidence does not indicate that any one source or component is consistently more strongly related to health effects than $PM_{2.5}$ mass.'' [710]

For both $PM_{10-2.5}$ and UFPs, for all health effects categories evaluated, the 2019 PM ISA concluded that the evidence was ''suggestive of, but not sufficient to infer, a causal relationship'' or ''inadequate to determine the presence or absence of a causal relationship.'' For $PM_{10-2.5}$, although a Federal Reference Method (FRM) was instituted in 2011 to measure $PM_{10-2.5}$ concentrations nationally, the causality determinations reflect that the same uncertainty identified in the 2009 PM ISA with respect to the method used to estimate $PM_{10-2.5}$ concentrations in epidemiologic studies persists. Specifically, across epidemiologic studies, different approaches are used to estimate $PM_{10-2.5}$ concentrations (*e.g.,* direct measurement of $PM_{10-2.5}$, difference between PM_{10} and $PM_{2.5}$ concentrations), and it remains unclear how well correlated $PM_{10-2.5}$ concentrations are both spatially and temporally across the different methods used.

For UFPs, which have often been defined as particles less than 0.1 µm, the uncertainty in the evidence for the health effect categories evaluated across experimental and epidemiologic studies reflects the inconsistency in the exposure metric used (*i.e.,* particle number concentration, surface area concentration, mass concentration) as well as the size fractions examined. In epidemiologic studies the size fraction examined can vary depending on the monitor used and exposure metric, with some studies examining number count over the entire particle size range, while experimental studies that use a particle concentrator often examine particles up to 0.3 µm. Additionally, due to the lack of a monitoring network, there is limited information on the spatial and temporal variability of UFPs within the United States, as well as population exposures to UFPs, which adds uncertainty to epidemiologic study results.

The 2019 PM ISA cites extensive evidence indicating that ''both the general population as well as specific populations and life stages are at risk for $PM_{2.5}$-related health effects.'' [711] For example, in support of its ''causal'' and ''likely to be causal'' determinations, the ISA cites substantial evidence for (1) PM-related mortality and cardiovascular effects in older adults; (2) PM-related cardiovascular effects in people with pre-existing cardiovascular disease; (3) PM-related respiratory effects in people with pre-existing respiratory disease, particularly asthma exacerbations in children; and (4) PM-related impairments in lung function growth and asthma development in children. The ISA additionally notes that stratified analyses (*i.e.,* analyses that directly compare PM-related health effects across groups) provide strong evidence for racial and ethnic differences in $PM_{2.5}$ exposures and in the risk of $PM_{2.5}$-related health effects, specifically within Hispanic and non-Hispanic Black populations, with some evidence of increased risk for populations of low socioeconomic status. Recent studies evaluated in the Supplement support the conclusion of the 2019 PM ISA with respect to disparities in both $PM_{2.5}$ exposure and health risk by race and ethnicity and provide additional support for disparities for populations of lower socioeconomic status.[712] Additionally, evidence spanning epidemiologic studies that conducted stratified analyses, experimental studies focusing on animal models of disease or individuals with pre-existing disease, dosimetry studies, as well as studies focusing on differential exposure suggest that populations with pre-existing cardiovascular or respiratory disease, populations that are overweight or obese, populations that have particular genetic variants, and current/former smokers could be at increased risk for adverse $PM_{2.5}$-related health effects. The 2022 Policy Assessment for the review of the PM NAAQS also highlights that factors that may contribute to increased risk of $PM_{2.5}$-related health effects include lifestage (children and older adults), pre-existing diseases (cardiovascular disease and respiratory disease), race/ethnicity, and socioeconomic status.[713]

ii. Ozone

This section provides a summary of the health effects associated with exposure to ambient concentrations of ozone.[714] The information in this section is based on the information and conclusions in the April 2020 Integrated Science Assessment for Ozone (Ozone ISA).[715] The Ozone ISA concludes that human exposures to ambient concentrations of ozone are associated with a number of adverse health effects and characterizes the weight of evidence for these health effects.[716] The discussion in this Section VI.B.2.ii highlights the Ozone ISA's conclusions pertaining to health effects associated with both short-term and long-term periods of exposure to ozone.

For short-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including lung function decrements, pulmonary inflammation, exacerbation of asthma, respiratory-related hospital admissions, and mortality, are causally associated with ozone exposure. It also concludes that metabolic effects, including metabolic syndrome (*i.e.,* changes in insulin or glucose levels, cholesterol levels, obesity and blood pressure) and complications due to diabetes are likely to be causally associated with short-term exposure to ozone and that evidence is suggestive of a causal relationship between cardiovascular effects, central nervous system effects

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[710] U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019.

[711] U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019.

[712] U.S. EPA. Supplement to the 2019 Integrated Science Assessment for Particulate Matter (Final Report, 2022). U.S. Environmental Protection Agency, Washington, DC, EPA/635/R–22/028, 2022.

[713] U.S. EPA. Policy Assessment (PA) for the Reconsideration of the National Ambient Air Quality Standards for Particulate Matter (Final Report, 2022). U.S. Environmental Protection Agency, Washington, DC, EPA–452/R–22–004, 2022, p. 3–53.

[714] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notably different ozone concentrations. Also, the amount of ozone delivered to the lung is influenced not only by the ambient concentrations but also by the breathing route and rate.

[715] U.S. EPA. Integrated Science Assessment (ISA) for Ozone and Related Photochemical Oxidants (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–20/012, 2020.

[716] The ISA evaluates evidence and draws conclusions on the causal relationship between relevant pollutant exposures and health effects, assigning one of five ''weight of evidence'' determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For more information on these levels of evidence, please refer to Table II in the Preamble of the ISA.

and total mortality and short-term exposure to ozone.

For long-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including new onset asthma, pulmonary inflammation and injury, are likely to be causally related with ozone exposure. The Ozone ISA characterizes the evidence as suggestive of a causal relationship for associations between long-term ozone exposure and cardiovascular effects, metabolic effects, reproductive and developmental effects, central nervous system effects and total mortality. The evidence is inadequate to infer a causal relationship between chronic ozone exposure and increased risk of cancer.

Finally, interindividual variation in human responses to ozone exposure can result in some groups being at increased risk for detrimental effects in response to exposure. In addition, some groups are at increased risk of exposure due to their activities, such as outdoor workers and children. The Ozone ISA identified several groups that are at increased risk for ozone-related health effects. These groups are people with asthma, children and older adults, individuals with reduced intake of certain nutrients (*i.e.,* Vitamins C and E), outdoor workers, and individuals having certain genetic variants related to oxidative metabolism or inflammation. Ozone exposure during childhood can have lasting effects through adulthood. Such effects include altered function of the respiratory and immune systems. Children absorb higher doses (normalized to lung surface area) of ambient ozone, compared to adults, due to their increased time spent outdoors, higher ventilation rates relative to body size, and a tendency to breathe a greater fraction of air through the mouth. Children also have a higher asthma prevalence compared to adults. Recent epidemiologic studies provide generally consistent evidence that long-term ozone exposure is associated with the development of asthma in children. Studies comparing age groups reported higher magnitude associations for short-term ozone exposure and respiratory hospital admissions and emergency room visits among children than among adults. Panel studies also provide support for experimental studies with consistent associations between short-term ozone exposure and lung function and pulmonary inflammation in healthy children. Additional children's vulnerability and susceptibility factors are listed in Section XI.G of the Preamble.

iii. Nitrogen Oxides

The most recent review of the health effects of oxides of nitrogen completed by EPA can be found in the 2016 Integrated Science Assessment for Oxides of Nitrogen—Health Criteria (Oxides of Nitrogen ISA).[717] The primary source of NO_2 is motor vehicle emissions, and ambient NO_2 concentrations tend to be highly correlated with other traffic-related pollutants. Thus, a key issue in characterizing the causality of NO_2-health effect relationships consists of evaluating the extent to which studies supported an effect of NO_2 that is independent of other traffic-related pollutants. EPA concluded that the findings for asthma exacerbation integrated from epidemiologic and controlled human exposure studies provided evidence that is sufficient to infer a causal relationship between respiratory effects and short-term NO_2 exposure. The strongest evidence supporting an independent effect of NO_2 exposure comes from controlled human exposure studies demonstrating increased airway responsiveness in individuals with asthma following ambient-relevant NO_2 exposures. The coherence of this evidence with epidemiologic findings for asthma hospital admissions and ED visits as well as lung function decrements and increased pulmonary inflammation in children with asthma describe a plausible pathway by which NO_2 exposure can cause an asthma exacerbation. The 2016 ISA for Oxides of Nitrogen also concluded that there is likely to be a causal relationship between long-term NO_2 exposure and respiratory effects. This conclusion is based on new epidemiologic evidence for associations of NO_2 with asthma development in children combined with biological plausibility from experimental studies.

In evaluating a broader range of health effects, the 2016 ISA for Oxides of Nitrogen concluded that evidence is ''suggestive of, but not sufficient to infer, a causal relationship'' between short-term NO_2 exposure and cardiovascular effects and mortality and between long-term NO_2 exposure and cardiovascular effects and diabetes, birth outcomes, and cancer. In addition, the scientific evidence is inadequate (insufficient consistency of epidemiologic and toxicological evidence) to infer a causal relationship for long-term NO_2 exposure with fertility, reproduction, and pregnancy, as well as with postnatal development. A key uncertainty in understanding the relationship between these non-respiratory health effects and short- or long-term exposure to NO_2 is co-pollutant confounding, particularly by other roadway pollutants. The available evidence for non-respiratory health effects does not adequately address whether NO_2 has an independent effect or whether it primarily represents effects related to other or a mixture of traffic-related pollutants.

The 2016 ISA for Oxides of Nitrogen concluded that people with asthma, children, and older adults are at increased risk for NO_2-related health effects. In these groups and lifestages, NO_2 is consistently related to larger effects on outcomes related to asthma exacerbation, for which there is confidence in the relationship with NO_2 exposure.

iv. Sulfur Oxides

This section provides an overview of the health effects associated with SO_2. Additional information on the health effects of SO_2 can be found in the 2017 Integrated Science Assessment for Sulfur Oxides—Health Criteria (SO_X ISA).[718] Following an extensive evaluation of health evidence from animal toxicological, controlled human exposure, and epidemiologic studies, the EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. People with asthma are more sensitive to the effects of SO_2, likely resulting from preexisting inflammation associated with this disease. In addition to those with asthma (both children and adults), there is suggestive evidence that all children and older adults may be at increased risk of SO_2-related health effects. In free-breathing laboratory studies involving controlled human exposures to SO_2, respiratory effects have consistently been observed following 5–10 min exposures at SO_2 concentrations ≥400 ppb in people with asthma engaged in moderate to heavy levels of exercise, with respiratory effects occurring at concentrations as low as 200 ppb in some individuals with asthma. A clear concentration-response relationship has been demonstrated in these studies following exposures to SO_2 at concentrations between 200 and 1000

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[717] U.S. EPA. Integrated Science Assessment for Oxides of Nitrogen—Health Criteria (2016 Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–15/068, 2016.

[718] U.S. EPA. Integrated Science Assessment (ISA) for Sulfur Oxides—Health Criteria (Final Report, Dec 2017). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–17/451, 2017.

ppb, both in terms of increasing severity of respiratory symptoms and decrements in lung function, as well as the percentage of individuals with asthma adversely affected. Epidemiologic studies have reported positive associations between short-term ambient SO_2 concentrations and hospital admissions and emergency department visits for asthma and for all respiratory causes, particularly among children and older adults (≥65 years). The studies provide supportive evidence for the causal relationship.

For long-term SO_2 exposure and respiratory effects, the EPA has concluded that the evidence is suggestive of a causal relationship. This conclusion is based on new epidemiologic evidence for positive associations between long-term SO_2 exposure and increases in asthma incidence among children, together with animal toxicological evidence that provides a pathophysiologic basis for the development of asthma. However, uncertainty remains regarding the influence of other pollutants on the observed associations with SO_2 because these epidemiologic studies have not examined the potential for co-pollutant confounding.

Consistent associations between short-term exposure to SO_2 and mortality have been observed in epidemiologic studies, with larger effect estimates reported for respiratory mortality than for cardiovascular mortality. While this finding is consistent with the demonstrated effects of SO_2 on respiratory morbidity, uncertainty remains with respect to the interpretation of these observed mortality associations due to potential confounding by various copollutants. Therefore, the EPA has concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality.

v. Carbon Monoxide

Information on the health effects of carbon monoxide (CO) can be found in the January 2010 Integrated Science Assessment for Carbon Monoxide (CO ISA).[719] The CO ISA presents conclusions regarding the presence of causal relationships between CO exposure and categories of adverse health effects.[720] This section provides a summary of the health effects associated with exposure to ambient concentrations of CO, along with the CO ISA conclusions.[721]

Controlled human exposure studies of subjects with coronary artery disease show a decrease in the time to onset of exercise-induced angina (chest pain) and electrocardiogram changes following CO exposure. In addition, epidemiologic studies observed associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease (including ischemic heart disease, myocardial infarction, and angina). Some epidemiologic evidence is also available for increased hospital admissions and emergency room visits for congestive heart failure and cardiovascular disease as a whole. The CO ISA concludes that a causal relationship is likely to exist between short-term exposures to CO and cardiovascular morbidity. It also concludes that available data are inadequate to conclude that a causal relationship exists between long-term exposures to CO and cardiovascular morbidity.

Animal studies show various neurological effects with in-utero CO exposure. Controlled human exposure studies report central nervous system and behavioral effects following low-level CO exposures, although the findings have not been consistent across all studies. The CO ISA concludes that the evidence is suggestive of a causal relationship with both short- and long-term exposure to CO and central nervous system effects.

A number of studies cited in the CO ISA have evaluated the role of CO exposure in birth outcomes such as preterm birth or cardiac birth defects. There is limited epidemiologic evidence of a CO-induced effect on preterm births and birth defects, with weak evidence for a decrease in birth weight. Animal toxicological studies have found perinatal CO exposure to affect birth weight, as well as other developmental outcomes. The CO ISA concludes that the evidence is suggestive of a causal relationship between long-term exposures to CO and developmental effects and birth outcomes.

Epidemiologic studies provide evidence of associations between short-term CO concentrations and respiratory morbidity such as changes in pulmonary function, respiratory symptoms, and hospital admissions. A limited number of epidemiologic studies considered copollutants such as ozone, SO_2, and PM in two-pollutant models and found that CO risk estimates were generally robust, although this limited evidence makes it difficult to disentangle effects attributed to CO itself from those of the larger complex air pollution mixture. Controlled human exposure studies have not extensively evaluated the effect of CO on respiratory morbidity. Animal studies at levels of 50–100 ppm CO show preliminary evidence of altered pulmonary vascular remodeling and oxidative injury. The CO ISA concludes that the evidence is suggestive of a causal relationship between short-term CO exposure and respiratory morbidity, and inadequate to conclude that a causal relationship exists between long-term exposure and respiratory morbidity.

Finally, the CO ISA concludes that the epidemiologic evidence is suggestive of a causal relationship between short-term concentrations of CO and mortality. Epidemiologic evidence suggests an association exists between short-term exposure to CO and mortality, but limited evidence is available to evaluate cause-specific mortality outcomes associated with CO exposure. In addition, the attenuation of CO risk estimates which was often observed in co-pollutant models contributes to the uncertainty as to whether CO is acting alone or as an indicator for other combustion-related pollutants. The CO ISA also concludes that there is not likely to be a causal relationship between relevant long-term exposures to CO and mortality.

vi. Diesel Exhaust

In EPA's 2002 Diesel Health Assessment Document (Diesel HAD), exposure to diesel exhaust was classified as likely to be carcinogenic to humans by inhalation from environmental exposures, in accordance with the revised draft 1996/1999 EPA cancer guidelines.[722] [723] A number of

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[719] U.S. EPA, (2010). Integrated Science Assessment for Carbon Monoxide (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–09/019F, 2010.

[720] The ISA evaluates the health evidence associated with different health effects, assigning one of five ''weight of evidence'' determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.6 of the ISA.

[721] Personal exposure includes contributions from many sources, and in many different environments. Total personal exposure to CO includes both ambient and non-ambient components; and both components may contribute to adverse health effects.

[722] U.S. EPA. (1999). Guidelines for Carcinogen Risk Assessment. Review Draft. NCEA–F–0644, July. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=54932.*

[723] U.S. EPA (2002). Health Assessment Document for Diesel Engine Exhaust. EPA/600/8–90/057F Office of research and Development, Washington DC. Retrieved on March 17, 2009 from *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=29060.* pp. 1–1 1–2.

other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the U.S. Department of Health and Human Services) made similar hazard classifications prior to 2002. EPA also concluded in the 2002 Diesel HAD that it was not possible to calculate a cancer unit risk for diesel exhaust due to limitations in the exposure data for the occupational groups or the absence of a dose-response relationship.

In the absence of a cancer unit risk, the Diesel HAD sought to provide additional insight into the significance of the diesel exhaust cancer hazard by estimating possible ranges of risk that might be present in the population. An exploratory analysis was used to characterize a range of possible lung cancer risk. The outcome was that environmental risks of cancer from long-term diesel exhaust exposures could plausibly range from as low as 10^{-5} to as high as 10^{-3}. Because of uncertainties, the analysis acknowledged that the risks could be lower than 10^{-5}, and a zero risk from diesel exhaust exposure could not be ruled out.

Noncancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern to EPA. EPA derived a diesel exhaust reference concentration (RfC) from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects. The RfC is 5 µg/m^3 for diesel exhaust measured as diesel particulate matter. This RfC does not consider allergenic effects such as those associated with asthma or immunologic or the potential for cardiac effects. There was emerging evidence in 2002, discussed in the Diesel HAD, that exposure to diesel exhaust can exacerbate these effects, but the exposure-response data were lacking at that time to derive an RfC based on these then-emerging considerations. The Diesel HAD states, ‘‘With [diesel particulate matter] being a ubiquitous component of ambient PM, there is an uncertainty about the adequacy of the existing [diesel exhaust] noncancer database to identify all of the pertinent [diesel exhaust]-caused noncancer health hazards.’’ The Diesel HAD also notes ‘‘that acute exposure to [diesel exhaust] has been associated with irritation of the eye, nose, and throat, respiratory symptoms (cough and phlegm), and neurophysiological symptoms such as headache, lightheadedness, nausea, vomiting, and numbness or tingling of the extremities.’’ The Diesel HAD notes that the cancer and noncancer hazard conclusions applied to the general use of diesel engines then on the market and as cleaner engines replace a substantial number of existing ones, the applicability of the conclusions would need to be reevaluated.

It is important to note that the Diesel HAD also briefly summarizes health effects associated with ambient PM and discusses EPA's then-annual $PM_{2.5}$ NAAQS of 15 µg/m^3.[724] There is a large and extensive body of human data showing a wide spectrum of adverse health effects associated with exposure to ambient PM, of which diesel exhaust is an important component. The $PM_{2.5}$ NAAQS is designed to provide protection from the noncancer health effects and premature mortality attributed to exposure to $PM_{2.5}$. The contribution of diesel PM to total ambient PM varies in different regions of the country and, also, within a region, from one area to another. The contribution can be high in near-roadway environments, for example, or in other locations where diesel engine use is concentrated.

Since 2002, several new studies have been published which continue to report increased lung cancer risk associated with occupational exposure to diesel exhaust from older engines. Of particular note since 2011 are three new epidemiology studies that have examined lung cancer in occupational populations, including truck drivers, underground nonmetal miners, and other diesel motor-related occupations. These studies reported increased risk of lung cancer related to exposure to diesel exhaust, with evidence of positive exposure-response relationships to varying degrees.[725] [726] [727] These newer studies (along with others that have appeared in the scientific literature) add to the evidence EPA evaluated in the 2002 Diesel HAD and further reinforce the concern that diesel exhaust exposure likely poses a lung cancer hazard. The findings from these newer studies do not necessarily apply to newer technology diesel engines (*i.e.,* heavy-duty highway engines from 2007 and later model years) since the newer engines have large reductions in the emission constituents compared to older technology diesel engines.

In light of the growing body of scientific literature evaluating the health effects of exposure to diesel exhaust, in June 2012 the World Health Organization's International Agency for Research on Cancer (IARC), a recognized international authority on the carcinogenic potential of chemicals and other agents, evaluated the full range of cancer-related health effects data for diesel engine exhaust. IARC concluded that diesel exhaust should be regarded as ‘‘carcinogenic to humans.’’ [728] This designation was an update from its 1988 evaluation that considered the evidence to be indicative of a ‘‘probable human carcinogen.’’

vii. Air Toxics

Heavy-duty engine emissions contribute to ambient levels of air toxics that are known or suspected human or animal carcinogens or that have noncancer health effects. These compounds include, but are not limited to, acetaldehyde, acrolein, benzene, 1,3-butadiene, ethylbenzene, formaldehyde, and naphthalene, which were all identified as national or regional health effects drivers or contributors in the 2018 AirToxScreen Assessment.[729] [730]

a. Acetaldehyde

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[731] The inhalation unit risk estimate (URE) in IRIS for acetaldehyde is 2.2 × 10–6 per µg/m3.[732]

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[724] See Section VI.B.i for discussion of the current $PM_{2.5}$ NAAQS standard, and *https://www.epa.gov/pm-pollution/national-ambient-air-quality-standards-naaqs-pm.*

[725] Garshick, Eric, Francine Laden, Jaime E. Hart, Mary E. Davis, Ellen A. Eisen, and Thomas J. Smith. 2012. Lung cancer and elemental carbon exposure in trucking industry workers. Environmental Health Perspectives 120(9): 1301–1306.

[726] Silverman, D.T., Samanic, C.M., Lubin, J.H., Blair, A.E., Stewart, P.A., Vermeulen, R., & Attfield, M.D. (2012). The diesel exhaust in miners study: a nested case–control study of lung cancer and diesel exhaust. Journal of the National Cancer Institute.

[727] Olsson, Ann C., et al. ‘‘Exposure to diesel motor exhaust and lung cancer risk in a pooled analysis from case-control studies in Europe and Canada.’’ American journal of respiratory and critical care medicine 183.7 (2011): 941–948.

[728] IARC [International Agency for Research on Cancer]. (2013). Diesel and gasoline engine exhausts and some nitroarenes. IARC Monographs Volume 105. Online at *http://monographs.iarc.fr/ENG/Monographs/vol105/index.php.*

[729] U.S. EPA (2022) Technical Support Document EPA Air Toxics Screening Assessment. 2017AirToxScreen TSD. *https://www.epa.gov/system/files/documents/2022-03/airtoxscreen_2017tsd.pdf.*

[730] U.S. EPA (2022) 2018 AirToxScreen Risk Drivers. *https://www.epa.gov/AirToxScreen/airtoxscreen-risk-drivers.*

[731] U.S. EPA (1991). Integrated Risk Information System File of Acetaldehyde. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at *https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=290.*

[732] U.S. EPA (1991). Integrated Risk Information System File of Acetaldehyde. This material is available electronically at *https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=290.*

Acetaldehyde is reasonably anticipated to be a human carcinogen by the NTP in the 14th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group 2B) by the IARC.[733] [734]

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[735] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[736] [737] Data from these studies were used by EPA to develop an inhalation reference concentration of 9 µg/m^3. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[738] Children, especially those with diagnosed asthma, may be more likely to show impaired pulmonary function and symptoms of asthma than are adults following exposure to acetaldehyde.[739]

b. Acrolein

EPA most recently evaluated the toxicological and health effects literature related to acrolein in 2003 and concluded that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans, and the animal data provided inadequate evidence of carcinogenicity.[740] In 2021, the IARC classified acrolein as probably carcinogenic to humans.[741]

Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein.[742] The agency has developed an RfC for acrolein of 0.02 µg/m3 and an RfD of 0.5 µg/kg-day.[743]

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure.[744] These data and additional studies regarding acute effects of human exposure to acrolein are summarized in EPA's 2003 IRIS Human Health Assessment for acrolein.[745] Studies in humans indicate that levels as low as 0.09 ppm (0.21 mg/m^3) for five minutes may elicit subjective complaints of eye irritation with increasing concentrations leading to more extensive eye, nose and respiratory symptoms. Acute exposures in animal studies report bronchial hyper-responsiveness. Based on animal data (more pronounced respiratory irritancy in mice with allergic airway disease in comparison to non-diseased mice [746]) and demonstration of similar effects in humans (*e.g.,* reduction in respiratory rate), individuals with compromised respiratory function (*e.g.,* emphysema, asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein. EPA does not currently have an acute reference concentration for acrolein. The available health effect reference values for acrolein have been summarized by EPA and include an ATSDR MRL for acute exposure to acrolein of 7 µg/m^3 for 1–14 days exposure and Reference Exposure Level (REL) values from the California Office of Environmental Health Hazard Assessment (OEHHA) for one-hour and 8-hour exposures of 2.5 µg/m^3 and 0.7 µg/m^3, respectively.[747]

c. Benzene

EPA's Integrated Risk Information System (IRIS) database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[748] [749] [750] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. EPA's IRIS documentation for benzene also lists a range of 2.2×10^{-6} to 7.8×10^{-6} per µg/m^3 as the unit risk estimate (URE) for benzene.[751] [752] The

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[733] NTP (National Toxicology Program). 2016. Report on Carcinogens, Fourteenth Edition.; Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service. *https://ntp.niehs.nih.gov/go/roc14.*

[734] International Agency for Research on Cancer (IARC). (1999). Re-evaluation of some organic chemicals, hydrazine, and hydrogen peroxide. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemical to Humans, Vol 71. Lyon, France.

[735] U.S. EPA (1991). Integrated Risk Information System File of Acetaldehyde. This material is available electronically at *https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=290.*

[736] U.S. EPA. (2003). Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at *https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=364.*

[737] Appleman, L.M., R.A. Woutersen, and V.J. Feron. (1982). Inhalation toxicity of acetaldehyde in rats. I. Acute and subacute studies. Toxicology. 23: 293–297.

[738] Myou, S.; Fujimura, M.; Nishi K.; Ohka, T.; and Matsuda, T. (1993). Aerosolized acetaldehyde induces histamine-mediated bronchoconstriction in asthmatics. Am. Rev. Respir.Dis.148(4 Pt 1): 940–943.

[739] California OEHHA, 2014. TSD for Noncancer RELs: Appendix D. Individual, Acute, 8-Hour, and Chronic Reference Exposure Level Summaries. December 2008 (updated July 2014). *https://oehha.ca.gov/media/downloads/crnr/appendixd1final.pdf.*

[740] U.S. EPA. (2003). Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at *https://iris.epa.gov/ChemicalLanding/&substance_nmbr=364.*

[741] International Agency for Research on Cancer (IARC). (2021). Monographs on the Identification of Carcinogenic Hazards to humans, Volume 128. Acrolein, Crotonaldehyde, and Arecoline, World Health Organization, Lyon, France.

[742] U.S. EPA. (2003). Integrated Risk Information System File of Acrolein. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at *http://www.epa.gov/iris/subst/0364.htm.*

[743] U.S. EPA. (2003). Integrated Risk Information System File of Acrolein. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at *https://iris.epa.gov/ChemicalLanding/&substance_nmbr=364.*

[744] U.S. EPA. (2003). Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R–03/003. p. 10. Available online at: *https://iris.epa.gov/static/pdfs/0364tr.pdf.*

[745] U.S. EPA. (2003). Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R–03/003. Available online at: *https://iris.epa.gov/static/pdfs/0364tr.pdf.*

[746] Morris JB, Symanowicz PT, Olsen JE, et al. (2003). Immediate sensory nerve-mediated respiratory responses to irritants in healthy and allergic airway-diseased mice. J Appl Physiol 94(4):1563–1571.

[747] U.S. EPA. (2009). Graphical Arrays of Chemical-Specific Health Effect Reference Values for Inhalation Exposures (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–09/061, 2009. *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=211003.*

[748] U.S. EPA. (2000). Integrated Risk Information System File for Benzene. This material is available electronically at: *https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=276.*

[749] International Agency for Research on Cancer. (1982). IARC monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29, Some industrial chemicals and dyestuffs, International Agency for Research on Cancer, World Health Organization, Lyon, France 1982.

[750] Irons, R.D.; Stillman, W.S.; Colagiovanni, D.B.; Henry, V.A. (1992). Synergistic action of the benzene metabolite hydroquinone on myelopoietic stimulating activity of granulocyte/macrophage colony-stimulating factor in vitro, Proc. Natl. Acad. Sci. 89:3691–3695.

[751] A unit risk estimate is defined as the increase in the lifetime risk of cancer of an individual who is exposed for a lifetime to 1 µg/m^3 benzene in air.

[752] U.S. EPA. (2000). Integrated Risk Information System File for Benzene. This material is available electronically at: *https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=276.*

International Agency for Research on Cancer (IARC) has determined that benzene is a human carcinogen, and the U.S. Department of Health and Human Services (DHHS) has characterized benzene as a known human carcinogen.[753] [754]

A number of adverse noncancer health effects, including blood disorders such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[755] [756] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[757] [758] EPA's inhalation reference concentration (RfC) for benzene is 30 $\mu g/m^3$. The RfC is based on suppressed absolute lymphocyte counts seen in humans under occupational exposure conditions. In addition, studies sponsored by the Health Effects Institute (HEI) provide evidence that biochemical responses occur at lower levels of benzene exposure than previously known.[759] [760] [761] [762] EPA's IRIS program has not yet evaluated these new data. EPA does not currently have an acute reference concentration for benzene. The Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Level (MRL) for acute inhalation exposure to benzene is 29 $\mu g/m^3$ for 1–14 days exposure.[763] [764]

There is limited information from two studies regarding an increased risk of adverse effects to children whose parents have been occupationally exposed to benzene.[765] [766] Data from animal studies have shown benzene exposures result in damage to the hematopoietic (blood cell formation) system during development.[767] [768] [769] Also, key changes related to the development of childhood leukemia occur in the developing fetus.[770] Several studies have reported that genetic changes related to eventual leukemia development occur before birth. For example, there is one study of genetic changes in twins who developed T cell leukemia at nine years of age.[771]

d. 1,3-Butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[772] [773] The IARC has determined that 1,3-butadiene is a human carcinogen, and the U.S. DHHS has characterized 1,3-butadiene as a known human carcinogen.[774] [775] [776] [777] There are numerous studies consistently demonstrating that 1,3-butadiene is metabolized into genotoxic metabolites by experimental animals and humans. The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown; however, the scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females may be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. The URE for 1,3-butadiene is 3×10^{-5} per $\mu g/m^3$.[778] 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[779] Based on this critical effect and the benchmark concentration methodology, an RfC for chronic health effects was

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[753] International Agency for Research on Cancer (IARC, 2018. Monographs on the evaluation of carcinogenic risks to humans, volume 120. World Health Organization—Lyon, France. *http://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Benzene-2018.*

[754] NTP (National Toxicology Program). 2016. Report on Carcinogens, Fourteenth Edition.; Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service. *https://ntp.niehs.nih.gov/go/roc14.*

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[756] Goldstein, B.D. (1988). Benzene toxicity. Occupational medicine. State of the Art Reviews. 3: 541–554.

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[758] U.S. EPA (2002). Toxicological Review of Benzene (Noncancer Effects). Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington DC. This material is available electronically at *https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/0276tr.pdf.*

[759] Qu, O.; Shore, R.; Li, G.; Jin, X.; Chen, C.L.; Cohen, B.; Melikian, A.; Eastmond, D.; Rappaport, S.; Li, H.; Rupa, D.; Suramaya, R.; Songnian, W.; Huifant, Y.; Meng, M.; Winnik, M.; Kwok, E.; Li, Y.; Mu, R.; Xu, B.; Zhang, X.; Li, K. (2003). HEI Report 115, Validation & Evaluation of Biomarkers in Workers Exposed to Benzene in China.

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[761] Lan, Qing, Zhang, L., Li, G., Vermeulen, R., et al. (2004). Hematotoxically in Workers Exposed to Low Levels of Benzene. Science 306: 1774–1776.

[762] Turtletaub, K.W. and Mani, C. (2003). Benzene metabolism in rodents at doses relevant to human exposure from Urban Air. Research Reports Health Effect Inst. Report No.113.

[763] U.S. Agency for Toxic Substances and Disease Registry (ATSDR). (2007). Toxicological profile for benzene. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. *http://www.atsdr.cdc.gov/ToxProfiles/tp3.pdf.*

[764] A minimal risk level (MRL) is defined as an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure.

[765] Corti, M; Snyder, CA. (1996) Influences of gender, development, pregnancy and ethanol consumption on the hematotoxicity of inhaled 10 ppm benzene. Arch Toxicol 70:209–217.

[766] McKinney P.A.; Alexander, F.E.; Cartwright, R.A.; et al. (1991) Parental occupations of children with leukemia in west Cumbria, north Humberside, and Gateshead. Br Med J 302:681–686.

[767] Keller, KA; Snyder, CA. (1986) Mice exposed in utero to low concentrations of benzene exhibit enduring changes in their colony forming hematopoietic cells. Toxicology 42:171–181.

[768] Keller, KA; Snyder, CA. (1988) Mice exposed in utero to 20 ppm benzene exhibit altered numbers of recognizable hematopoietic cells up to seven weeks after exposure. Fundam Appl Toxicol 10:224–232.

[769] Corti, M; Snyder, CA. (1996) Influences of gender, development, pregnancy and ethanol consumption on the hematotoxicity of inhaled 10 ppm benzene. Arch Toxicol 70:209–217.

[770] U.S. EPA. (2002). Toxicological Review of Benzene (Noncancer Effects). National Center for Environmental Assessment, Washington, DC. Report No. EPA/635/R–02/001F. *https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/0276tr.pdf.*

[771] Ford, AM; Pombo-de-Oliveira, MS; McCarthy, KP; MacLean, JM; Carrico, KC; Vincent, RF; Greaves, M. (1997) Monoclonal origin of concordant T-cell malignancy in identical twins. Blood 89:281–285.

[772] U.S. EPA. (2002). Health Assessment of 1,3-Butadiene. Office of Research and Development, National Center for Environmental Assessment, Washington Office, Washington, DC. Report No. EPA600–P–98–001F. This document is available electronically at *https://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=54499.*

[773] U.S. EPA. (2002) ''Full IRIS Summary for 1,3-butadiene (CASRN 106–99–0)'' Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington, DC *https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=139.*

[774] International Agency for Research on Cancer (IARC). (1999). Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 71, Re-evaluation of some organic chemicals, hydrazine and hydrogen peroxide, World Health Organization, Lyon, France.

[775] International Agency for Research on Cancer (IARC). (2008). Monographs on the evaluation of carcinogenic risk of chemicals to humans, 1,3-Butadiene, Ethylene Oxide and Vinyl Halides (Vinyl Fluoride, Vinyl Chloride and Vinyl Bromide) Volume 97, World Health Organization, Lyon, France.

[776] NTP (National Toxicology Program). 2016. Report on Carcinogens, Fourteenth Edition.; Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service. *https://ntp.niehs.nih.gov/go/roc14.*

[777] International Agency for Research on Cancer (IARC). (2012). Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 100F chemical agents and related occupations, World Health Organization, Lyon, France.

[778] U.S. EPA. (2002). ''Full IRIS Summary for 1,3-butadiene (CASRN 106–99–0)'' Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington, DC *https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=139.*

[779] Bevan, C.; Stadler, J.C.; Elliot, G.S.; et al. (1996). Subchronic toxicity of 4-vinylcyclohexene in rats and mice by inhalation. Fundam. Appl. Toxicol. 32:1–10.

calculated at 0.9 ppb (approximately 2 $\mu g/m^3$).

e. Ethylbenzene

EPA's inhalation RfC for ethylbenzene is 1 mg/m3. This conclusion on a weight of evidence determination and RfC is contained in the 1991 IRIS file for ethylbenzene.[780] The RfC is based on developmental effects. A study in rabbits found reductions in live rabbit kits per litter at 1000 ppm. In addition, a study on rats found an increased incidence of supernumerary and rudimentary ribs at 1000 ppm and elevated incidence of extra ribs at 100 ppm. In 1988, EPA concluded that data were inadequate to give a weight of evidence characterization for carcinogenic effects. EPA released an IRIS Assessment Plan for Ethylbenzene in 2017,[781] and EPA will be releasing the Systematic Review Protocol for ethylbenzene in 2023.[782]

California EPA completed a cancer risk assessment for ethylbenzene in 2007 and developed an inhalation unit risk estimate of 2.5×10^{-6}.[783] This value was based on incidence of kidney cancer in male rats. California EPA also developed a chronic inhalation noncancer reference exposure level (REL) of 2000 $\mu g/m^3$, based on nephrotoxicity and body weight reduction in rats, liver cellular alterations, necrosis in mice, and hyperplasia of the pituitary gland in mice.[784]

ATSDR developed a chronic inhalation Minimal Risk Level (MRL) for ethylbenzene of 0.06 ppm based on renal effects and an acute MRL of 5 ppm based on auditory effects.

f. Formaldehyde

In 1991, EPA concluded that formaldehyde is a Class B1 probable human carcinogen based on limited evidence in humans and sufficient evidence in animals.[785] An inhalation URE for cancer and a reference dose for oral noncancer effects were developed by EPA and posted on the IRIS database. Since that time, the NTP and IARC have concluded that formaldehyde is a known human carcinogen.[786] [787] [788]

The conclusions by IARC and NTP reflect the results of epidemiologic research published since 1991 in combination with previous animal, human and mechanistic evidence. Research conducted by the National Cancer Institute reported an increased risk of nasopharyngeal cancer and specific lymphohematopoietic malignancies among workers exposed to formaldehyde.[789] [790] [791] A National Institute of Occupational Safety and Health study of garment workers also reported increased risk of death due to leukemia among workers exposed to formaldehyde.[792] Extended follow-up of a cohort of British chemical workers did not report evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[793] Finally, a study of embalmers reported formaldehyde exposures to be associated with an increased risk of myeloid leukemia but not brain cancer.[794]

Health effects of formaldehyde in addition to cancer were reviewed by the Agency for Toxics Substances and Disease Registry in 1999, supplemented in 2010, and by the World Health Organization.[795] [796] [797] These organizations reviewed the scientific literature concerning health effects linked to formaldehyde exposure to evaluate hazards and dose response relationships and defined exposure concentrations for minimal risk levels (MRLs). The health endpoints reviewed included sensory irritation of eyes and respiratory tract, reduced pulmonary function, nasal histopathology, and immune system effects. In addition, research on reproductive and developmental effects and neurological effects was discussed along with several studies that suggest that formaldehyde may increase the risk of asthma—particularly in the young.

In June 2010, EPA released a draft Toxicological Review of Formaldehyde—Inhalation Assessment through the IRIS program for peer review by the National Research Council (NRC) and public comment.[798] That draft assessment reviewed more recent research from animal and human studies on cancer and other health effects. The NRC released their review report in April 2011.[799] EPA's draft assessment, which addresses NRC recommendations, was suspended in 2018.[800] The draft assessment was unsuspended in March 2021, and an external review draft was released in

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[780] U.S. EPA. (1991). Integrated Risk Information System File for Ethylbenzene. This material is available electronically at: *https://iris.epa.gov/ChemicalLanding/&substance_nmbr=51*.

[781] U.S. EPA (2017). IRIS Assessment Plan for Ethylbenzene. EPA/635/R–17/332. This document is available electronically at: *https://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=337468*.

[782] U.S. EPA (2022). IRIS Program Outlook. June, 2022. This material is available electronically at: *https://www.epa.gov/system/files/documents/2022-06/IRIS%20Program%20Outlook_June22.pdf*.

[783] California OEHHA, 2007. Adoption of a Unit Risk Value for Ethylbenzene. This material is available electronically at: *https://oehha.ca.gov/air/report-hot-spots/adoption-unit-risk-value-ethylbenzene*.

[784] California OEHHA, 2008. Technical Supporting Document for Noncancer RELs, Appendix D3. This material is available electronically at: *https://oehha.ca.gov/media/downloads/crnr/appendixd3final.pdf*.

[785] EPA. Integrated Risk Information System. Formaldehyde (CASRN 50–00–0) *https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=419*.

[786] NTP (National Toxicology Program). 2016. Report on Carcinogens, Fourteenth Edition.; Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service. *https://ntp.niehs.nih.gov/go/roc14*.

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April 2022.[801] This draft assessment is now undergoing review by the National Academy of Sciences.[802]

g. Naphthalene

Naphthalene is found in small quantities in gasoline and diesel fuels. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust compared with evaporative emissions from mobile sources, indicating it is primarily a product of combustion.

Acute (short-term) exposure of humans to naphthalene by inhalation, ingestion, or dermal contact is associated with hemolytic anemia and damage to the liver and the nervous system.[803] Chronic (long term) exposure of workers and rodents to naphthalene has been reported to cause cataracts and retinal damage.[804] Children, especially neonates, appear to be more susceptible to acute naphthalene poisoning based on the number of reports of lethal cases in children and infants (hypothesized to be due to immature naphthalene detoxification pathways).[805] EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[806] The draft reassessment completed external peer review.[807] Based on external peer review comments received, EPA is developing a revised draft assessment that considers inhalation and oral routes of exposure, as well as cancer and noncancer effects.[808] The external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. The NTP listed naphthalene as ''reasonably anticipated to be a human carcinogen'' in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[809] California EPA has released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[810]

Naphthalene also causes a number of non-cancer effects in animals following chronic and less-than-chronic exposure, including abnormal cell changes and growth in respiratory and nasal tissues.[811] The current EPA IRIS assessment includes noncancer data on hyperplasia and metaplasia in nasal tissue that form the basis of the inhalation RfC of 3 μg/m3.[812] The ATSDR MRL for acute and intermediate duration oral exposure to naphthalene is 0.6 mg/kg/day based on maternal toxicity in a developmental toxicology study in rats.[813] ATSDR also derived an ad hoc reference value of 6 × 10–2 mg/m3 for acute (≤24-hour) inhalation exposure to naphthalene in a Letter Health Consultation dated March 24, 2014 to address a potential exposure concern in Illinois.[814] The ATSDR acute inhalation reference value was based on a qualitative identification of an exposure level interpreted not to cause pulmonary lesions in mice. More recently, EPA developed acute RfCs for 1-, 8-, and 24-hour exposure scenarios; the ≤24-hour reference value is 2 × 10×2 mg/m3.[815] EPA's acute RfCs are based on a systematic review of the literature, benchmark dose modeling of naphthalene-induced nasal lesions in rats, and application of a PBPK (physiologically based pharmacokinetic) model.

viii. Exposure and Health Effects Associated With Traffic

Locations in close proximity to major roadways generally have elevated concentrations of many air pollutants emitted from motor vehicles. Hundreds of studies have been published in peer-reviewed journals, concluding that concentrations of CO, CO_2, NO, NO_2, benzene, aldehydes, particulate matter, black carbon, and many other compounds are elevated in ambient air within approximately 300–600 meters (about 1,000–2,000 feet) of major roadways. The highest concentrations of most pollutants emitted directly by motor vehicles are found at locations within 50 meters (about 165 feet) of the edge of a roadway's traffic lanes.

A large-scale review of air quality measurements in the vicinity of major roadways between 1978 and 2008 concluded that the pollutants with the steepest concentration gradients in vicinities of roadways were CO, ultrafine particles, metals, elemental carbon (EC), NO, NO_X, and several VOCs.[816] These pollutants showed a large reduction in concentrations within 100 meters downwind of the roadway. Pollutants that showed more gradual reductions with distance from roadways included benzene, NO2, $PM_{2.5}$, and PM_{10}. In reviewing the literature, Karner et al., (2010) reported that results varied based on the method of statistical analysis used to determine the gradient

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[814] ATSDR. Letter Health Consultation, Radiac Abrasives, Inc., Chicago, Illinois (2014). *https://www.atsdr.cdc.gov/HAC/pha/RadiacAbrasives/Radiac%20Abrasives,%20Inc.%20_%20LHC%20(Final)%20_%2003-24-2014%20(2)_508.pdf.*

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in pollutant concentration. More recent studies continue to show significant concentration gradients of traffic-related air pollution around major roads.[817] [818] [819] [820] [821]; [822] [823] [824] There is evidence that EPA's regulations for vehicles have lowered the near-road concentrations and gradients.[825] Starting in 2010, EPA required through the NAAQS process that air quality monitors be placed near high-traffic roadways for determining concentrations of CO, NO2, and $PM_{2.5}$ (in addition to those existing monitors located in neighborhoods and other locations farther away from pollution sources). The monitoring data for NO2 indicate that in urban areas, monitors near roadways often report the highest concentrations of NO2.[826] More recent studies of traffic-related air pollutants continue to report sharp gradients around roadways, particularly within several hundred meters.[827] [828]

For pollutants with relatively high background concentrations relative to near-road concentrations, detecting concentration gradients can be difficult. For example, many carbonyls have high background concentrations as a result of photochemical breakdown of precursors from many different organic compounds. However, several studies have measured carbonyls in multiple weather conditions and found higher concentrations of many carbonyls downwind of roadways.[829] [830] These findings suggest a substantial roadway source of these carbonyls.

In the past 30 years, many studies have been published with results reporting that populations who live, work, or go to school near high-traffic roadways experience higher rates of numerous adverse health effects, compared to populations far away from major roads.[831] In addition, numerous studies have found adverse health effects associated with spending time in traffic, such as commuting or walking along high-traffic roadways, including studies among children.[832] [833] [834] [835] The health outcomes with the strongest evidence linking them with traffic-associated air pollutants are respiratory effects, particularly in asthmatic children, and cardiovascular effects.

Numerous reviews of this body of health literature have been published. In a 2022 final report, an expert panel of the Health Effects Institute (HEI) employed a systematic review focusing on selected health endpoints related to exposure to traffic-related air pollution.[836] The HEI panel concluded that there was a high level of confidence in evidence between long-term exposure to traffic-related air pollution and health effects in adults, including all-cause, circulatory, and ischemic heart disease mortality.[837] The panel also found that there is a moderate-to-high level of confidence in evidence of associations with asthma onset and acute respiratory infections in children and lung cancer and asthma onset in adults. This report follows on an earlier expert review published by HEI in 2010, where it found strongest evidence for asthma-related traffic impacts. Other literature reviews have been published with conclusions generally similar to the HEI panels'.[838] [839] [840] [841] Additionally, in

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[836] HEI Panel on the Health Effects of Long-Term Exposure to Traffic-Related Air Pollution (2022) Systematic review and meta-analysis of selected health effects of long-term exposure to traffic-related air pollution. Health Effects Institute Special Report 23. [Online at *https://www.healtheffects.org/publication/systematic-review-and-meta-analysis-selected-health-effects-long-term-exposure-traffic*] This more recent review focused on health outcomes related to birth effects, respiratory effects, cardiometabolic effects, and mortality.

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Continued

2014, researchers from the U.S. Centers for Disease Control and Prevention (CDC) published a systematic review and meta-analysis of studies evaluating the risk of childhood leukemia associated with traffic exposure and reported positive associations between ''postnatal'' proximity to traffic and leukemia risks, but no such association for ''prenatal'' exposures.[842] The U.S. Department of Health and Human Services' National Toxicology Program published a monograph including a systematic review of traffic-related air pollution and its impacts on hypertensive disorders of pregnancy. The National Toxicology Program concluded that exposure to traffic-related air pollution is ''presumed to be a hazard to pregnant women'' for developing hypertensive disorders of pregnancy.[843]

Health outcomes with few publications suggest the possibility of other effects still lacking sufficient evidence to draw definitive conclusions. Among these outcomes with a small number of positive studies are neurological impacts (*e.g.,* autism and reduced cognitive function) and reproductive outcomes (*e.g.,* preterm birth, low birth weight).[844] [845] [846] [847] [848]

In addition to health outcomes, particularly cardiopulmonary effects, conclusions of numerous studies suggest mechanisms by which traffic-related air pollution affects health. For example, numerous studies indicate that near-roadway exposures may increase systemic inflammation, affecting organ systems, including blood vessels and lungs.[849] [850] [851] [852] Additionally, long-term exposures in near-road environments have been associated with inflammation-associated conditions, such as atherosclerosis and asthma.[853] [854] [855]

Several studies suggest that some factors may increase susceptibility to the effects of traffic-associated air pollution. Several studies have found stronger respiratory associations in children experiencing chronic social stress, such as in violent neighborhoods or in homes with high family stress.[856] [857] [858]

The risks associated with residence, workplace, or schools near major roads are of potentially high public health significance due to the large population in such locations. Every two years from 1997 to 2009 and in 2011, the U.S. Census Bureau's American Housing Survey (AHS) conducted a survey that includes whether housing units are within 300 feet of an ''airport, railroad, or highway with four or more lanes.'' [859] The 2013 AHS was the last AHS that included that question. The 2013 survey reports that 17.3 million housing units, or 13 percent of all housing units in the United States, were in such areas. Assuming that populations and housing units are in the same locations, this corresponds to a population of more than 41 million U.S. residents in close proximity to high-traffic roadways or other transportation sources. According to the Central Intelligence Agency's World Factbook, based on data collected between 2012–2014, the United States had 6,586,610 km of roadways, 293,564 km of railways, and 13,513 airports. As such, highways represent the overwhelming majority of transportation facilities described by this factor in the AHS.

EPA also conducted a study to estimate the number of people living near truck freight routes in the United States.[860] Based on a population analysis using the U.S. Department of Transportation's (USDOT) Freight Analysis Framework 4 (FAF4) and population data from the 2010 decennial census, an estimated 72 million people live within 200 meters (about 650 feet) of these freight routes.[861] [862] In addition, as described in Section VI.D.2, relative to the rest of the population, people of color and those with lower incomes are more likely to live near FAF4 truck routes. They are also more likely to live in metropolitan areas. The EPA's Exposure Factor Handbook also indicates that, on average, Americans spend more than an hour traveling each day, bringing nearly all residents into a high-exposure microenvironment for part of the day.

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[861] FAF4 is a model from the USDOT's Bureau of Transportation Statistics (BTS) and Federal Highway Administration (FHWA), which provides data associated with freight movement in the U.S. It includes data from the 2012 Commodity Flow Survey (CFS), the Census Bureau on international trade, as well as data associated with construction, agriculture, utilities, warehouses, and other industries. FAF4 estimates the modal choices for moving goods by trucks, trains, boats, and other types of freight modes. It includes traffic assignments, including truck flows on a network of truck routes. *https://ops.fhwa.dot.gov/freight/freight_analysis/faf/.*

[862] The same analysis estimated the population living within 100 meters of a FAF4 truck route is 41 million.

[863] [864] While near-roadway studies focus on residents near roads or others spending considerable time near major roads, the duration of commuting results in another important contributor to overall exposure to traffic-related air pollution. Studies of health that address time spent in transit have found evidence of elevated risk of cardiac impacts. [865] [866] [867] Studies have also found that school bus emissions can increase student exposures to diesel-related air pollutants, and that programs that reduce school bus emissions may improve health and reduce school absenteeism. [868] [869] [870] [871]

As described in Section VI.D.2, we estimate that about 10 million students attend schools within 200 meters of major roads. Research into the impact of traffic-related air pollution on school performance is tentative. A review of this literature found some evidence that children exposed to higher levels of traffic-related air pollution show poorer academic performance than those exposed to lower levels of traffic-related air pollution.[872] [873] However, this evidence was judged to be weak due to limitations in the assessment methods.

3. Welfare Effects Associated With Exposure to Non-GHG Pollutants

This section discusses the environmental effects associated with non-GHG pollutants affected by this rule, specifically particulate matter, ozone, NO_X, SO_X, and air toxics.

i. Visibility

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[874] Visibility impairment is caused by light scattering and absorption by suspended particles and gases. It is dominated by contributions from suspended particles except under pristine conditions. Visibility is important because it has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas, such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the final 2019 p.m. ISA.[875]

EPA is working to address visibility impairment. Reductions in air pollution from implementation of various programs associated with the Clean Air Act Amendments of 1990 provisions have resulted in substantial improvements in visibility and will continue to do so in the future. Nationally, because trends in haze are closely associated with trends in particulate sulfate and nitrate due to the relationship between their concentration and light extinction, visibility trends have improved as emissions of SO_2 and NO_X have decreased over time due to air pollution regulations such as the Acid Rain Program.[876] However, in the western part of the country, changes in total light extinction were smaller, and the contribution of particulate organic matter to atmospheric light extinction was increasing due to increasing wildfire emissions.[877]

In the Clean Air Act Amendments of 1977, Congress recognized visibility's value to society by establishing a national goal to protect national parks and wilderness areas from visibility impairment caused by manmade pollution.[878] In 1999, EPA finalized the regional haze program to protect the visibility in Mandatory Class I Federal areas.[879] There are 156 national parks, forests and wilderness areas categorized as Mandatory Class I Federal areas.[880] These areas are defined in CAA section 162 as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977.

EPA has also concluded that $PM_{2.5}$ causes adverse effects on visibility in other areas that are not targeted by the Regional Haze Rule, such as urban areas, depending on $PM_{2.5}$ concentrations and other factors such as dry chemical composition and relative humidity (*i.e.,* an indicator of the water composition of the particles). The secondary (welfare-based) PM NAAQS provide protection against visibility effects. In recent PM NAAQS reviews, EPA evaluated a target level of protection for visibility impairment that is expected to be met through attainment of the existing secondary PM standards.[881]

ii. Ozone Effects on Ecosystems

The welfare effects of ozone include effects on ecosystems, which can be observed across a variety of scales, *i.e.,* subcellular, cellular, leaf, whole plant, population and ecosystem. Ozone effects that begin at small spatial scales, such as the leaf of an individual plant, when they occur at sufficient magnitudes (or to a sufficient degree) can result in effects being propagated

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[863] EPA. (2011) Exposure Factors Handbook: 2011 Edition. Chapter 16. Online at *https://www.epa.gov/expobox/about-exposure-factors-handbook.*

[864] It is not yet possible to estimate the long-term impact of growth in telework associated with the COVID–19 pandemic on travel behavior. There were notable changes during the pandemic. For example, according to the 2021 American Time Use Survey, a greater fraction of workers did at least part of their work at home (38%) as compared with the 2019 survey (24%). [Online at *https://www.bls.gov/news.release/atus.nr0.htm.*]

[865] Riediker, M.; Cascio, W.E.; Griggs, T.R.; et al. (2004) Particulate matter exposure in cars is associated with cardiovascular effects in healthy young men. Am J Respir Crit Care Med 169. [Online at *https://doi.org/10.1164/rccm.200310-1463OC.*]

[866] Peters, A.; von Klot, S.; Heier, M.; et al. (2004) Exposure to traffic and the onset of myocardial infarction. New Engl J Med 1721–1730. [Online at *https://doi.org/10.1056/NEJMoa040203.*]

[867] Adar, S.D.; Gold, D.R.; Coull, B.A.; (2007) Focused exposure to airborne traffic particles and heart rate variability in the elderly. Epidemiology 18: 95–103 [Online at 351: *https://doi.org/10.1097/01.ede.0000249409.81050.46.*]

[868] Sabin, L.; Behrentz, E.; Winer, A.M.; et al. Characterizing the range of children's air pollutant exposure during school bus commutes. J Expo Anal Environ Epidemiol 15: 377–387. [Online at *https://doi.org/10.1038/sj.jea.7500414.*]

[869] Li, C.; N, Q.; Ryan, P.H.; School bus pollution and changes in the air quality at schools: a case study. J Environ Monit 11: 1037–1042. [*https://doi.org/10.1039/b819458k.*]

[870] Austin, W.; Heutel, G.; Kreisman, D. (2019) School bus emissions, student health and academic performance. Econ Edu Rev 70: 108–12.

[871] Adar, S.D.; D.Souza, J.; Sheppard, L.; et al. (2015) Adopting clean fuels and technologies on school buses. Pollution and health impacts in children. Am J Respir Crit Care Med 191. [Online at *http://doi.org/10.1164/rccm.201410-1924OC.*]

[872] Stenson, C.; Wheeler, A.J.; Carver, A.; et al. (2021) The impact of traffic-related air pollution on child and adolescent academic performance: a systematic review. Environ Intl 155: 106696. [Online at *https://doi.org/10.1016/j.envint.2021.106696.*]

[873] Gartland, N; Aljofi, H.E.; Dienes, K.; Munford, L.A.; Theakston, A.L.; van Tongeren, M. (2022) The effects of traffic air pollution in and around schools on executive function and academic performance in children: a rapid review. Int J Environ Res Public Health 10: 749. [Online at *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8776123.*]

[874] National Research Council, (1993). Protecting Visibility in National Parks and Wilderness Areas. National Academy of Sciences Committee on Haze in National Parks and Wilderness Areas. National Academy Press, Washington, DC. This book can be viewed on the National Academy Press website at *https://www.nap.edu/catalog/2097/protecting-visibility-in-national-parks-and-wilderness-areas.*

[875] U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019.

[876] U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019.

[877] Hand, JL; Prenni, AJ; Copeland, S; Schichtel, BA; Malm, WC. (2020). Thirty years of the Clean Air Act Amendments: Impacts on haze in remote regions of the United States (1990–2018). Atmos Environ 243: 117865.

[878] See CAA Section 169(a).

[879] 64 FR 35714, July 1, 1999.

[880] 62 FR 38680–38681, July 18, 1997.

[881] On June 10, 2021, EPA announced that it will reconsider the decision to retain the PM NAAQS. *https://www.epa.gov/pm-pollution/national-ambient-air-quality-standards-naaqs-pm.*

along a continuum to higher and higher levels of biological organization. For example, effects at the individual plant level, such as altered rates of leaf gas exchange, growth and reproduction, can, when widespread, result in broad changes in ecosystems, such as productivity, carbon storage, water cycling, nutrient cycling, and community composition.

Ozone can produce both acute and chronic injury in sensitive plant species depending on the concentration level and the duration of the exposure.[882] In those sensitive species,[883] effects from repeated exposure to ozone throughout the growing season of the plant can tend to accumulate, so even relatively low concentrations experienced for a longer duration have the potential to create chronic stress on vegetation.[884] [885] Ozone damage to sensitive plant species includes impaired photosynthesis and visible injury to leaves. The impairment of photosynthesis, the process by which the plant makes carbohydrates (its source of energy and food), can lead to reduced crop yields, timber production, and plant productivity and growth. Impaired photosynthesis can also lead to a reduction in root growth and carbohydrate storage below ground, resulting in other, more subtle plant and ecosystems impacts.[886] These latter impacts include increased susceptibility of plants to insect attack, disease, harsh weather, interspecies competition and overall decreased plant vigor. The adverse effects of ozone on areas with sensitive species could potentially lead to species shifts and loss from the affected ecosystems,[887] resulting in a loss or reduction in associated ecosystem goods and services. Additionally, visible ozone injury to leaves can result in a loss of aesthetic value in areas of special scenic significance like national parks and wilderness areas and reduced use of sensitive ornamentals in landscaping.[888] In addition to ozone effects on vegetation, newer evidence suggests that ozone affects interactions between plants and insects by altering chemical signals (*e.g.,* floral scents) that plants use to communicate to other community members, such as attraction of pollinators.

The Ozone ISA presents more detailed information on how ozone affects vegetation and ecosystems.[889] The Ozone ISA reports causal and likely causal relationships between ozone exposure and a number of welfare effects and characterizes the weight of evidence for different effects associated with ozone.[890] The ISA concludes that visible foliar injury effects on vegetation, reduced vegetation growth, reduced plant reproduction, reduced productivity in terrestrial ecosystems, reduced yield and quality of agricultural crops, alteration of below-ground biogeochemical cycles, and altered terrestrial community composition are causally associated with exposure to ozone. It also concludes that increased tree mortality, altered herbivore growth and reproduction, altered plant-insect signaling, reduced carbon sequestration in terrestrial ecosystems, and alteration of terrestrial ecosystem water cycling are likely to be causally associated with exposure to ozone.

iii. Deposition

The Integrated Science Assessment for Oxides of Nitrogen, Oxides of Sulfur, and Particulate Matter—Ecological Criteria documents the ecological effects of the deposition of these criteria air pollutants.[891] It is clear from the body of evidence that oxides of nitrogen, oxides of sulfur, and particulate matter contribute to total nitrogen (N) and sulfur (S) deposition. In turn, N and S deposition cause either nutrient enrichment or acidification depending on the sensitivity of the landscape or the species in question. Both enrichment and acidification are characterized by an alteration of the biogeochemistry and the physiology of organisms, resulting in harmful declines in biodiversity in terrestrial, freshwater, wetland, and estuarine ecosystems in the U.S. Decreases in biodiversity mean that some species become relatively less abundant and may be locally extirpated. In addition to the loss of unique living species, the decline in total biodiversity can be harmful because biodiversity is an important determinant of the stability of ecosystems and their ability to provide socially valuable ecosystem services.

Terrestrial, wetland, freshwater, and estuarine ecosystems in the United States are affected by N enrichment/eutrophication caused by N deposition. These effects have been consistently documented across the United States for hundreds of species. In aquatic systems increased nitrogen can alter species assemblages and cause eutrophication. In terrestrial systems nitrogen loading can lead to loss of nitrogen-sensitive lichen species, decreased biodiversity of grasslands, meadows and other sensitive habitats, and increased potential for invasive species.

The sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition is predominantly governed by geology. Prolonged exposure to excess nitrogen and sulfur deposition in sensitive areas acidifies lakes, rivers, and soils. Increased acidity in surface waters creates inhospitable conditions for biota and affects the abundance and biodiversity of fishes, zooplankton and macroinvertebrates and ecosystem function. Over time, acidifying deposition also removes essential nutrients from forest soils, depleting the capacity of soils to neutralize future acid loadings and negatively affecting forest sustainability. Major effects in forests include a decline in sensitive tree species, such as red spruce (Picea rubens) and sugar maple (Acer saccharum).

Building materials including metals, stones, cements, and paints undergo natural weathering processes from exposure to environmental elements (*e.g.,* wind, moisture, temperature fluctuations, sunlight, etc.). Pollution can worsen and accelerate these effects. Deposition of PM is associated with both physical damage (materials damage effects) and impaired aesthetic qualities (soiling effects). Wet and dry deposition of PM can physically affect materials, adding to the effects of natural weathering processes, by potentially promoting or accelerating the corrosion of metals, by degrading paints and by deteriorating building materials such as

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[882] 73 FR 16486, March 27, 2008.

[883] 73 FR 16491, March 27, 2008. Only a small percentage of all the plant species growing within the U.S. (over 43,000 species have been catalogued in the USDA PLANTS database) have been studied with respect to ozone sensitivity.

[884] U.S. EPA. Integrated Science Assessment (ISA) for Ozone and Related Photochemical Oxidants (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–20/012, 2020.

[885] The concentration at which ozone levels overwhelm a plant's ability to detoxify or compensate for oxidant exposure varies. Thus, whether a plant is classified as sensitive or tolerant depends in part on the exposure levels being considered.

[886] 73 FR 16492, March 27, 2008.

[887] 73 FR 16493–16494, March 27, 2008. Ozone impacts could be occurring in areas where plant species sensitive to ozone have not yet been studied or identified.

[888] 73 FR 16490–16497, March 27, 2008.

[889] U.S. EPA. Integrated Science Assessment (ISA) for Ozone and Related Photochemical Oxidants (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–20/012, 2020.

[890] The Ozone ISA evaluates the evidence associated with different ozone related health and welfare effects, assigning one of five ''weight of evidence'' determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For more information on these levels of evidence, please refer to Table II of the ISA.

[891] U.S. EPA. Integrated Science Assessment (ISA) for Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter Ecological Criteria (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–20/278, 2020.

stone, concrete and marble.[892] The effects of PM are exacerbated by the presence of acidic gases and can be additive or synergistic due to the complex mixture of pollutants in the air and surface characteristics of the material. Acidic deposition has been shown to have an effect on materials including zinc/galvanized steel and other metal, carbonate stone (as monuments and building facings), and surface coatings (paints).[893] The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects. In addition to aesthetic and functional effects on metals, stone and glass, altered energy efficiency of photovoltaic panels by PM deposition is also becoming an important consideration for impacts of air pollutants on materials.

iv. Welfare Effects Associated With Air Toxics

Emissions from producing, transporting, and combusting fuel contribute to ambient levels of pollutants that contribute to adverse effects on vegetation. VOCs, some of which are considered air toxics, have long been suspected to play a role in vegetation damage.[894] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[895] Decreases in harvested seed pod weight have been reported for the more sensitive plants, and some studies have reported effects on seed germination, flowering, and fruit ripening. Effects of individual VOCs or their role in conjunction with other stressors (*e.g.,* acidification, drought, temperature extremes) have not been well studied. In a recent study of a mixture of VOCs including ethanol and toluene on herbaceous plants, significant effects on seed production, leaf water content, and photosynthetic efficiency were reported for some plant species.[896]

Research suggests an adverse impact of vehicle exhaust on plants, which has in some cases been attributed to aromatic compounds and in other cases to NO_X.[897] [898] [899] The impacts of VOCs on plant reproduction may have long-term implications for biodiversity and survival of native species near major roadways. Most of the studies of the impacts of VOCs on vegetation have focused on short-term exposure, and few studies have focused on long-term effects of VOCs on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

C. Air Quality Impacts of Non-GHG Pollutants

Section V of the preamble presents projections of the changes in criteria pollutant and air toxics emissions due to the proposed standards. However, the atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex, and evaluating air quality impacts of this proposed rule based solely on emissions changes is difficult. Photochemical air quality modeling is necessary to accurately project levels of most criteria and air toxic pollutants, including ozone and PM. Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and secondary pollutants that are formed through complex chemical reactions within the atmosphere. Photochemical air quality models have become widely recognized and routinely utilized tools in regulatory analysis for assessing the impacts of control strategies. Because of the length of time needed to prepare the necessary emissions inventories, in addition to the processing time associated with the modeling itself, we do not have air quality modeling results available for this proposed rule.

D. Environmental Justice

EPA's 2016 ''Technical Guidance for Assessing Environmental Justice in Regulatory Analysis'' provides recommendations on conducting the highest quality analysis feasible, recognizing that data limitations, time and resource constraints, and analytic challenges will vary by media and regulatory context.[900] When assessing the potential for disproportionately high and adverse health or environmental impacts of regulatory actions on populations with potential EJ concerns, the EPA strives to answer three broad questions: (1) Is there evidence of potential environmental justice (EJ) concerns in the baseline (the state of the world absent the regulatory action)? Assessing the baseline will allow the EPA to determine whether pre-existing disparities are associated with the pollutant(s) under consideration (*e.g.,* if the effects of the pollutant(s) are more concentrated in some population groups); (2) Is there evidence of potential EJ concerns for the regulatory option(s) under consideration? Specifically, how are the pollutant(s) and its effects distributed for the regulatory options under consideration?; and (3) Do the regulatory option(s) under consideration exacerbate or mitigate EJ concerns relative to the baseline? It is not always possible to quantitatively assess these questions.

In this section, we discuss the EJ impacts of the proposed CO_2 emission standards from the anticipated reduction of GHGs (Section VI.D.1). EPA did not consider any potential disproportionate impacts of vehicle emissions in selecting the proposed CO_2 emission standards, but we view mitigation of disproportionate impacts of vehicle GHG emissions as one element of protecting public health consistent with CAA section 202. We also discuss potential additional EJ impacts from the non-GHG (criteria pollutants and air toxics) emissions changes we estimate would result from compliance with the proposed CO_2 emission standards (Section VI.D.2). EPA requests comment on the EJ impact analysis presented in this proposal.

1. GHG Impacts

In 2009, under the *Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act* (''Endangerment Finding''), the Administrator considered

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[892] U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–19/188, 2019.

[893] Irving, P.M., e.d. 1991. Acid Deposition: State of Science and Technology, Volume III, Terrestrial, Materials, Health, and Visibility Effects, The U.S. National Acid Precipitation Assessment Program, Chapter 24, page 24–76.

[894] U.S. EPA. (1991). Effects of organic chemicals in the atmosphere on terrestrial plants. EPA/600/3–91/001.

[895] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. (2003). Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341–343.

[896] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. (2003). Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341–343.

[897] Viskari E–L. (2000). Epicuticular wax of Norway spruce needles as indicator of traffic pollutant deposition. Water, Air, and Soil Pollut. 121:327–337.

[898] Ugrekhelidze D, F Korte, G Kvesitadze. (1997). Uptake and transformation of benzene and toluene by plant leaves. Ecotox. Environ. Safety 37:24–29.

[899] Kammerbauer H, H Selinger, R Rommelt, A Ziegler-Jons, D Knoppik, B Hock. (1987). Toxic components of motor vehicle emissions for the spruce Picea abies. Environ. Pollut. 48:235–243.

[900] ''Technical Guidance for Assessing Environmental Justice in Regulatory Analysis.'' Epa.gov, Environmental Protection Agency, *https://www.epa.gov/sites/production/files/2016-06/documents/ejtg_5_6_16_v5.1.pdf.* (June 2016).

how climate change threatens the health and welfare of the U.S. population. As part of that consideration, she also considered risks to people of color and low-income individuals and communities, finding that certain parts of the U.S. population may be especially vulnerable based on their characteristics or circumstances. These groups include economically and socially disadvantaged communities; individuals at vulnerable life stages, such as the elderly, the very young, and pregnant or nursing women; those already in poor health or with comorbidities; the disabled; those experiencing homelessness, mental illness, or substance abuse; and Indigenous or other populations dependent on one or limited resources for subsistence due to factors including but not limited to geography, access, and mobility.

Scientific assessment reports produced over the past decade by the U.S. Global Change Research Program (USGCRP),[901] [902] the Intergovernmental Panel on Climate Change IPCC),[903] [904] [905] [906] and the National Academies of Science, Engineering, and Medicine [907] [908] add more evidence that the impacts of climate change raise potential environmental justice concerns. These reports conclude that poorer or predominantly non-White communities can be especially vulnerable to climate change impacts because they tend to have limited adaptive capacities, are more dependent on climate-sensitive resources such as local water and food supplies, or have less access to social and information resources. Some communities of color, specifically populations defined jointly by ethnic/racial characteristics and geographic location, may be uniquely vulnerable to climate change health impacts in the United States. In particular, the 2016 scientific assessment on the *Impacts of Climate Change on Human Health*[909] found with high confidence that vulnerabilities are place- and time-specific, life stages and ages are linked to immediate and future health impacts, and social determinants of health are linked to greater extent and severity of climate change-related health impacts. The GHG emission reductions from this proposal would contribute to efforts to reduce the probability of severe impacts related to climate change.

i. Effects on Specific Populations of Concern

Individuals living in socially and economically vulnerable communities, such as those living at or below the poverty line or who are experiencing homelessness or social isolation, are at greater risk of health effects from climate change. This is also true with respect to people at vulnerable life stages, specifically women who are pre- and perinatal or are nursing; *in utero* fetuses; children at all stages of development; and the elderly. Per the Fourth National Climate Assessment (NCA4), ''Climate change affects human health by altering exposures to heat waves, floods, droughts, and other extreme events; vector-, food- and waterborne infectious diseases; changes in the quality and safety of air, food, and water; and stresses to mental health and well-being.'' [910] Many health conditions such as cardiopulmonary or respiratory illness and other health impacts are associated with and exacerbated by an increase in GHGs and climate change outcomes, which is problematic as these diseases occur at higher rates within vulnerable communities. Importantly, negative public health outcomes include those that are physical in nature, as well as mental, emotional, social, and economic.

To this end, the scientific assessment literature, including the aforementioned reports, demonstrates that there are myriad ways in which these populations may be affected at the individual and community levels. Individuals face differential exposure to criteria pollutants, in part due to the proximities of highways, trains, factories, and other major sources of pollutant-emitting sources to less-affluent residential areas. Outdoor workers, such as construction or utility crews and agricultural laborers, who frequently are comprised of already at-risk groups, are exposed to poor air quality and extreme temperatures without relief. Furthermore, people in communities with EJ concerns face greater housing, clean water, and food insecurity and bear disproportionate economic impacts and health burdens associated with climate change effects. They have less or limited access to healthcare and affordable, adequate

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[901] USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

[902] USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp. *http://dx.doi.org/10.7930/J0R49NQX.*

[903] Oppenheimer, M., M. Campos, R.Warren, J. Birkmann, G. Luber, B. O'Neill, and K. Takahashi, 2014: Emergent risks and key vulnerabilities. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039–1099.

[904] Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell, and M.I. Travasso, 2014: Food security and food production systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 485–533.

[905] Smith, K.R., A.Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn, 2014: Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel,A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709–754.

[906] IPCC, 2018: Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

[907] National Research Council. 2011. America's Climate Choices. Washington, DC: The National Academies Press. *https://doi.org/10.17226/12781.*

[908] National Academies of Sciences, Engineering, and Medicine. 2017. Communities in Action: Pathways to Health Equity. Washington, DC: The National Academies Press. *https://doi.org/10.17226/24624.*

[909] USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp. *http://dx.doi.org/10.7930/J0R49NQX.*

[910] Ebi, K.L., J.M. Balbus, G. Luber, A. Bole, A. Crimmins, G. Glass, S. Saha, M.M. Shimamoto, J. Trtanj, and J.L. White-Newsome, 2018: Human Health. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 539–571. doi: 10.7930/NCA4.2018.CH14.

health or homeowner insurance. Finally, resiliency and adaptation are more difficult for economically vulnerable communities; they have less liquidity, individually and collectively, to move or to make the types of infrastructure or policy changes to limit or reduce the hazards they face. They frequently are less able to self-advocate for resources that would otherwise aid in building resilience and hazard reduction and mitigation.

The assessment literature cited in EPA's 2009 and 2016 Endangerment and Cause or Contribute Findings, as well as *Impacts of Climate Change on Human Health,* also concluded that certain populations and life stages, including children, are most vulnerable to climate-related health effects.[911] The assessment literature produced from 2016 to the present strengthens these conclusions by providing more detailed findings regarding related vulnerabilities and the projected impacts youth may experience. These assessments—including the NCA4 and *The Impacts of Climate Change on Human Health in the United States* (2016)—describe how children's unique physiological and developmental factors contribute to making them particularly vulnerable to climate change. Impacts to children are expected from heat waves, air pollution, infectious and waterborne illnesses, and mental health effects resulting from extreme weather events. In addition, children are among those especially susceptible to allergens, as well as health effects associated with heat waves, storms, and floods. Additional health concerns may arise in low-income households, especially those with children, if climate change reduces food availability and increases prices, leading to food insecurity within households.

The Impacts of Climate Change on Human Health[912] also found that some communities of color, low-income groups, people with limited English proficiency, and certain immigrant groups (especially those who are undocumented) live with many of the factors that contribute to their vulnerability to the health impacts of climate change. While difficult to isolate from related socioeconomic factors, race appears to be an important factor in vulnerability to climate-related stress, with elevated risks for mortality from high temperatures reported for Black or African American individuals compared to White individuals after controlling for factors such as air conditioning use. Moreover, people of color are disproportionately exposed to air pollution based on where they live, and disproportionately vulnerable due to higher baseline prevalence of underlying diseases such as asthma, so climate exacerbations of air pollution are expected to have disproportionate effects on these communities.

Native American Tribal communities possess unique vulnerabilities to climate change, particularly those impacted by degradation of natural and cultural resources within established reservation boundaries and threats to traditional subsistence lifestyles. Tribal communities whose health, economic well-being, and cultural traditions depend upon the natural environment will likely be affected by the degradation of ecosystem goods and services associated with climate change. The IPCC indicates that losses of customs and historical knowledge may cause communities to be less resilient or adaptable.[913] The NCA4 noted that while Indigenous peoples are diverse and will be impacted by the climate changes universal to all Americans, there are several ways in which climate change uniquely threatens Indigenous peoples' livelihoods and economies.[914] In addition, there can institutional barriers to their management of water, land, and other natural resources that could impede adaptive measures.

For example, Indigenous agriculture in the Southwest is already being adversely affected by changing patterns of flooding, drought, dust storms, and rising temperatures leading to increased soil erosion, irrigation water demand, and decreased crop quality and herd sizes. The Confederated Tribes of the Umatilla Indian Reservation in the Northwest have identified climate risks to salmon, elk, deer, roots, and huckleberry habitat. Housing and sanitary water supply infrastructure are vulnerable to disruption from extreme precipitation events.

NCA4 noted that Indigenous peoples often have disproportionately higher rates of asthma, cardiovascular disease, Alzheimer's, diabetes, and obesity, which can all contribute to increased vulnerability to climate-driven extreme heat and air pollution events. These factors also may be exacerbated by stressful situations, such as extreme weather events, wildfires, and other circumstances.

NCA4 and IPCC Fifth Assessment Report also highlighted several impacts specific to Alaskan Indigenous Peoples. Permafrost thaw will lead to more coastal erosion, exacerbated risks of winter travel, and damage to buildings, roads, and other infrastructure—these impacts on archaeological sites, structures, and objects will lead to a loss of cultural heritage for Alaska's Indigenous people. In terms of food security, the NCA4 discussed reductions in suitable ice conditions for hunting, warmer temperatures impairing the use of traditional ice cellars for food storage, and declining shellfish populations due to warming and acidification. While the NCA also noted that climate change provided more opportunity to hunt from boats later in the fall season or earlier in the spring, the assessment found that the net impact was an overall decrease in food security.

In addition, the U.S. Pacific Islands and the indigenous communities that live there are also uniquely vulnerable to the effects of climate change due to their remote location and geographic isolation. They rely on the land, ocean, and natural resources for their livelihoods, but they face challenges in obtaining energy and food supplies that need to be shipped in at high costs. As a result, they face higher energy costs than the rest of the nation and depend on imported fossil fuels for electricity generation and diesel. These challenges exacerbate the climate impacts that the Pacific Islands are experiencing. NCA4 notes that Indigenous peoples of the Pacific are threatened by rising sea levels, diminishing freshwater availability, and negative effects to ecosystem services that threaten these individuals' health and well-being.

2. Non-GHG Impacts

In Section V.B., in addition to GHG emissions impacts, we also discuss potential additional impacts to emissions of non-GHGs (*i.e.,* criteria and air toxic pollutants) that we estimate would result from compliance with the proposed GHG emission standards. This section VI.D.2 describes evidence that communities with EJ concerns are disproportionately impacted by the non-GHG emissions affected by this rule.

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[911] 74 FR 66496, December 15, 2009; 81 FR 54422, August 15, 2016.

[912] USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp. *http://dx.doi.org/10.7930/J0R49NQX.*

[913] Porter et al., 2014: Food security and food production systems.

[914] Jantarasami, L.C., R. Novak, R. Delgado, E. Marino, S. McNeeley, C. Narducci, J. Raymond-Yakoubian, L. Singletary, and K. Powys Whyte, 2018: Tribes and Indigenous Peoples. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 572–603. doi: 10.7930/NCA4.2018.CH15.

Numerous studies have found that environmental hazards such as air pollution are more prevalent in areas where people of color and low-income populations represent a higher fraction of the population compared with the general population.[915] [916] [917] Consistent with this evidence, a recent study found that most anthropogenic sources of $PM_{2.5}$, including industrial sources and light- and heavy-duty vehicle sources, disproportionately affect people of color.[918] In addition, compared to non-Hispanic Whites, some other racial groups experience greater levels of health problems during some life stages. For example, in 2018–2020, about 12 percent of non-Hispanic Black; 9 percent of non-Hispanic American Indian/Alaska Native; and 7 percent of Hispanic children were estimated to currently have asthma, compared with 6 percent of non-Hispanic White children.[919] Nationally, on average, non-Hispanic Black and Non-Hispanic American Indian or Alaska Native people also have lower than average life expectancy based on 2019 data, the latest year for which CDC estimates are available.[920]

We discuss near-roadway issues in Section VI.D.2.i and upstream sources in Section VI.D.2.ii.

i. Near-Roadway Analysis

As described in Section VI.B of this preamble, concentrations of many air pollutants are elevated near high-traffic roadways. We recently conducted an analysis of the populations within the CONUS living in close proximity to truck freight routes as identified in USDOT's FAF4.[921] FAF4 is a model from the USDOT's Bureau of Transportation Statistics (BTS) and Federal Highway Administration (FHWA), which provides data associated with freight movement in the United States [922] Relative to the rest of the population, people living near FAF4 truck routes are more likely to be people of color and have lower incomes than the general population. People living near FAF4 truck routes are also more likely to live in metropolitan areas. Even controlling for region of the country, county characteristics, population density, and household structure, race, ethnicity, and income are significant determinants of whether someone lives near a FAF4 truck route.

We additionally analyzed other national databases that allowed us to evaluate whether homes and schools were located near a major road and whether disparities in exposure may be occurring in these environments. Until 2009, the U.S. Census Bureau's American Housing Survey (AHS) included descriptive statistics of over 70,000 housing units across the nation and asked about transportation infrastructure near respondents' homes every two years.[923] [924] We also analyzed the U.S. Department of Education's Common Core of Data, which includes enrollment and location information for schools across the United States.[925]

In analyzing the 2009 AHS, we focused on whether a housing unit was located within 300 feet of a ''4-or-more lane highway, railroad, or airport'' (this distance was used in the AHS analysis).[926] We analyzed whether there were differences between households in such locations compared with those in locations farther from these transportation facilities.[927] We included other variables, such as land use category, region of country, and housing type. We found that homes with a non-White householder were 22–34 percent more likely to be located within 300 feet of these large transportation facilities than homes with White householders. Homes with a Hispanic householder were 17–33 percent more likely to be located within 300 feet of these large transportation facilities than homes with non-Hispanic householders. Households near large transportation facilities were, on average, lower in income and educational attainment and more likely to be a rental property and located in an urban area compared with households more distant from transportation facilities.

In examining schools near major roadways, we used the Common Core of Data (CCD) from the U.S. Department of Education, which includes information on all public elementary and secondary schools and school districts nationwide.[928] To determine school proximities to major roadways, we used a geographic information system (GIS) to map each school and roadways based on the U.S. Census's TIGER roadway file.[929] We estimated that about 10 million students attend schools within 200 meters of major roads, about 20 percent of the total number of public school students in the United States.[930] About 800,000 students attend public schools within 200 meters of primary roads, or about 2 percent of the total. We found that students of color were overrepresented at schools within 200 meters of primary roadways, and schools within 200 meters of primary roadways had a disproportionate population of students eligible for free or reduced-price lunches.[931] Black

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[915] Rowangould, G.M. (2013) A census of the near-roadway population: public health and environmental justice considerations. Trans Res D 25: 59–67. *http://dx.doi.org/10.1016/j.trd.2013.08.003.*

[916] Marshall, J.D., Swor, K.R.; Nguyen, N.P (2014) Prioritizing environmental justice and equality: diesel emissions in Southern California. Environ Sci Technol 48: 4063–4068. *https://doi.org/10.1021/es405167f.*

[917] Marshall, J.D. (2008) Environmental inequality: air pollution exposures in California's South Coast Air Basin. Atmos Environ 21: 5499–5503. *https://doi.org/10.1016/j.atmosenv.2008.02.005.*

[918] C. W. Tessum, D. A. Paolella, S. E. Chambliss, J. S. Apte, J. D. Hill, J. D. Marshall, $PM_{2.5}$ polluters disproportionately and systemically affect people of color in the United States. Sci. Adv. 7, eabf4491 (2021).

[919] *http://www.cdc.gov/asthma/most_recent_data.htm.*

[920] Arias, E. Xu, J. (2022) United States Life Tables, 2019. National Vital Statistics Report, Volume 70, Number 19. [Online at *https://www.cdc.gov/nchs/data/nvsr/nvsr70/nvsr70-19.pdf*].

[921] U.S. EPA (2021). Estimation of Population Size and Demographic Characteristics among People Living Near Truck Routes in the Conterminous United States. Memorandum to the Docket.

[922] FAF4 includes data from the 2012 Commodity Flow Survey (CFS), the Census Bureau on international trade, as well as data associated with construction, agriculture, utilities, warehouses, and other industries. FAF4 estimates the modal choices for moving goods by trucks, trains, boats, and other types of freight modes. It includes traffic assignments, including truck flows on a network of truck routes. *https://ops.fhwa.dot.gov/freight/freight_analysis/faf/.*

[923] U.S. Department of Housing and Urban Development, & U.S. Census Bureau. (n.d.). Age of other residential buildings within 300 feet. In American Housing Survey for the United States: 2009 (pp. A–1). Retrieved from *https://www.census.gov/programs-surveys/ahs/data/2009/ahs-2009-summary-tables0/h150-09.html.*

[924] The 2013 AHS again included the ''etrans'' question about highways, airports, and railroads within half a block of the housing unit but has not maintained the question since then.

[925] *http://nces.ed.gov/ccd/.*

[926] This variable primarily represents roadway proximity. According to the Central Intelligence Agency's World Factbook, in 2010, the United States had 6,506,204 km of roadways, 224,792 km of railways, and 15,079 airports. Highways thus represent the overwhelming majority of transportation facilities described by this factor in the AHS.

[927] Bailey, C. (2011) Demographic and Social Patterns in Housing Units Near Large Highways and other Transportation Sources. Memorandum to docket.

[928] *http://nces.ed.gov/ccd/.*

[929] Pedde, M.; Bailey, C. (2011) Identification of Schools within 200 Meters of U.S. Primary and Secondary Roads. Memorandum to the docket.

[930] Here, ''major roads'' refer to those TIGER classifies as either ''Primary'' or ''Secondary.'' The Census Bureau describes primary roads as ''generally divided limited-access highways within the Federal interstate system or under state management.'' Secondary roads are ''main arteries, usually in the U.S. highway, state highway, or county highway system.''

[931] For this analysis we analyzed a 200-meter distance based on the understanding that roadways generally influence air quality within a few hundred meters from the vicinity of heavily traveled roadways or along corridors with significant trucking traffic. See U.S. EPA, 2014. Near Roadway Air Pollution and Health: Frequently Asked Questions. EPA–420–F–14–044.

students represent 22 percent of students at schools located within 200 meters of a primary road, compared to 17 percent of students in all U.S. schools. Hispanic students represent 30 percent of students at schools located within 200 meters of a primary road, compared to 22 percent of students in all U.S. schools.

We also reviewed existing scholarly literature examining the potential for disproportionate exposure among people of color and people with low socioeconomic status (SES). Numerous studies evaluating the demographics and socioeconomic status of populations or schools near roadways have found that they include a greater percentage of residents of color, as well as lower SES populations (as indicated by variables such as median household income). Locations in these studies include Los Angeles, CA; Seattle, WA; Wayne County, MI; Orange County, FL; and the State of California, and nationally.[932] [933] [934] [935] [936] [937] [938] Such disparities may be due to multiple factors.[939] [940] [941] [942] [943]

Additionally, people with low SES often live in neighborhoods with multiple stressors and health risk factors, including reduced health insurance coverage rates, higher smoking and drug use rates, limited access to fresh food, visible neighborhood violence, and elevated rates of obesity and some diseases such as asthma, diabetes, and ischemic heart disease. Although questions remain, several studies find stronger associations between air pollution and health in locations with such chronic neighborhood stress, suggesting that populations in these areas may be more susceptible to the effects of air pollution.[944] [945] [946] [947]

Several publications report nationwide analyses that compare the demographic patterns of people who do or do not live near major roadways.[948] [949] [950] [951] [952] [953] Three of these studies found that people living near major roadways are more likely to be people of color or of low SES.[954] [955] [956] They also found that the outcomes of their analyses varied between regions within the United States. However, only one such study looked at whether such conclusions were confounded by living in a location with higher population density and how demographics differ between locations nationwide.[957] In general, it found that higher density areas have higher proportions of low-income residents and people of color. In other publications assessing a city, county, or state, the results are similar.[958] [959]

Two recent studies provide strong evidence that reducing emissions from heavy-duty vehicles is extremely likely to reduce the disparity in exposures to traffic-related air pollutants, both using NO_2 observations from the recently launched TROPospheric Ozone Monitoring Instrument (TROPOMI) satellite sensor as a measure of air quality, which provides the highest-resolution observations heretofore unavailable from any satellite.[960]

One study evaluated NO_2 concentrations during the COVID–19 lockdowns in 2020 and compared them to NO_2 concentrations from the same dates in 2019.[961] That study found that

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[932] Marshall, J.D. (2008) Environmental inequality: air pollution exposures in California's South Coast Air Basin. Atmos Environ 42: 5499–5503. doi:10.1016/j.atmosenv.2008.02.00.

[933] Su, J.G.; Larson, T.; Gould, T.; Cohen, M.; Buzzelli, M. (2010) Transboundary air pollution and environmental justice: Vancouver and Seattle compared. GeoJournal 57: 595–608. doi:10.1007/s10708–009–9269–6.

[934] Chakraborty, J.; Zandbergen, P.A. (2007) Children at risk: measuring racial/ethnic disparities in potential exposure to air pollution at school and home. J Epidemiol Community Health 61: 1074–1079. doi:10.1136/jech.2006.054130.

[935] Green, R.S.; Smorodinsky, S.; Kim, J.J.; McLaughlin, R.; Ostro, B. (20042004) Proximity of California public schools to busy roads. Environ Health Perspect 112: 61–66. doi:10.1289/ehp.6566.

[936] Wu, Y; Batterman, S.A. (2006) Proximity of schools in Detroit, Michigan to automobile and truck traffic. J Exposure Sci & Environ Epidemiol. doi:10.1038/sj.jes.7500484.

[937] Su, J.G.; Jerrett, M.; de Nazelle, A.; Wolch, J. (2011) Does exposure to air pollution in urban parks have socioeconomic, racial, or ethnic gradients? Environ Res 111: 319–328.

[938] Jones, M.R.; Diez-Roux, A.; Hajat, A.; et al. (2014) Race/ethnicity, residential segregation, and exposure to ambient air pollution: The Multi-Ethnic Study of Atherosclerosis (MESA). Am J Public Health 104: 2130–2137. [Online at: *https://doi.org/10.2105/AJPH.2014.302135.*].

[939] Depro, B.; Timmins, C. (2008) Mobility and environmental equity: do housing choices determine exposure to air pollution? Duke University Working Paper.

[940] Rothstein, R. The Color of Law: A Forgotten History of How Our Government Segregated America. New York: Liveright, 2018.

[941] Lane, H.J.; Morello-Frosch, R.; Marshall, J.D.; Apte, J.S. (2022) Historical redlining is associated with present-day air pollution disparities in US Cities. Environ Sci & Technol Letters 9: 345–350. DOI: [Online at: *https://doi.org/10.1021/acs.estlett.1c01012*].

[942] Ware, L. (2021) Plessy's legacy: the government's role in the development and perpetuation of segregated neighborhoods. RSF: The Russel Sage Foundation Journal of the Social Sciences, 7:92–109. DOI: DOI: 10.7758/RSF.2021.7.1.06.

[943] Archer, D.N. (2020) ''White Men's Roads through Black Men's Homes'': advancing racial equity through highway reconstruction. Vanderbilt Law Rev 73: 1259.

[944] Clougherty, J.E.; Kubzansky, L.D. (2009) A framework for examining social stress and susceptibility to air pollution in respiratory health. Environ Health Perspect 117: 1351–1358. Doi:10.1289/ehp.0900612.

[945] Clougherty, J.E.; Levy, J.I.; Kubzansky, L.D.; Ryan, P.B.; Franco Suglia, S.; Jacobson Canner, M.; Wright, R.J. (2007) Synergistic effects of traffic-related air pollution and exposure to violence on urban asthma etiology. Environ Health Perspect 115: 1140–1146. doi:10.1289/ehp.9863.

[946] Finkelstein, M.M.; Jerrett, M.; DeLuca, P.; Finkelstein, N.; Verma, D.K.; Chapman, K.; Sears, M.R. (2003) Relation between income, air pollution and mortality: a cohort study. Canadian Med Assn J 169: 397–402.

[947] Shankardass, K.; McConnell, R.; Jerrett, M.; Milam, J.; Richardson, J.; Berhane, K. (2009) Parental stress increases the effect of traffic-related air pollution on childhood asthma incidence. Proc Natl Acad Sci 106: 12406–12411. doi:10.1073/pnas.0812910106.

[948] Rowangould, G.M. (2013) A census of the U.S. near-roadway population: public health and environmental justice considerations. Transportation Research Part D; 59–67.

[949] Tian, N.; Xue, J.; Barzyk. T.M. (2013) Evaluating socioeconomic and racial differences in traffic-related metrics in the United States using a GIS approach. J Exposure Sci Environ Epidemiol 23: 215–222.

[950] CDC (2013) Residential proximity to major highways—United States, 2010. Morbidity and Mortality Weekly Report 62(3): 46–50.

[951] Clark, L.P.; Millet, D.B., Marshall, J.D. (2017) Changes in transportation-related air pollution exposures by race-ethnicity and socioeconomic status: outdoor nitrogen dioxide in the United States in 2000 and 2010. Environ Health Perspect *https://doi.org/10.1289/EHP959.*

[952] Mikati, I.; Benson, A.F.; Luben, T.J.; Sacks, J.D.; Richmond-Bryant, J. (2018) Disparities in distribution of particulate matter emission sources by race and poverty status. Am J Pub Health *https://ajph.aphapublications.org/doi/abs/10.2105/AJPH.2017.304297?journalCode=ajph.*

[953] Alotaibi, R.; Bechle, M.; Marshall, J.D.; Ramani, T.; Zietsman, J.; Nieuwenhuijsen, M.J.; Khreis, H. (2019) Traffic related air pollution and the burden of childhood asthma in the continuous United States in 2000 and 2010. Environ International 127: 858–867. *https://www.sciencedirect.com/science/article/pii/S0160412018325388.*

[954] Tian, N.; Xue, J.; Barzyk. T.M. (2013) Evaluating socioeconomic and racial differences in traffic-related metrics in the United States using a GIS approach. J Exposure Sci Environ Epidemiol 23: 215–222.

[955] Rowangould, G.M. (2013) A census of the U.S. near-roadway population: public health and environmental justice considerations. Transportation Research Part D; 59–67.

[956] CDC (2013) Residential proximity to major highways—United States, 2010. Morbidity and Mortality Weekly Report 62(3): 46–50.

[957] Rowangould, G.M. (2013) A census of the U.S. near-roadway population: public health and environmental justice considerations. Transportation Research Part D; 59–67.

[958] Pratt, G.C.; Vadali, M.L.; Kvale, D.L.; Ellickson, K.M. (2015) Traffic, air pollution, minority, and socio-economic status: addressing inequities in exposure and risk. Int J Environ Res Public Health 12: 5355–5372. *http://dx.doi.org/10.3390/ijerph120505355.*

[959] Sohrabi, S.; Zietsman, J.; Khreis, H. (2020) Burden of disease assessment of ambient air pollution and premature mortality in urban areas: the role of socioeconomic status and transportation. Int J Env Res Public Health doi:10.3390/ijerph17041166.

[960] TROPospheric Ozone Monitoring Instrument (TROPOMI) is part of the Copernicus Sentinel-5 Precursor satellite.

[961] Kerr, G.H.; Goldberg, D.L.; Anenberg, S.C. (2021) COVID–19 pandemic reveals persistent disparities in nitrogen dioxide pollution. PNAS 118. [Online at *https://doi.org/10.1073/pnas.2022409118*].

average NO_2 concentrations were highest in areas with the lowest percentage of white populations, and that the areas with the greatest percentages of non-white or Hispanic populations experienced the greatest declines in NO_2 concentrations during the lockdown. These NO_2 reductions were associated with the density of highways in the local area.

In the second study, NO_2 measured from 2018–2020 was averaged by racial groups and income levels in 52 large U.S. cities.[962] Using census tract-level NO_2, the study reported average population-weighted NO_2 levels to be 28 percent higher for low-income non-White people compared with high-income white people. The study also used weekday-weekend differences and bottom-up emission estimates to estimate that diesel traffic is the dominant source of NO_2 disparities in the studied cities.

Overall, there is substantial evidence that people who live or attend school near major roadways are more likely to be of a non-White race, Hispanic, and/or have a low SES. We expect communities near roads will benefit from the reduced tailpipe emissions of PM, NO_X, SO_2, VOC, CO, and mobile source air toxics from heavy-duty vehicles in this proposal. EPA is considering how to better estimate the near-roadway air quality impacts of its regulatory actions and how those impacts are distributed across populations.

ii. Upstream Source Impacts

As described in Section V.B.2, we expect some non-GHG emissions reductions from sources related to refining petroleum fuels and increases in emissions from EGUs, both of which would lead to changes in exposure for people living in communities near these facilities. The EGU emissions increases become smaller over time because of changes in the projected power generation mix as electricity generation uses less fossil fuels; in 2055, the reductions in vehicle and refinery-related emissions of NO_X, VOC, $PM_{2.5}$, and SO_2 are larger than the EGU-related increases. Analyses of communities in close proximity to EGUs have found that a higher percentage of communities of color and low-income communities live near these sources when compared to national averages.[963] Analysis of populations near refineries also indicates there may be potential disparities in pollution-related health risk from that source.[964]

E. Economic Impacts

1. Impacts on Vehicle Sales, Fleet Turnover, Mode Shift, Class Shift and Domestic Production

In this section, we qualitatively discuss the impacts the proposed regulation may have on HD vehicle sales, including pre-buy and low-buy decisions, effects on decisions regarding the mode of transportation used to move goods, possible shifting of purchases between HD vehicle classes, and possible effects on domestic production of HD vehicles. Pre-buy occurs when a purchaser pulls ahead a planned future purchase to make the purchase prior to the implementation of an EPA regulation in anticipation that a future vehicle may have a higher upfront cost, a higher operational cost, or have reduced reliability due to the new regulation. Low-buy occurs when a vehicle that would have been purchased after the implementation of a regulation is either not purchased at all, or the purchase is delayed due to the regulation. Low-buy may occur directly as a function of pre-buy (where a vehicle was instead purchased prior to implementation of the new regulation), or due to a vehicle purchaser delaying the purchase of a vehicle due to cost or uncertainty. Pre- and low-buy are short-term effects, with research indicating that effects are seen for one year or less before and after a regulation in implemented.[965] Pre-buy and low-buy impact fleet turnover, which can result in a level of emission reduction attributable to the new emission standards that is different from the level of emission reduction EPA estimated would be achieved by the new regulation.

Additional possible, though unlikely, effects of this proposed regulation include mode shift, class shift and effects on domestic production. Mode shift would occur if goods that would normally be shipped by HD vehicle are instead shipped by another method (*e.g.,* rail, boat, air) as a result of this action. Class shift occurs when a vehicle purchaser decides to purchase a different class of vehicle than originally intended due to the new regulation. For example, a purchaser may buy a Class 8 vehicle instead of the Class 7 vehicle they may have purchased in the absence of a regulation. Domestic production could be affected if the regulation creates incentives for manufacturers to shift between domestic and foreign production.

i. Vehicle Sales and Fleet Turnover

The proposed emission standards may lead to a change in the timing of planned vehicle purchases, phenomena known as ‘‘pre-buy’’ and ‘‘low-buy.’’ Pre-buy occurs when purchasers of HD vehicles pull their planned future vehicle purchase forward to the months before a regulation is implemented compared to when they otherwise would have purchased a new vehicle in the absence of the regulation. Pre-buy may occur due to expected cost increases of post-regulation vehicles, or in order to avoid perceived cost, quality, or other changes associated with new emission standards. Another reason pre-buy might occur is due to purchaser beliefs about the availability of their vehicle type of choice in the post-regulation market. For example, if purchasers think that they might not be able to get the HD ICE vehicle they want after the proposed regulation is promulgated, they may pre-buy an ICE vehicle. Pre-buy, to the extent it might occur, could be mitigated in multiple ways, including by reducing the higher upfront cost of post-regulation vehicles, by purchasers considering the lower operational costs of post-regulation vehicles when making their purchase decision, or through the phasing in of the proposed standards. With respect to possible purchaser anxiety over being unable to purchase an ICE vehicle after promulgation of the proposed regulation, we expect that the federal vehicle and battery tax credits in the IRA, as well as purchasers' consideration of the lower operational costs of ZEVs, would mitigate possible pre-buy by reducing the perceived purchase price or lifetime operational costs difference of a new, post-rule ZEV compared to a new pre- or post-rule ICE vehicle. Additionally, pre-buy may be mitigated by educating purchasers on benefits of ZEV ownership (for example, reduced operational costs) or on charging and hydrogen refueling infrastructure technology and

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[962] Demetillo, M.A.; Harkins, C.; McDonald, B.C.; et al. (2021) Space-based observational constraints on NO_2 air pollution inequality from diesel traffic in major US cities. Geophys Res Lett 48, e2021GL094333. [Online at *https://doi.org/10.1029/2021GL094333*].

[963] See 80 FR 64662, 64915–64916 (October 23, 2015).

[964] U.S. EPA (2014). Risk and Technology Review—Analysis of Socio-Economic Factors for Populations Living Near Petroleum Refineries. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. January.

[965] See the EPA report ‘‘Analysis of Heavy-Duty Vehicle Sales Impacts Due to New Regulation’’ at *https://cfpub.epa.gov/si/si_public_pra_view.cfm?dirEntryID=349838&Lab=OTAQ* for a literature review and EPA analysis of pre-buy and low-buy due to HD regulations.

availability.[966] Our proposed standards will increase purchaser exposure to ZEVs, as well as incentivize manufacturers and dealers to educate HD vehicle purchasers on ZEVs, including the benefits of ZEVs, accelerating the reduction of purchaser risk aversion. In addition, we expect recent congessional actions to support ZEV infrastructure and supply chain, including the CHIPS Act, BIL and IRA, will reduce uncertainty related to infrastructure.[967] We note that the proposed standards do not mandate the use of a specific technology, and EPA anticipates that a compliant fleet under the proposed standards would include a diverse range of technologies, including ICE and ZEV technologies. The phasing-in of the proposed standards, which do not eliminate any specific technology from the market, would allow ample time for purchasers to make decisions about their vehicle of choice.

In addition to pre-buy, there is the possibility of ''low-buy'' occurring in response to new regulation. In a low-buy scenario, sales of HD vehicles would decrease in the months after a regulation becomes effective, compared to what would have happened in the absence of a regulation, due to purchasers either pre-buying or delaying a planned purchase. Low-buy may be directly attributable to pre-buy, where purchases originally planned for the months following the effective date of new emission standards are instead purchased in the months preceding the effective date of the new emission standards. Low-buy may also be attributable to purchasers delaying the planned purchase of a new vehicle due to the new emission standards, and may occur for reasons such as increased costs or uncertainty about the new vehicles. If pre-buy is smaller than low-buy, to the extent both might occur, this would lead to a slower fleet turnover, at least in the short term.[968] In this scenario, older HD vehicles would remain in use longer than they would have in the absence of the new emission standards. This would lead to lower emission reductions than we estimate would be achieved as a result of the proposed emission standards. Conversely, if pre-buy is larger than low-buy, short-term fleet turnover would increase; fleets would, on average, be comprised of newer model year vehicles. Though these new vehicles are expected to have lower emissions than the vehicles they are replacing, and emission reductions would be expected to be larger than under a scenario where low-buy exceeds pre-buy, emission reductions would still be lower than we estimated would be achieved as a result of the proposed emission standards. Under a situation where low-buy matches pre-buy, we would also expect lower emission reductions than estimated, and emission reductions would likely be somewhere between the two relative pre-buy/low-buy scenarios discussed in the previous paragraph. We expect low-buy, to the extent that it might occur, to be mitigated under the same circumstances described in this section for pre-buy.

Analysis of previously promulgated EPA HD emission standards indicates that where pre-buy or low-buy has been seen, the magnitude of these phenomena has been small.[969] Recent analysis conducted by EPA of pre-buy and low-buy indicates that pre-buy and low-buy effects typically occur for up to one year before or one year after a regulation becomes effective, if pre-buy or low-buy occur at all.[970] EPA contracted with ERG to complete a literature review of research estimating HD vehicle sales impacts resulting from HD regulations, and to conduct original research to estimate the existence and magnitude of pre-buy and low-buy sales impacts of previous EPA HD regulations.[971] The resulting analysis examined the effect of four HD regulations (those that became effective in 2004, 2007, 2010 and 2014) on the sales of Class 6, 7 and 8 vehicles over the twelve months before and after each standard. For the purposes of this discussion, we will call these the 2004 rule, 2007 rule, 2010 rule and 2014 rule. The 2004, 2007 and 2010 rules focused on reducing criteria pollutant emissions from HD vehicles and engines, and the 2014 rule (the HD GHG Phase 1 rule promulgated in 2014) focused on reducing GHG emissions from HD vehicles and engines.[972] The ERG report found little evidence of pre-buy or low-buy sales impacts on Class 6 and 7 vehicles for any of the rules. For Class 8 vehicles, evidence of pre-buy was found for up to eight months before promulgation of the 2010 rule, as well as for up to one month prior to promulgation of the 2014 rule. Evidence of low-buy was found after promulgation of the 2002 (up to six months), 2007 (up to 12 months) and 2010 rules (up to five months). The results of the ERG report also suggest that the range of possible results include a lower bound of zero, or no pre-buy or low-buy due to EPA rules.

While it is instructive that the ERG report found little to no pre-buy or low-buy effects due to our HD rules, EPA does not believe the approach to estimate a change in the sales of HD vehicles before and after the promulgation of a rule due to the cost of that rule (as was done in the ERG report) should be used to estimate sales effects from this proposed rule for three main reasons.[973] First, as outlined in the previous paragraph, most of the statistically significant sales effects in the ERG report were estimated using data from criteria pollutant rules (the 2002, 2004 and 2007 rules), which are not appropriate for use in estimating effects from HD GHG rules. This is because differences in how costs are incurred and benefits are accrued as a result of HD vehicle criteria pollutant regulations versus HD GHG regulations

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[966] For more information on purchaser acceptance of HD ZEVs, see DRIA Chapter 6.2. For more information on the charging and hydrogen refueling infrastructure analysis in this proposed rule, see DRIA Chapter 2.6.

[967] The CHIPS Act is the Creating Helpful Incentives to Produce Semiconductors and Science Act and was signed into lay on August 9, 2022. It is designed to strengthen supply chains, domestic manufacturing and national security. More information on how all of these Acts are expected to support opportunities for growth along the supply chain can be found in the January 2023 White House publication ''Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action.'' found online at *https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf.*

[968] Fleet turnover refers to the pace at which new vehicles are purchased and older vehicles are retired. A slower fleet turnover means older vehicles are kept on the road longer, and the fleet is older on average. A faster fleet turnover means that the fleet is younger, on average.

[969] For example, Lam and Bausell (YEAR), Rittenhouse and Zaragoza-Watkins (YEAR), and an unpublished report by Harrison and LeBel (2008). For EPA's summary on these studies, see the EPA peer review cited in the footnote below, or the recently published EPA Heavy-Duty 2027 rule at Docket ID EPA–HQ–2019–0555.

[970] ''Analysis of Heavy-Duty Vehicle Sales Impacts Due to New Regulation.'' At *https://cfpub.epa.gov/si/si_public_pra_view.cfm?dirEntryID=349838&Lab=OTAQ.*

[971] ''Analysis of Heavy-Duty Vehicle Sales Impacts Due to New Regulation.'' At *https://cfpub.epa.gov/si/si_public_pra_view.cfm?dirEntryID=349838&Lab=OTAQ.*

[972] The 2004 rule, 'Final Rule for Control of Emission of Air Pollution From Highway Heavy-Duty Engines', was finalized in 1997. The 2007 and 2010 rules were finalized as phase-ins in the 'Final Rule for Control of Emissions of Air Pollution from 2004 and Later Model Year Heavy-Duty Highway Engines and Vehicles; Revision of Light-Duty On-Board Diagnostics Requirements' in 2000. The 2014 GHG rule, 'Final Rule for Phase 1 Greenhouse House Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles,' was finalized in 2011. These rules can be found on the EPA website *https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-commercial-trucks-and-buses-heavy.*

[973] See the RIA for the HD 2027 rule for an example of how we might estimate potential impacts of a HD regulation on vehicle sales, including pre-buy and low-buy using the approach introduced in the ERG report. 87 FR 17590. March 28, 2022.

may lead to differences in how HD vehicle buyers react to a particular regulation. For example, the 2014 rule [974] led to reductions in GHG emissions and had lower associated technology costs compared to the criteria pollutant rules, and compliance with the GHG regulation was associated with fuel savings. We also expect fuel savings effects in this proposal, as described in Section IV. Second, the pre-buy and low-buy sales effects were estimated as a function of the average change in cost of a HD vehicle for each vehicle class due to the specific rule under consideration (for example, the 2007 rule or 2014 rule). However, unlike criteria pollutant rules, there were multiple pathways to compliance with 2014 rule, and therefore uncertainty in the price change due to the rule, which led to uncertainty in the results estimated using these price changes. Third, the approach outlined in the ERG report was estimated only using HD ICE vehicle data (*i.e.,* cost of compliance due to adding technology to a HD ICE engine). The research and methodology in the ERG report did not include any data from the production, sale, or purchase of HD ZEVs. For these reasons, we are not using the method in the ERG report to estimate sales effects due to this rule. We request comment on data or methods to estimate the possible effects of this regulation on the sale of HD ICE vehicles and HD ZEV sales, including potential impacts associated with pre-buy and low-buy.

This proposed rulemaking would be expected to lead to reductions in emissions across the HD vehicle fleet (Section V of this preamble), though such reductions are expected to happen gradually as the HD fleet turns over. This is because the fraction of the total HD vehicle fleet that is new ZEVs would initially be a small portion of the entire HD market. As more HD ZEVs are sold, and as older HD ICE vehicles are retired, greater emission reductions are expected to occur. The emission reductions attributable to each HD segment that would be affected by this proposed rule would depend on many factors, including the individual increase in ZEV adoption in each market segment over time, as well as relative usage, measured in VMT, for a HD ZEV when compared to a similar HD ICE vehicle. For example, if ZEV uptake occurs faster than predicted, emission reductions would happen faster than estimated. If, assuming no change in total fleet VMT, the VMT attributed to a HD ZEV is less than that of the HD ICE vehicle it is displacing, emission reductions would happen slower than estimated. In addition, if pre-buy or low-buy occurs as a result of this proposed rulemaking, emission reductions would be smaller than anticipated. This is because, under pre-buy conditions, the pre-bought vehicles will not be subject to the tighter emission standards, and are less likely to be ZEVs; however, the pre-bought new vehicles are likely to be less polluting than the older HD vehicles they are replacing due to more stringent HD emission standards for new engines and vehicles (if it is a replacement purchase). Under low-buy, we would expect older, more polluting, HD vehicles would remain in use longer than they otherwise would in the absence of new regulation. We expect pre-buy and low-buy to be very small, if they occur at all. For more information on sales impacts, see Chapter 6.1.1 of the DRIA. We request comment on data and methods to estimate possible effects of the proposed emission standards on fleet turnover and to estimate the VMT of HD ZEVs in comparison to HD ICE vehicles.

ii. Mode Shift

Another potential, though unlikely, effect of this proposed regulation may be mode shift. Mode shift would occur if goods that would normally be shipped by HD vehicle are instead shipped by another method (*e.g.,* rail, boat, air) as a result of this action. Whether shippers switch to a different mode of transportation for freight depends not only on the cost per mile of the shipment (*i.e.,* freight rate), but also the value of the shipment, the speed of transport needed for shipment (for example, for non-durable goods), and the availability of supporting infrastructure (*e.g.,* rail lines, highways, waterways). Shifting from HD vehicles to other modes of transportation may occur if the cost of shipping goods by HD vehicles increases relative to other modes of transport, and it is feasible to switch the shipment from truck to another mode of transport. Chapter 3.3 of the DRIA and Section IV.D of this preamble discuss the estimated decrease in operational costs of this proposed rule, mainly due to the increase in the share of ZEVs in the on-road HD fleet. Because the effects of this proposed action are expected to reduce operational costs for trucks, we do not think mode shift would be a likely outcome of this proposed regulation.[975] We are asking for comment on data and methods to estimate possible effects of the proposed emission standards on mode shift. For more information on mode shift, see Chapter 6.1.2 of the DRIA.

iii. Class Shift

Class shift is also a possible effect of this proposed rule. Class shift would occur if purchasers shift their purchases from one class of vehicle to another class of vehicle due to differences in cost among vehicle types. We expect that class shifting, if it does occur, would be limited. The proposed emission standards are projected to lead to an increase in the incremental cost per vehicle for many classes of vehicles across both vocational vehicles and tractor categories before accounting for the IRA vehicle and battery tax credits. After accounting for these credits, our estimates show that this upfront increase in cost is reduced, and in fact, we estimate that some vocational vehicles and tractor ZEVs have lower or equivalent upfront costs compared to comparable ICE vehicles. For more information, see Preamble Section IV.D or DRIA Chapter 3.4. Furthermore, the upfront costs for vocational vehicles and tractors would be offset by operational cost savings.

Another reason EPA believes class shift would be limited, if it occurs, is that HD vehicles are typically configured and purchased to perform a specific function. For example, a concrete mixer is purchased to transport concrete, or a combination tractor is purchased to move freight with the use of a trailer. In addition, a purchaser in need of a specific vocational vehicle, such as a bus, box truck or street sweeper, would not be able to shift the purchase to a vehicle with a less stringent emission standard (such as the optional custom chassis standards for emergency vehicles, recreational vehicles, or mixed use (nonroad) type vehicles) and still meet their needs. The purchaser makes decisions based on many attributes of the vehicle, including the gross vehicle weight rating or gross combined weight rating of the vehicle, which in part determines the amount of freight or equipment that can be carried. Due to this, it may not be feasible for purchasers to switch to other vehicle classes. If a limited amount of shifting were to occur, we would expect negligible emission impacts (compared

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[974] 'Final Rule for Phase 1 Greenhouse House Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles' can be found at *https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-phase-1-greenhouse-gas-emissions-standards.*

[975] If manufacturers comply by adding technology to ICE vehicles, we would also expect to see reduced operational costs through reduced fuel consumption.

to those emission reductions estimated to occur as a result of the proposed emission standards) because the vehicle classes that would be feasibly 'switched' are all subject to this proposed rule. We request comment on data or methods to estimate the effect the proposed emission standards might have on class shifting.

iv. Domestic Production

The proposed emission standards are not expected to provide incentives for manufacturers to shift between domestic and foreign production. This is because the emission standards apply to vehicles sold in the United States regardless of where such vehicles are produced. If foreign manufacturers already have increased expertise in satisfying the requirements of the emission standards, there may be some initial incentive for foreign production. However, given increasing global interest in reducing vehicle emissions, specifically through the use of ZEVs, as domestic manufacturers produce vehicles with reduced emissions, including ZEVs, the opportunity for domestic manufacturers to sell in other markets might increase. To the extent that the proposed emission standards might lead to application and use of technologies that other countries may seek now or in the future, developing this capacity for domestic producers now may provide some additional ability to serve those markets.

As discussed in Preamble Section 1.C, and DRIA Chapter 1, the IRA contains tax credit incentives that are impacted by the location of production and may encourage domestic production of ZEV vehicles or components. A portion of these tax incentives are included in our cost analysis for the proposed rule, as describe in Section IV, and DRIA Chapter 3. We request comment on whether our standards would impact the domestic production of HD vehicle components.

2. Purchaser Acceptance

We expect this proposed rule to lead to an increase in the adoption of HD BEVs and FCEVs for most HD vehicle types beginning in MY 2027 (see Section II of this preamble or DRIA Chapter 2 for details). Businesses that operate HD vehicles are under competitive pressure to reduce operating costs, which should encourage purchasers to identify and rapidly adopt new vehicle technologies that reduce operating costs. As outlays for labor and fuel generally constitute the two largest shares of HD vehicle operating costs, depending on the price of fuel, distance traveled, type of HD vehicle, and commodity transported (if any), businesses that operate HDVs face strong incentives to reduce these costs.[976] [977] As explained in Section IV and Chapter 3 of the DRIA, though HD ZEVs in general have higher upfront costs than comparable ICE vehicles, our costs analysis shows that the incremental upfront cost difference between a ZEV and a comparable ICE vehicle would be partially or fully offset by a combination of the federal vehicle tax credit and battery tax credit for HD ZEVs that are available through MY 2032 and operational savings.[978] For the vehicle types for which we propose new CO_2 emission standards, we expect that the ZEVs will have a lower total cost of ownership when compared to a comparable ICE vehicle (even after considering the upfront cost of purchasing the associated EVSE for a BEV), due to the expected cost savings in fuel, maintenance, and repair over the life of the HD ZEV when compared to comparable ICE vehicle. See Section IV of this preamble and Chapter 3 of the DRIA for more information on the estimated costs of this proposed rule.

In DRIA Chapter 6.2, we discuss the possibility that an "energy efficiency gap" or "energy paradox" has existed, where available technologies that would reduce the total cost of ownership for the vehicle (when evaluated over their expected lifetimes using conventional discount rates) have not been widely adopted, or the adoption is relatively slow, despite their potential to repay buyers' initial investments rapidly. We recognize that there are factors that may impact adoption of HD ZEVs, including uncertainty related to the technology and supporting infrastructure, as well as incentives created by this proposed rule for manufacturers to develop ZEV technology and educate purchasers.

We expect that adoption rates of HD ZEVs will be impacted by buyers taking advantage of existing incentives, specifically the IRA vehicle tax credit and battery tax credit, as well as the extent to which buyers consider the cost savings of purchasing a ZEV over a HD ICE vehicle in their purchase decision, mainly observed through operational cost savings. We expect purchasing decisions would also be affected by purchasers' impressions of charging infrastructure support and availability, perceptions of the comparisons of quality and durability of the different HD powertrains, and resale value of the vehicle.

The availability of existing incentives, specifically the Federal purchaser and battery manufacturing tax credits in the IRA, is expected to lead to lower upfront costs for purchasers of HD ZEVs than would otherwise occur.[979] We expect this will result in a higher ZEV adoption rate than would otherwise exist absent such incentives. In addition, as purchasers consider more of the operational cost savings of a ZEV over a comparable ICE vehicle in their purchase decision, the smaller the impact of the higher upfront costs for purchasers of a ZEV compared to an ICE vehicle has on that decision, and purchasers are more likely to purchase a ZEV. We note that ZEVs may not be purchased at the rates estimated in the analysis for this proposed rule. They may be smaller if purchasers do not consider the full, or even a portion of, value of operational cost savings, which may happen due to uncertainty, *e.g.,* uncertainty about future fuel prices. Additionally, this may occur if a principal-agent problem exists, causing split incentives.[980] A principal-agent problem would exist if truck operators (agents) and truck purchasers who are not also operators (principals) value operational cost savings differently (split incentives), which could lead to differences in purchase decisions between truck operators and truck purchasers. For example, a HD vehicle purchaser may not be directly responsible for the future fuel costs of the vehicle they purchase, or the person who would be responsible for those fuel costs may not be involved in the purchase decision. In this case, truck operators may place a higher value on the potential savings in operational costs over the lifetime of a vehicle and give less weight to the increase in upfront cost that may be associated with a ZEV purchase, whereas a truck purchaser may weigh higher upfront costs more heavily than possible operational cost savings. Such potential split incentives, or market failures, could lead to lower ZEV adoption rates than we are estimating in this proposal, which may reduce the non-GHG environmental benefits of the proposed emission standards due to lower non-

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[976] American Transportation Research Institute, *An Analysis of the Operational Costs of Trucking,* September 2013. Docket ID: EPA–HQ–OAR–2014–0827–0512.

[977] Transport Canada, Operating Cost of Trucks, 2005. Docket ID: EPA–HQ–OAR–2014–0827–0070.

[978] For more information on the Federal tax credits, see Section I.C.

[979] Note that the incentives exist in the baseline and under the scenario with our proposed standards.

[980] A principal-agent problem happens when there is a conflict in priorities (split incentives) between a "principal," or the owner of an asset, and an "agent," or the the person to whom control of the asset has been delegated, such as a manager or HD vehicle operator.

GHG emission reductions than estimated in this proposal. Other examples of this might include if a purchaser values charging or fueling infrastructure, either the cost of installation or the availability, differently than the operator. The direction of the effect in this case would depend on who was responsible for the cost of the infrastructure installation, or who places more value on the availability of widespread infrastructure.

Uncertainty about ZEV technology, charging infrastructure technology and availability for BEVs, or hydrogen refueling infrastructure for FCEVs, may affect ZEV adoption rates. As ZEVs become increasingly more affordable and ubiquitous, we expect uncertainty related to these technologies will diminish over time. As uncertainty related to these technologies decreases, it may lead to higher rates of ZEV adoption that estimated. In addition, ZEVs may be purchased at higher rates than estimated in the analysis if, for example, ZEV costs decrease faster than expected, or due to increasing commitments from fleet owners or operators to purchase ZEVs.

We expect that the Federal vehicle and battery tax credits in the IRA, as well as purchasers' consideration of the lower operational costs of ZEVs, would mitigate any possible pre-buy by reducing the perceived purchase price or lifetime operational costs difference of a new, post-rule ZEV compared to a new pre- or post-rule ICE vehicle. We expect this would increase purchaser willingness to purchase a new ZEV. When purchasers are educated on charging or refueling infrastructure technology and availability, both as it stands at the time of possible purchase, as well as plans for future availability, uncertainty related to operating a new ZEV decreases.

EPA recognizes that there is uncertainty related to ZEVs that may impact the adoption of this technology even though it reduces operating costs. Markets for both new and used HD vehicles may face these problems, although it is difficult to assess empirically the degree to which they do. We expect the proposed Phase 3 standards, if finalized, will help overcome such barriers by incentivizing the development of ZEV technologies and the education of HD vehicle purchasers on ZEV benefits and infrastructure.

We request comment and data on acceptance of HD ZEVs.

3. VMT Rebound

Historically, the ''rebound effect'' has been interpreted as more intensive vehicle use, resulting in an increase in liquid fuel in response to increased ICE vehicle fuel efficiency. Although much of this possible vehicle use increase is likely to take the form of an increase in the number of miles vehicles are driven, it can also take the form of an increase in the loaded operating weight of a vehicle or altering routes and schedules in response to improved fuel efficiency. More intensive use of those HD ICE vehicles consumes fuel and generates emissions, which reduces the fuel savings and avoided emissions that would otherwise be expected to result from increasing fuel efficiency of HD ICE vehicles.

Unlike the LD vehicle rebound effect, there is little published literature on the HD vehicle rebound effect, and all of it focuses on the rebound effect due to increased ICE fuel efficiency. Winebrake et al. (2015) suggests that vocational trucks and tractor trailers have a rebound effect of essentially zero. Leard et al. (2015) estimate that tractor trailers have a rebound effect of 30 percent, while vocational vehicles have a 10 percent rebound rate.[981] Patwary et al. (2021) estimated that the average rebound effect of the U.S. road freight sector is between about 7 to 9 percent, although their study indicated that rebound has increased over time.[982] This is slightly smaller than the value found by Leard et al. (2015) for the similar sector of tractors. We do not have data that operational cost savings of switching from an ICE vehicle to a ZEV will affect the VMT driven of that vehicle, nor do we have data on how changing fuel prices might affect VMT of ZEVs over time. Given the increasing penetration of ZEVs in the HD fleet, and the estimated increase over the time frame of this proposed rule, we do not believe the rebound estimates in literature cited here are appropriate for use in our analysis. Therefore, we are not estimating any VMT rebound due to this rule. We request comment on the VMT response of HD ICE vehicles and HD ZEVs due to this rule, including the response of increasing efficiency within ICE vehicles, as well as the response to switching from an ICE vehicle to a ZEV. We request comment and data on the rebound assumptions for HD ICE vehicles and HD ZEVs.

4. Employment Impacts

Economic theories of labor demand indicate that employers affected by environmental regulation may change their demand for different types of labor in different ways, increasing demand for some types, decreasing demand for other types, or not changing it at all for still other types. A variety of conditions can affect employment impacts of environmental regulation, including baseline labor market conditions and employer and worker characteristics such as industry and region. A growing body of literature has examined employment effects of environmental regulation. Morgenstern et al. decompose the labor consequences in a regulated industry facing increased abatement costs.[983] This study identifies three separate components of labor demand effects. First, there is a demand effect caused by higher production costs, which in turn, results in increased market prices. Increased market prices reduce consumption (and production), thereby reducing demand for labor within the regulated industry. Second, there is a cost effect. As production costs increase, manufacturing plants use more of all inputs, including labor, to produce the same level of output. Third, there is a factor-shift effect, which occurs when post-regulation production technologies may have different labor intensities than pre-regulation production technologies.[984]

Due to a lack of data, we are not able to estimate employment effects from this proposed rule. The overall effect of the proposed rule on employment in the heavy-duty vehicle manufacturing sector depends on the relative magnitude of factor-shift, cost, and demand effects, as well as possible differences in employment related to HD ICE and ZEV manufacturing. As markets shift to HD ZEVs, employment needs will shift as well. In Chapter 6.4.2 of the DRIA, we show that the amount of labor per million dollars in sales in motor vehicle manufacturing sectors has generally declined over time, indicating that fewer people have been needed to produce the same value of goods. For example, in 1997, motor vehicle body and trailer manufacturing employed

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[981] Leard, B., Linn, J., McConnell, V., and Raich, W. (2015). Fuel Costs, Economic Activity, and the Rebound Effect for Heavy-Duty Trucks. Resources For the Future Discussion Paper, 14–43.

[982] Patwary, A. L., Yu, T. E., English, B.C., Hughes, D. W., and Cho, S. H. (2021). Estimating the rebound effect of the US road freight transport. Transportation Research Record, 2675(6), 165–174.

[983] Morgenstern, R.D.; Pizer, W.A.; and Shih, J.-S. ''Jobs Versus the Environment: An Industry-Level Perspective.'' Journal of Environmental Economics and Management 43: 412–436. 2002.

[984] Additional literature using similar frameworks include Berman and Bui (2001) and Deschênes (2018). For more information on this literature, see the Chapter 10 of the RIA for the HD2027 rule, found at Docket ID EPA–HQ–OAR–2019–0055.

almost 3.4 employees per million dollars in sales. This fell to almost 2.7 in 2021. In the electrical equipment manufacturing sector, which is involved in the production of EVs, employment has increased from almost 2.3 to almost 2.7 per million dollars from 2007 to 2021. The International Union, United Automobile, Aerospace and Agricultural Implement Workers of America (UAW) states that re-training programs will be needed to support auto workers in a market with an increasing share of electric vehicles in order to prepare workers that might be displaced by the shift to the new technology.[985] Volkswagen states that labor requirements for ICE vehicles are about 70 percent higher than their electric counterpart, but these changes in employment intensities in the manufacturing of the vehicles can be offset by shifting to the production of new components, for example batteries or battery cells.[986] Climate Nexus indicates that transitioning to electric vehicles will lead to a net increase in jobs, a claim that is partially supported by the rising investment in batteries, vehicle manufacturing and charging stations.[987] Though most of these statements are specifically referring to light-duty vehicles, they hold true for the HD market as well. The expected investment mentioned by Climate Nexus is also supported by recent Federal investment which will allow for increased investment along the vehicle supply chain, including domestic battery manufacturing, charging infrastructure, and vehicle manufacturing, both in the LD and HD markets.[988] This investment includes the BIL, the CHIPS Act,[989] and the IRA, which are expected to create domestic employment opportunities along the full automotive sector supply chain, from components and equipment manufacturing and processing to final assembly, as well as incentivize the development of reliable EV battery supply chains.[990] For example, the IRA is expected to impact domestic employment through conditions on eligibility for purchase incentives and battery manufacturing incentives. These conditions include contingencies for domestic assembly, domestic critical materials production, and domestic battery manufacturing. The BlueGreen Alliance and the Political Economy Research Institute estimate that IRA will create over 9 million jobs over the next decade, with about 400,000 of those jobs being attributed directly to the battery and fuel cell vehicle provisions in the act.[991] In addition, the IRA is expected to lead to increased demand in ZEVs through tax credits for purchasers of ZEVs.

The factor-shift effect on employment reflects potential employment changes due to changes in labor intensity of production resulting from compliance activities. The proposed standards do not mandate the use of a specific technology, and EPA anticipates that a compliant fleet under the proposed standards would include a diverse range of technologies including ICE and ZEV technologies. In our assessment that supports the appropriateness and feasibility of the proposed standards, we developed a technology pathway that could be used to meet each of the standards, which project the increased ZEV adoption rates. ZEVs and ICE vehicles require different inputs and have different costs of production, though there are some common parts as well. There is little research on the relative labor intensity needs of producing a HD ICE vehicle versus producing an equivalent HD ZEV. Though there are some news articles and research from the light-duty motor vehicle market, they do not provide a clear indication of the relationship between employment needs for ZEVs and ICE vehicles. Some studies find that LD BEVs are less complex, requiring fewer person-hours to assemble than an equivalent ICE vehicle.[992] Others find that there is not a significant difference in the employment needed to produce ICE vehicles when compared to ZEVs.[993] We do not have data on employment differences in traditional ICE manufacturing sectors and ZEV manufacturing sectors, especially for expected effects in the future, nor do we have data on the employment needed for the level of battery production we anticipate will be required to meet future HD ZEV demand. We request comment on data concerning the potential employment impacts of HD component and vehicle manufacturing of ZEVs, including batteries.

The demand effect reflects potential employment changes due to changes in new HD vehicle sales. If HD ICE vehicle sales decrease, fewer people would be needed to assemble trucks and the components used to manufacture them. On the other hand, if HD ZEV sales increase, more people would be needed to assemble HD ZEVs and their components, including batteries. Additional, short-term, effects might be seen if pre-buy or low-buy were to occur. If pre-buy occurs, HD vehicle sales may increase temporarily, leading to temporary increases in employment in the related manufacturing sectors. If low-buy occurs, there may be temporary decreases in employment in the manufacturing sectors related to HD vehicles.

The cost effect reflects the potential impact on employment due to increased costs from adopting technologies needed for vehicles to meet the new emission standards. In the HD ICE vehicle manufacturing sector, if firms invest in lower emitting HD ICE vehicles, we would expect labor to be used to implement those technologies. We do not expect the rule to require compliance activities in the production of ZEVs, as these vehicles, by definition, emit zero emissions. In addition, though the proposed standards do not mandate the use of a specific technology, and EPA anticipates that a compliant fleet

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[985] More information on UAW's comments can be found in the white paper ''Making EVs work for American workers'' found at *https://uaw.org/wp-content/uploads/2019/07/190416-EV-White-Paper-REVISED-January-2020-Final.pdf.*

[986] Herrmann, F., Beinhauer, W., Borrmann, D., Hertwig, M., Mack, J., Potinecke, T., Praeg, C., Rally, P. 2020. Effects of Electric Mobility and Digitlaisation on the Quality and Quantity of Employment at Volkswagen. Fraunhofer Institute for Industrial Engineering IAO. Study on behalf of the Sustainability Council of the Volkswagen Group. *https://www.volkswagenag.com/presence/stories/2020/12/frauenhofer-studie/6095_EMDI_VW_Summary_um.pdf.*

[987] See the report from Climate Nexus at *https://climatenexus.org/climate-issues/energy/ev-job-impacts/.*

[988] See Preamble Section I for information on the BIL and IRA provisions relevant to vehicle electrification, and the associated infrastructure.

[989] The CHIPS Act is the Creating Helpful Incentives to Produce Semiconductors and Science Act and was signed into lay on August 9, 2022. It is designed to strengthen supply chains, domestic manufacturing and national security. More information can be found at *https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/.*

[990] More information on how these acts are expected to aid employment growth and create opportunities for growth along the supply chain can be found in the January, 2023 White House publication ''Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action.'' found online at *https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf.*

[991] Political Economy Research Institute. (2022). *Job Creation Estimates Through Proposed Inflation Reduction Act.* University of Massachusetts Amherst. Retrieved from *https://www.bluegreenalliance.org/site/9-million-good-jobs-from-climate-action-the-inflation-reduction-act.*

[992] Barret, J. and Bivens, J. (2021). The stakes for workers in how policymakers manage the coming shift to all-electric vehicles. Economic Policy Institute. *https://www.epi.org/publication/ev-policy-workers.*

[993] Kupper, D., Kuhlmann, K., Tominaga, K., Arora, A., Schlageter, J.. (2020). Shifting Gears in Auto Manufacturing. *https://www.bcg.com/publications/2020/transformative-impact-of-electric-vehicles-on-auto-manufacturing.*

under the proposed standards would include a diverse range of technologies including ICE and ZEV technologies, in our assessment that supports the appropriateness and feasibility of the proposed standards, we developed a technology pathway that could be used to meet each of the standards, which project increased ZEV adoption rates. Therefore, we expect little cost effect on employment due to this rule.

We request comment on data and methods that could be used to estimate the potential effects of this action on employment in HD vehicle manufacturing sectors, and on how increasing electrification in the HD market in general, might impact employment in HD manufacturing sectors, both for ICE powertrains as well as electrified powertrains. We request comment on data and methods to estimate possible effects of the proposed emission standards on employment in the HD ICE and ZEVs manufacturing markets.

As the share of ZEVs in the HD market increases, there may also be effects on employment in the associated BEV charging and hydrogen refueling infrastructure industries. These impacts may occur in several ways, including through greater demand for charging and fueling infrastructure to support more ZEVs, leading to more private and public charging and fueling facilities being constructed, or through greater use of existing facilities, which can lead to increased maintenance needs for those facilities. We request comment on data and methods that could be used to estimate the effect of this action on the HD BEV vehicle charging infrastructure industry.

Because of the diversity of the HD vehicle market, we expect that entities from a wide range of transportation sectors would purchase vehicles subject to the proposed emission standards. HD vehicles are typically commercial in nature, and typically provide an ‘‘intermediate good,’’ meaning that such vehicles are used to provide a commercial service (transporting goods, municipal service vehicles, etc.), rather than serving as final consumer goods themselves (as most light-duty vehicles do). As a result, the purchase price of a new HD vehicle likely impacts the price of the service provided by that vehicle. If lifetime operational cost savings, or purchase incentives (as might be available for a new ZEV), are not accounted for in the prices for services provided by the new vehicles, this may result in higher prices for the services provided by these vehicles compared to the same services provided by a pre-regulation vehicle, and potentially reduce demand for the services such vehicles provide. In turn, there may be less employment in the sectors providing such services. On the other hand, if these cost savings are passed on to consumers through lower prices for services provided, it may lead to an increase in demand for those services, and therefore may lead to an increase in employment in those sectors providing those services. We expect that the actual effects on demand for the services provided by these vehicles and related employment would depend on cost pass-through, as well as responsiveness of demand to increases in transportation cost, should such increases occur.[994]

This action may also produce employment effects in other sectors, for example, in firms providing fuel. While reduced fuel consumption represents cost savings for purchasers of fuel, it could also represent a loss in value of output for the petroleum refining industry, which could result in reduced employment in that sector. Because the petroleum refining industry is material-intensive, and EPA estimates the reduction in fuel consumption will be mainly met by reductions in oil imports (see Section VI.F), the employment effect is not expected to be large.

This proposed action could also provide some positive impacts on driver employment in the heavy-duty trucking industry. As discussed in Section IV, the reduction in fuel costs from purchasing a ZEV instead of an ICE vehicle would be expected to not only reduce operational costs for ZEV owners and operators, compared to an ICE vehicle, but may also provide additional incentives to purchase a HD ZEV over a HD ICE vehicle. For example, in comments submitted as part of the recent HD 2027 proposal, the Zero Emission Transportation Association stated that driver satisfaction due to ‘‘a smoother ride with minimal vibrations, less noise pollution, and a high-tech driving experience free from the fumes of diesel exhaust’’ has the possibility of decreasing truck driver shortages and increasing driver retention.

F. Oil Imports and Electricity and Hydrogen Consumption

The proposed standards would reduce not only GHG emissions but also liquid fuel consumption (*i.e.,* oil consumption) while simultaneously increasing electricity and hydrogen consumption. Reducing liquid fuel consumption is a significant means of reducing GHG emissions from the transportation sector. As discussed in Section V and DRIA Chapter 4, we used an updated version of EPA's MOVES model to estimate the impact of the proposed standards on heavy-duty vehicle emissions, fuel consumption, and electricity consumption. In Chapter 6.5 of the DRIA, we present fossil fuel—diesel, gasoline, CNG—consumption impacts. Table 6–1 in Chapter 6 of the DRIA shows the estimated reduction in U.S. oil imports under the proposed standards relative to the reference case scenario. This proposal is projected to reduce U.S. oil imports 4.3 billion gallons through 2055. The oil import reductions are the result of reduced consumption (*i.e.,* reduced liquid fuel demand) of both diesel fuel and gasoline and our estimate that 86.4 percent of reduced liquid fuel demand results in reduced imports.[995] DRIA Table 6–1 also includes the projected increase in electricity and hydrogen consumption due to the proposed rule.

VII. Benefits of the Proposed Program

A. Social Cost of GHGs

EPA estimated the climate benefits for the proposed standards using measures of the social cost of three GHGs: Carbon, Methane, and Nitrous oxide. The social cost of each gas (*i.e.,* the social cost of carbon (SC-CO_2), methane (SC-CH_4), and nitrous oxide (SC-N_2O)) is the monetary value of the net harm to society associated with a marginal increase in emissions in a given year, or the benefit of avoiding such an increase. Collectively, these values are referenced as the ‘‘social cost of greenhouse gases’’ (SC-GHG). In principle, SC-GHG includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk and natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG, therefore, reflects the societal value of reducing emissions of the gas in question by one metric ton and is the theoretically appropriate value to use in conducting benefit-cost analyses of policies that affect GHG emissions. EPA and other Federal agencies began regularly incorporating SC-GHG estimates in their benefit-cost analyses conducted under Executive

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[994] Cost pass-through refers to the amount of increase in up-front cost incurred by the HD vehicle owner that is then passed on to their customers in the form of higher prices for services provided by the HD vehicle owner.

[995] To estimate the 86.4 percent import reduction factor, we look at changes in U.S. crude oil imports/exports and net refined petroleum products in the AEO 2022 Reference Case, Table 11. Petroleum and Other Liquids Supply and Disposition, in comparison to the Low Economic Growth Case from the AEO 2022. See the spreadsheet, ‘‘Low vs Reference case impact on Imports 2022 AEO.xlsx’’.

Order (E.O.) 12866[996] since 2008, following a Ninth Circuit Court of Appeals remand of a rule for failing to monetize the benefits of reducing CO_2 emissions in a rulemaking process.

We estimate the global social benefits of CO_2, CH_4, and N_2O emission reductions expected from the proposed rule using the SC-GHG estimates presented in the February 2021 Technical Support Document (TSD): Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under E.O. 13990 (IWG 2021). These SC-GHG estimates are interim values developed under E.O. 13990 for use in benefit-cost analyses until updated estimates of the impacts of climate change can be developed based on the best available climate science and economics. We have evaluated the SC-GHG estimates in the TSD and have determined that these estimates are appropriate for use in estimating the global social benefits of CO_2, CH4, and N2O emission reductions expected from this proposed rule. After considering the TSD, and the issues and studies discussed therein, EPA finds that these estimates, while likely an underestimate, are the best currently available SC-GHG estimates. These SC-GHG estimates were developed over many years using a transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. As discussed in Chapter 7 of the DRIA, these interim SC-GHG estimates have a number of limitations, including that the models used to produce them do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate-change literature and that several modeling input assumptions are outdated. As discussed in the February 2021 TSD, the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG) finds that, taken together, the limitations suggest that these SC-GHG estimates likely underestimate the damages from GHG emissions. The IWG is currently working on a comprehensive update of the SC-GHG estimates (under E.O. 13990) taking into consideration recommendations from the National Academies of Sciences, Engineering and Medicine, recent scientific literature, public comments received on the February 2021 TSD and other input from experts and diverse stakeholder groups. The EPA is participating in the IWG's work. In addition, while that process continues, EPA is continuously reviewing developments in the scientific literature on the SC-GHG, including more robust methodologies for estimating damages from emissions, and looking for opportunities to further improve SC-GHG estimation going forward. Most recently, EPA has developed a draft updated SC-GHG methodology within a sensitivity analysis in the regulatory impact analysis of EPA's November 2022 supplemental proposal for oil and gas standards that is currently undergoing external peer review and a public comment process. See Chapter 7 of the DRIA for more discussion of this effort.

We monetize benefits of the proposed standards and evaluate other costs in part to better enable a comparison of costs and benefits pursuant to E.O. 12866, but we recognize that there are benefits that we are currently unable to fully quantify. EPA's consistent practice has been to set standards to achieve improved air quality consistent with CAA section 202 and not to rely on cost-benefit calculations, with their uncertainties and limitations, in identifying the appropriate standards. Nonetheless, our conclusion that the estimated benefits considerably exceed the estimated costs of the proposed program reinforces our view that the proposed standards represent an appropriate weighing of the statutory factors and other relevant considerations.

Table VII–1 presents the estimated annual, undiscounted climate benefits of reduced GHG emissions, and consequently the annual quantified benefits (*i.e.,* total GHG benefits), for each of the four interim social cost of GHG (SC-GHG) values estimated by the interagency working group for the stream of years beginning with the first year of rule implementation, 2027, through 2055 for the proposed program. Also shown are the present values (PV) and equivalent annualized values (EAV) associated with each of the four interim SC-GHG values. As discussed in the DRIA Chapter 7, there are some limitations to the SC-GHG analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. Our analysis includes CO_2 emission increases from EGUs that would result from our proposal (see Section V) but we have not quantified upstream emissions impacts associated with liquid fuel refining.

TABLE VII–1—CLIMATE BENEFITS FROM REDUCTION IN GHG EMISSIONS ASSOCIATED WITH THE PROPOSAL

[Millions of 2021 Dollars]

Calendar Year	Proposal			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2027	$33	$110	$160	$320
2028	74	240	350	710
2029	120	400	580	1,200
2030	190	610	880	1,800
2031	290	900	1,300	2,700
2032	410	1,300	1,800	3,800
2033	530	1,600	2,300	4,900
2034	660	2,000	2,800	6,000
2035	780	2,300	3,300	7,100
2036	940	2,800	4,000	8,500
2037	1,100	3,300	4,700	9,900

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[996] Benefit-cost analyses have been an integral part of executive branch rulemaking for decades. Presidents since the 1970s have issued executive orders requiring agencies to conduct analysis of the economic consequences of regulations as part of the rulemaking development process. E.O. 12866, released in 1993 and still in effect today, requires that for all regulatory actions that are significant under 3(f)(1), an agency provide an assessment of the potential costs and benefits of the regulatory action, and that this assessment include a quantification of benefits and costs to the extent feasible.''

TABLE VII–1—CLIMATE BENEFITS FROM REDUCTION IN GHG EMISSIONS ASSOCIATED WITH THE PROPOSAL—Continued

[Millions of 2021 Dollars]

Calendar Year	Proposal			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2038	1,300	3,800	5,400	12,000
2039	1,500	4,300	6,100	13,000
2040	1,700	4,900	6,900	15,000
2041	1,900	5,400	7,600	16,000
2042	2,100	5,900	8,300	18,000
2043	2,300	6,500	9,000	20,000
2044	2,500	7,000	9,800	21,000
2045	2,700	7,500	10,000	23,000
2046	2,900	8,000	11,000	24,000
2047	3,100	8,400	12,000	26,000
2048	3,300	8,800	12,000	27,000
2049	3,500	9,200	13,000	28,000
2050	3,700	9,700	13,000	30,000
2051	3,800	10,000	14,000	30,000
2052	4,000	10,000	14,000	31,000
2053	4,100	11,000	15,000	32,000
2054	4,300	11,000	15,000	32,000
2055	4,400	11,000	15,000	33,000
Present Value	22,000	87,000	130,000	260,000
Equivalent Annualized Value	1,400	4,600	6,500	14,000

Note: Climate benefits include changes in vehicle GHGs and EGU CO_2 emissions, but do not include changes in other EGU GHGs or refinery GHGs.

B. Criteria Pollutant Health Benefits

This section discusses the economic benefits from reductions in adverse health impacts resulting from non-GHG emission reductions that can be expected to occur as a result of the proposed CO_2 emission standards. GHG emissions are predominantly the byproduct of fossil fuel combustion processes that also produce criteria and hazardous air pollutant emissions. The heavy-duty vehicles that are subject to the proposed CO_2 emission standards are also significant sources of mobile source air pollution such as directly-emitted PM, NO_X, VOCs, CO, SO_2 and air toxics. We expect the proposed CO_2 emission standards would lead to an increase in HD ZEVs and a decrease in HD ICE vehicles, which would result in reductions of these non-GHG pollutants (see Section V). Zero-emission technologies would also affect emissions from upstream sources that occur during, for example, electricity generation and from the refining and distribution of liquid fuel (see Section V). This proposal's benefits analysis includes added emissions due to increased electricity generation but does not include emissions reductions from reduced petroleum refining.

Changes in ambient concentrations of ozone, $PM_{2.5}$, and air toxics that would result from the proposed CO_2 emission standards are expected to affect human health by reducing premature deaths and other serious human health effects, and they are also expected to result in other important improvements in public health and welfare (see Section VI). Children, especially, benefit from reduced exposures to criteria and toxic pollutants because they tend to be more sensitive to the effects of these respiratory pollutants. Ozone and particulate matter have been associated with increased incidence of asthma and other respiratory effects in children, and particulate matter has been associated with a decrease in lung maturation.

When feasible, EPA conducts full-scale photochemical air quality modeling to demonstrate how its national mobile source regulatory actions affect ambient concentrations of regional pollutants throughout the United States. The estimation of the human health impacts of a regulatory action requires national-scale photochemical air quality modeling to conduct a full-scale assessment of $PM_{2.5}$ and ozone-related health benefits. Air quality modeling and associated analyses are not available for this document.

For the analysis of the proposed CO_2 emission standards (and analysis of the alternative standards in Section IX), we instead use a reduced-form ''benefit-per-ton'' (BPT) approach to estimate the monetized $PM_{2.5}$-related health benefits of this proposal. The BPT approach estimates the monetized economic value of $PM_{2.5}$-related emission reductions (such as direct PM, (NO_X, and SO_2) due to implementation of the proposed program. Similar to the SC-GHG approach for monetizing reductions in GHGs, the BPT approach estimates monetized health benefits of avoiding one ton of $PM_{2.5}$-related emissions from a particular source sector. The value of health benefits from reductions (or increases) in $PM_{2.5}$ emissions associated with this proposal were estimated by multiplying $PM_{2.5}$-related BPT values by the corresponding annual reduction in tons of directly-emitted $PM_{2.5}$ and $PM_{2.5}$ precursor emissions (NO_X and SO_2). As explained in Chapter 7.2 in the DRIA, the $PM_{2.5}$ BPT values represent the monetized value of human health benefits, including reductions in both premature mortality and nonfatal illnesses.

The mobile sector BPT estimates used in this proposal were published in 2019, but were recently updated using the suite of premature mortality and morbidity studies in use by EPA for the 2023 p.m. NAAQS Reconsideration Proposal.[997] [998] The EGU BPT estimates used in this proposal were also recently updated.[999] The health benefits

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[997] Wolfe, P.; Davidson, K.; Fulcher, C.; Fann, N.; Zawacki, M.; Baker, K.R. 2019. Monetized Health Benefits Attributable to Mobile Source Emission Reductions across the United States in 2025. Sci. Total Environ. 650, 2490–2498. Available at: *https://doi.org/10.1016/J.SCITOTENV.2018.09.273.*

[998] U.S. Environmental Protection Agency (U.S. EPA). 2023. PM NAAQS Reconsideration Proposal RIA. EPA–HQ–OAR–2019–0587. January.

[999] U.S. Environmental Protection Agency (U.S. EPA). 2023. Technical Support Document: Estimating the Benefit per Ton of Reducing

Technical Support Document (Benefits TSD) that accompanied the PM NAAQS Reconsideration Proposal details the approach used to estimate the $PM_{2.5}$-related benefits reflected in the mobile source BPTs.[1000] For more detailed information about the benefits analysis conducted for this proposal, including the BPT unit values used in this analysis, please refer to Chapter 7 of the DRIA.

A chief limitation to using $PM_{2.5}$-related BPT values is that they do not reflect benefits associated with reducing ambient concentrations of ozone. The $PM_{2.5}$-related BPT values also do not capture the benefits associated with reductions in direct exposure to NO_2 and mobile source air toxics, nor do they account for improved ecosystem effects or visibility. The estimated benefits of this proposal would be larger if we were able to monetize these unquantified benefits at this time.

Table VII–2 presents the annual, undiscounted $PM_{2.5}$-related health benefits estimated for the stream of years beginning with the first year of rule implementation, 2027, through calendar year 2055 for the proposed standards. Benefits are presented by **Source:** Onroad heavy-duty vehicles and EGUs. Because premature mortality typically constitutes the vast majority of monetized benefits in a $PM_{2.5}$ benefits assessment, we present benefits based on risk estimates reported from two different long-term exposure studies using different cohorts to account for uncertainty in the benefits associated with avoiding PM-related premature deaths.[1001] [1002] Although annual benefits presented in the table are not discounted for the purposes of present value or annualized value calculations, annual benefits do reflect the use of 3-percent and 7-percent discount rates to account for avoided health outcomes that are expected to accrue over more than a single year (the ''cessation lag'' between the change in PM exposures and the total realization of changes in health effects). Table VII–2 also displays the present and annualized values of estimated benefits that occur from 2027 to 2055, discounted using both 3-percent and 7-percent discount rates and reported in 2021 dollars. We estimate that the present value of benefits for the proposed program is $15 to $29 billion at a 3-percent discount rate and $5.8 to $11 billion at a 7-percent discount rate (2021 dollars).

TABLE VII–2—YEAR-OVER-YEAR MONETIZED $PM_{2.5}$-RELATED HEALTH BENEFITS OF THE PROPOSED PROGRAM

[Millions, 2021$]

	Onroad heavy-duty vehicles		EGUs		Total benefits	
	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate
2027	$23–49	$21–44	$(17)–(35)	$(15)–(32)	$6.4–13	$5.7–12
2028	51–110	46–97	(37)–(76)	(33)–(69)	15–31	13–28
2029	87–180	78–160	(61)–(130)	(55)–(110)	26–53	23–48
2030	140–290	130–260	(120)–(260)	(110)–(230)	16–33	14–30
2031	220–460	200–410	(240)–(500)	(220)–(450)	(22)–(45)	(20)–(40)
2032	330–670	290–610	(400)–(820)	(360)–(730)	(70)–(140)	(64)–(130)
2033	440–900	400–810	(560)–(1100)	(500)–(1000)	(120)–(240)	(110)–(210)
2034	560–1,100	500–1,000	(720)–(1500)	(650)–(1300)	(160)–(330)	(150)–(300)
2035	690–1,400	620–1,200	(890)–(1800)	(800)–(1600)	(210)–(410)	(190)–(370)
2036	820–1,700	740–1,500	(930)–(1900)	(840)–(1700)	(110)–(220)	(100)–(200)
2037	970–1,900	870–1,700	(930)–(1900)	(840)–(1700)	31–62	27–57
2038	1,100–2,200	1,000–2,000	(890)–(1800)	(800)–(1600)	220–440	200–400
2039	1,300–2,500	1,100–2,200	(810)–(1600)	(730)–(1500)	440–880	400–790
2040	1,400–2,800	1,300–2,500	(700)–(1400)	(630)–(1200)	700–1,400	630–1,300
2041	1,500–3,000	1,400–2,700	(660)–(1300)	(590)–(1200)	870–1,700	780–1,500
2042	1,700–3,300	1,500–2,900	(610)–(1200)	(550)–(1100)	1,000–2,100	940–1,900
2043	1,800–3,500	1,600–3,100	(540)–(1100)	(490)–(970)	1,200–2,400	1,100–2,200
2044	1,900–3,700	1,700–3,300	(470)–(930)	(420)–(830)	1,400–2,800	1,300–2,500
2045	2,000–3,900	1,800–3,500	(380)–(760)	(340)–(680)	1,600–3,100	1,400–2,800
2046	2,100–4,100	1,900–3,700	(350)–(690)	(310)–(620)	1,700–3,400	1,600–3,100
2047	2,200–4,300	2,000–3,800	(310)–(620)	(280)–(550)	1,900–3,600	1,700–3,300
2048	2,300–4,400	2,000–4,000	(270)–(540)	(240)–(480)	2,000–3,900	1,800–3,500
2049	2,300–4,600	2,100–4,100	(230)–(450)	(200)–(410)	2,100–4,100	1,900–3,700
2050	2,400–4,700	2,200–4,300	(180)–(370)	(170)–(330)	2,300–4,400	2,000–3,900
2051	2,500–4,900	2,300–4,400	(190)–(370)	(170)–(330)	2,300–4,500	2,100–4,100
2052	2,600–5,100	2,400–4,600	(190)–(380)	(170)–(340)	2,400–4,700	2,200–4,200
2053	2,700–5,200	2,400–4,700	(190)–(380)	(170)–(340)	2,500–4,800	2,300–4,400
2054	2,800–5,400	2,500–4,800	(190)–(390)	(170)–(350)	2,600–5,000	2,300–4,500
2055	2,900–5,500	2,600–5,000	(200)–(390)	(180)–(350)	2,700–5,200	2,400–4,600
Present Value	23,000–46,000	10,000–20,000	(8,200)–(17,000)	(4,600)–(9,300)	15,000–29,000	5,800–11,000

Directly-Emitted $PM_{2.5}$, $PM_{2.5}$ Precursors and Ozone Precursors from 21 Sectors. January.

[1000] U.S. Environmental Protection Agency (U.S. EPA). 2023. Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits. Technical Support Document (TSD) for the PM NAAQS Reconsideration Proposal RIA. EPA–HQ–OAR–2019–0587. January.

[1001] Wu, X, Braun, D, Schwartz, J, Kioumourtzoglou, M and Dominici, F (2020). Evaluating the impact of long-term exposure to fine particulate matter on mortality among the elderly. Science advances 6(29): eaba5692.

[1002] Pope III, CA, Lefler, JS, Ezzati, M, Higbee, JD, Marshall, JD, Kim, S–Y, Bechle, M, Gilliat, KS, Vernon, SE and Robinson, AL (2019). Mortality risk and fine particulate air pollution in a large, representative cohort of US adults. Environmental health perspectives 127(7): 077007.

TABLE VII–2—YEAR-OVER-YEAR MONETIZED $PM_{2.5}$-RELATED HEALTH BENEFITS OF THE PROPOSED PROGRAM—Continued

[Millions, 2021$]

	Onroad heavy-duty vehicles		EGUs		Total benefits	
	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate
Equivalent Annualized Value ...	1,200–2,400	840–1,700	(430)–(860)	(380)–(760)	780–1,500	470–910

Notes: The range of benefits in this table reflect the range of premature mortality estimates derived from the Medicare study (Wu et al., 2020) and the NHIS study (Pope et al., 2019). All benefits estimates are rounded to two significant figures. Annual benefit values presented here are not discounted. Negative values in parentheses are health disbenefits related to increases in estimated emissions. The present value of benefits is the total aggregated value of the series of discounted annual benefits that occur between 2027–2055 (in 2021 dollars) using either a 3% or 7% discount rate. The benefits associated with the standards presented here do not include health benefits associated with reduced criteria pollutant emissions from refineries. The benefits in this table also do not include the full complement of health and environmental benefits that, if quantified and monetized, would increase the total monetized benefits.

This analysis includes many data sources that are each subject to uncertainty, including projected emission inventories, air quality data from models, population data, population estimates, health effect estimates from epidemiology studies, economic data, and assumptions regarding the future state of the world (*i.e.,* regulations, technology, and human behavior). When compounded, even small uncertainties can greatly influence the size of the total quantified benefits. There are also inherent limitations associated with using the BPT approach. Despite these uncertainties, we believe the criteria pollutant benefits presented here are our best estimate of benefits absent air quality modeling and we have confidence in the BPT approach and the appropriateness of relying on BPT health estimates for this rulemaking. Please refer to DRIA Chapter 7 for more information on the uncertainty associated with the benefits presented here.

C. Energy Security

The proposed CO_2 emission standards are designed to require reductions in GHG emissions from HD vehicles in the 2027–2032 and beyond timeframe and, thereby, reduce liquid fuel consumption. We expect the standards will be met through a combination of zero-emission technologies and improvements in ICE vehicle technologies, which would, in turn, reduce the demand for liquid fuels and enable the United States to reduce petroleum imports. A reduction of U.S. petroleum imports reduces both financial and strategic risks caused by potential sudden disruptions in the supply of imported petroleum to the United States, thus increasing U.S. energy security.

Energy security is broadly defined as the uninterrupted availability of energy sources at affordable prices.[1003] Energy independence and energy security are distinct but related concepts. The goal of U.S. energy independence is the elimination of all U.S. imports of petroleum and other foreign sources of energy, but more broadly it is the elimination of U.S. sensitivity to the variations in the price and supply of foreign sources of energy.[1004] See Chapter 7 of the DRIA for a more detailed assessment of energy security and energy independence impacts of this proposed rule and Section II.D.2.ii for a discussion on battery critical materials and supply.

In order to understand the energy security implications of reducing U.S. oil imports, EPA has worked with Oak Ridge National Laboratory (ORNL), which has developed approaches for evaluating the social costs and energy security implications of oil use. When conducting this analysis, ORNL estimates the risk of reductions in U.S. economic output and disruption to the U.S. economy caused by sudden disruptions in world oil supply and associated price shocks (*i.e.,* labeled the avoided macroeconomic disruption/adjustment costs). These risks are quantified as ''macroeconomic oil security premiums,'' *i.e.,* the extra costs of oil use besides its market price.

For this proposed rule, EPA is using macroeconomic oil security premiums estimated using ORNL's methodology, which incorporates updated oil price projections and energy market and economic trends from the U.S. Department of Energy's Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2022. EPA and ORNL have worked together to revise the macroeconomic oil security premiums based upon recent energy security literature. We do not consider military cost impacts as a result of reductions in U.S. oil imports from this proposed rule due to methodological issues in quantifying these impacts.

To calculate the oil security benefits of this proposed rule, EPA is using the ORNL macroeconomic oil security premium methodology with: (1) Estimated oil savings calculated by EPA and (2) An oil import reduction factor of 86.4 percent, which shows how much U.S. oil imports are reduced from changes in U.S. oil consumption. In Table VII–3, EPA presents the macroeconomic oil security premiums and the energy security benefits for the proposed HDV standards for the years from 2027–2055.

[1003] International Energy Agency. ''Energy security: Ensuring the uninterrupted availability of energy sources at an affordable price''. Last updated December 2, 2019.

[1004] Greene, D. 2010. Measuring energy security: Can the United States achieve oil independence? Energy Policy 38, pp. 1614–1621.

Table VII–3—Macroeconomic Oil Security Premiums (2021$/Barrel) and Energy Security Benefits With the Proposal

[In millions of 2021$]

Calendar year	Macroeconomic oil security premiums (range)	Energy security benefits
2027	$3.57 ($0.79–$6.65)	$15
2028	$3.65 ($0.80–$6.79)	33
2029	$3.72 ($0.80–$6.92)	55
2030	$3.79 ($0.81–$7.06)	91
2031	$3.87 ($0.85–$7.22)	140
2032	$3.96 ($0.89–$7.38)	210
2033	$4.04 ($0.92–$7.53)	280
2034	$4.13 ($0.96–$7.69)	350
2035	$4.21 ($1.00–$7.85)	420
2036	$4.29 ($1.03–$7.98)	490
2037	$4.36 ($1.06–$8.11)	560
2038	$4.44 ($1.10–$8.24)	620
2039	$4.51 ($1.13–$8.37)	690
2040	$4.59 ($1.16–$8.50)	750
2041	$4.65 ($1.19–$8.62)	800
2042	$4.71 ($1.21–$8.73)	850
2043	$4.76 ($1.24–$8.85)	900
2044	$4.82 ($1.26–$8.96)	940
2045	$4.88 ($1.29–$9.08)	990
2046	$4.94 ($1.32–$9.18)	1,000
2047	$5.00 ($1.35–$9.28)	1,100
2048	$5.06 ($1.37–$9.37)	1,100
2049	$5.12 ($1.40–$9.46)	1,100
2050	$5.18 ($1.43–$9.56)	1,200
2051	$5.18 ($1.43–$9.56)	1,200
2052	$5.18 ($1.43–$9.56)	1,200
2053	$5.18 ($1.43–$9.56)	1,200
2054	$5.18 ($1.43–$9.56)	1,300
2055	$5.18 ($1.43–$9.56)	1,300
PV, 3%		12,000
PV, 7%		6,000
EAV, 3%		620
EAV, 7%		490

VIII. Comparison of Benefits and Costs

This section compares the estimated range of benefits associated with reductions of GHGs, monetized health benefits from reductions in $PM_{2.5}$, energy security benefits, fuel savings, and vehicle-related operating savings to total costs associated with the proposal and the alternative. Estimated costs are detailed and presented in Section IV of this preamble. Those costs include costs for both the new technology in our technology package and the operating costs associated with that new technology. Importantly, as detailed in Section IV of this preamble, the vehicle costs presented here exclude both the IRA battery tax credit and vehicle tax credit while the fuel savings exclude fuel taxes; as such, these costs, along with other operating costs, represent the social costs and/or savings associated with the proposed standards. Benefits from the reduction of GHG emissions and criteria pollutant emissions, and energy security benefits associated with reductions of imported oil, are presented in Section VII.

A. Methods

EPA presents three different benefit-cost comparisons for the proposal and the alternative:

1. A future-year snapshot comparison of annual benefits and costs in the year 2055, chosen to approximate the annual health benefits that would occur in a year when the program would be fully implemented and when most of the regulated fleet would have turned over. Benefits, costs, and net benefits are presented in year 2021 dollars and are not discounted. However, 3-percent and 7-percent discount rates were applied to account for avoided health outcomes that are expected to accrue over more than a single year (the ''cessation lag'' between the change in PM exposures and the total realization of changes in health effects).
2. The present value (PV) of the stream of benefits, costs, and net benefits calculated for the years 2027 through 2055, discounted back to the first year of implementation of the proposed rule (2027) using both 3-percent and 7-percent discount rates, and presented in year 2021 dollars. Note that year-over-year costs are presented in Section IV and year-over-year benefits may be found in Section VII.
3. The equivalent annualized value (EAV) of benefits, costs, and net benefits representing a flow of constant annual values that, had they occurred in each year from 2027 through 2055, would yield an equivalent present value to those estimated in method 2 (using either a 3-percent or 7-percent discount rate). Each EAV represents a typical benefit, cost, or net benefit for each year of the analysis and is presented in year 2021 dollars.

B. Results

Table VIII–1 shows the undiscounted annual monetized vehicle-related technology package RPE costs of the proposal and alternative in calendar year 2055. The table also shows the PV and EAV of those costs for the calendar years 2027 through 2055 using both 3-percent and 7-percent discount rates. The table includes an estimate of the vehicle technology package RPE costs and the costs associated with EVSE.

Note that all costs, savings, and benefits estimates presented in the tables that follow are rounded to two significant figures; numbers may not sum due to independent rounding.

TABLE VIII–1—VEHICLE-RELATED TECHNOLOGY COSTS ASSOCIATED WITH THE PROPOSAL AND ALTERNATIVE

[Millions of 2021 dollars]

	Proposal			Alternative		
	Vehicle technology package RPE	EVSE RPE	Sum	Vehicle technology package RPE	EVSE RPE	Sum
2055	−$1,500	$2,900	$1,400	−$1,200	$2,100	$880
PV, 3%	9,000	47,000	56,000	4,000	33,000	37,000
PV, 7%	10,000	29,000	39,000	5,400	20,000	25,000
EAV, 3%	470	2,500	2,900	210	1,700	1,900
EAV, 7%	820	2,300	3,200	440	1,600	2,100

Table VIII–2 shows the undiscounted annual monetized vehicle-related operating savings of the proposal and alternative in calendar year 2055. The table also shows the PV and EAV of those savings for calendar years 2027 through 2055 using both 3-percent and 7-percent discount rates. The savings in diesel exhaust fluid (DEF) consumption arise from the electrification of the HD fleet and the corresponding decrease in diesel engine equipped vehicles which require DEF to maintain compliance with NO_X emission standards. The maintenance and repair savings are substantial due again to electrification of the HD fleet, with HD BEVs and FCEVs projected to require 71 percent and 75 percent, respectively, of the maintenance and repair costs required of HD vehicles equipped with internal combustion engines.

TABLE VIII–2—VEHICLE-RELATED OPERATING SAVINGS ASSOCIATED WITH THE PROPOSAL AND ALTERNATIVE

[Millions of 2021 dollars *]

	Proposal			Alternative				
	Pre-tax fuel savings	DEF savings	Maintenance & repair savings	Sum of savings	Pre-tax fuel savings	DEF savings	Maintenance & repair savings	Sum of savings
2055	$4,300	$2,300	$24,000	$31,000	$2,800	$1,700	$17,000	$22,000
PV, 3%	28,000	22,000	200,000	250,000	18,000	15,000	140,000	180,000
PV, 7%	14,000	11,000	99,000	120,000	8,900	7,900	71,000	87,000
EAV, 3%	1,400	1,100	10,000	13,000	920	810	7,400	9,100
EAV, 7%	1,100	900	8,100	10,000	720	640	5,800	7,100

* Fuel savings are net of savings in diesel, gasoline, and CNG consumption with increased electricity and hydrogen consumption; DEF savings accrue only to diesel vehicles; maintenance and repair savings include impacts associated with all fuels.

Table VIII–3 shows the undiscounted annual monetized energy security benefits of the proposal and alternative in calendar year 2055. The table also shows the PV and EAV of those benefits for calendar years 2027 through 2055 using both 3-percent and 7-percent discount rates.

TABLE VIII–3—ENERGY SECURITY BENEFITS ASSOCIATED WITH THE PROPOSAL AND ALTERNATIVE

[Millions of 2021 dollars]

	Proposal	Alternative
2055	$1,300	$910
PV, 3%	12,000	8,500
PV, 7%	6,000	4,300
EAV, 3%	620	440
EAV, 7%	490	350

Table VIII–4 shows the benefits of reduced GHG emissions, and consequently the annual quantified benefits (*i.e.,* total GHG benefits), for each of the four interim social cost of GHG (SC–GHG) values estimated by the Interagency Working Group (IWG). As discussed in DRIA Chapter 7, there are some limitations to the SC–GHG analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. These climate benefits include benefits associated with reduced vehicle GHGs and increased EGU CO_2 emissions, but do not include any impacts associated with petroleum extraction, petroleum transportation, or liquid fuel refining.

Table VIII–5 shows the undiscounted annual monetized $PM_{2.5}$-related health benefits of the proposal and alternative in calendar year 2055. The table also shows the PV and EAV of those benefits for calendar years 2027 through 2055 using both 3-percent and 7-percent discount rates. The range of benefits in this table reflect the two premature mortality estimates derived from the Medicare study (Wu et al., 2020) and the NHIS study (Pope et al., 2019).[1005] [1006]

[1005] Wu, X, Braun, D, Schwartz, J, Kioumourtzoglou, M and Dominici, F (2020). Evaluating the impact of long-term exposure to fine particulate matter on mortality among the elderly. Science advances 6(29): eaba5692.

[1006] Pope III, CA, Lefler, JS, Ezzati, M, Higbee, JD, Marshall, JD, Kim, S–Y, Bechle, M, Gilliat, KS, Vernon, SE and Robinson, AL (2019). Mortality risk and fine particulate air pollution in a large, representative cohort of U.S. adults. Environmental health perspectives 127(7): 077007.

TABLE VIII–4—CLIMATE BENEFITS FROM REDUCTION IN GHG EMISSIONS ASSOCIATED WITH THE PROPOSAL AND ALTERNATIVE

[Millions of 2021 dollars]

	Proposal				Alternative			
	5% Average	3% Average	2.5% Average	3% 95th Percentile	5% Average	3% Average	2.5% Average	3% 95th Percentile
2055	$4,400	$11,000	$15,000	$33,000	$3,200	$8,000	$11,000	$24,000
PV	22,000	87,000	130,000	260,000	16,000	62,000	96,000	190,000
EAV	1,400	4,600	6,500	14,000	1,000	3,300	4,700	9,900

Notes: Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5-percent, 3-percent, and 5-percent discount rates; 95th percentile at 3-percent discount rate). The 95th perncentile estimate was included to provide information on potentially higher-than-expected economic impacts from climate change, conditional on the 3 percent estimate of the discount rate. We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

The same discount rate used to discount the value of damages from future emissions (SC-GHGs at 5, 3, 2.5 percent) is used to calculate the present value of SC-GHGs for internal consistency. Annual benefits shown are undiscounted values.

TABLE VIII–5—PM$_{2.5}$-RELATED EMISSION REDUCTION BENEFITS ASSOCIATED WITH THE PROPOSAL AND ALTERNATIVE

[Millions of 2021 dollars]

	Proposal		Alternative	
	3%	7%	3%	7%
2055	$2,700–$5,200	$2,400–$4,600	$1,900–$3,700	$1,700–$3,300
PV	15,000–29,000	5,800–11,000	11,000–21,000	4,200–8,200
EAV	780–1,500	470–910	570–1,100	340–670

Notes: The range of benefits in this table reflects the range of premature mortality estimates derived from the Medicare study (Wu et al., 2020) and the NHIS study (Pope III et al., 2019). All benefits estimates are rounded to two significant figures. The present value of benefits is the total aggregated value of the series of discounted annual benefits that occur between 2027–2055 (in 2021 dollars) using either a 3-percent or 7-percent discount rate. The benefits associated with the standards presented here do not include health benefits associated with reduced criteria pollutant emissions from refineries. The benefits in this table also do not include the full complement of health and environmental benefits that, if quantified and monetized, would increase the total monetized benefits.

Table VIII–6 shows the undiscounted annual net benefits of the proposal and alternative in calendar year 2055 using each of the four social cost of GHG valuations. The table also shows the PV and EAV of the net benefits for calendar years 2027 through 2055 using both 3-percent and 7-percent discount rates. For presentational simplicity, we use the mid-point of the range of PM$_{2.5}$ benefits in the annual 2055 net benefit calculation. For the calculation of PV and EAV net benefits, we use the high-end estimate of PM$_{2.5}$ benefits assuming a 3-percent discount rate and the low-end estimate of benefits assuming a 7-percent discount rate in the corresponding 3- and 7-percent PV and EAV estimates. These choices do not fundamentally alter the net benefit calculations since differences between the chosen PM$_{2.5}$ benefit estimates are not reflected when net benefits are rounded to two significant figures. These net benefits include benefits associated with reduced vehicle GHGs and increased EGU CO_2 emissions, but do not include any impacts associated with petroleum extraction, petroleum transportation or liquid fuel refining.

TABLE VIII–6—NET BENEFITS ASSOCIATED WITH THE PROPOSAL AND ALTERNATIVE

[Millions of 2021 dollars]

	Proposal Average				Alternative			
	5% Average	3% Average	2.5% Average	3% 95th Percentile	5% Average	3% Average	2.5% Average	3% 95th percentile
2055	$39,000	$46,000	$50,000	$68,000	$28,000	$33,000	$36,000	$49,000
PV, 3%	260,000	320,000	370,000	500,000	180,000	230,000	260,000	360,000
PV, 7%	120,000	180,000	230,000	360,000	86,000	130,000	170,000	260,000
EAV, 3%	14,000	17,000	19,000	26,000	9,800	12,000	13,000	19,000
EAV, 7%	9,300	12,000	14,000	22,000	6,800	9,000	10,000	16,000

Notes: Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5-percent, 3-percent, and 5-percent discount rates; 95th percentile at 3-percent discount rate). The 95th perncentile estimate was included to provide information on potentially higher-than-expected economic impacts from climate change, conditional on the 3 percent estimate of the discount rate. We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts. The same discount rate used to discount the value of damages from future emissions (SC-GHG at 5, 3, 2.5 percent) is used to calculate present value of SC-GHGs for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent. Annual costs and benefits in 2055 are undiscounted values. Note that the benefits attributable to reductions in non-GHG pollutants associated with the standards included here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG pollutant benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in PM$_{2.5}$ exposure. For the purposes of presentational clarity in the calculation of net benefits, PM$_{2.5}$-related benefits are averaged across the range of alternative estimates for 2055. For PV and EAV estimated with a 3% discount rate, we calculate net benefits using PM$_{2.5}$-related benefits based on the Pope III et al., 2019 study of premature mortality. For PV and EAV estimated with a 7% discount rate, net benefits reflect PM$_{2.5}$-related benefits based on the Wu et al., 2020 study.

We summarize the vehicle costs, operational savings, and benefits of the proposal, as shown in Table VIII–7. Table VIII–7 presents the proposal's costs from Table VIII–1, operating savings from Table VIII–2, benefits from Table VIII–3 through Table VIII–5, and net benefits from Table VIII–6 in a single table.

TABLE VIII–7—SUMMARY OF VEHICLE COSTS, OPERATING SAVINGS, AND BENEFITS OF THE PROPOSAL

[Billions of 2021 dollars]

	CY 2055	PV, 3%	PV, 7%	EAV, 3%	EAV, 7%
Vehicle Technology Package RPE	−$1.5	$9	$10	$0.47	$0.82
EVSE RPE	2.9	47	29	2.5	2.3
Sum of Vehicle Costs	1.40	56	39	2.9	3.2
Pre-tax Fuel Savings	4	28	14	1.4	1.1
Diesel Exhaust Fluid Savings	2.3	22	11	1.1	0.9
Repair & Maintenance Savings	24	200	99	10	8
Sum of Operating Savings	31	250	120	13	10
Energy Security Benefits	1.3	12	6.0	0.62	0.49
Climate Benefits:[a]					
5% Average	4.4	22	22	1.4	1.4
3% Average	11	87	87	4.6	4.6
2.5% Average	15	130	130	6.5	6.5
3% 95th Percentile	33	260	260	14	14
Criteria Air Pollutant Benefits:[b]					
PM$_{2.5}$ Health Benefits—Wu et al., 2020	2.4–2.7	15	5.8	0.78	0.47
PM$_{2.5}$ Health Benefits—Pope III et al., 2019	4.6–5.2	29	11.0	1.5	0.91
Net Benefits:[a c]					
With Climate 5% Average	39	260	120	14	9.3
With Climate 3% Average	46	320	180	17	12
With Climate 2.5% Average	50	370	230	19	14
With Climate 3% 95th Percentile	68	500	360	26	22

[a] The same discount rate used to discount the value of damages from future emissions (SC-GHG at 5, 3, 2.5 percent) is used to calculate present and equivalent annualized values of SC-GHGs for internal consistency, while all other costs and benefits are discounted at either 3% or 7%.

[b] PM$_{2.5}$-related health benefits are presented based on two different long-term exposure studies of mortality risk: a Medicare study (Wu et al., 2020) and a National Health Interview Survey study (Pope III et al., 2019). The benefits associated with the standards presented here do not include health benefits associated with reduced criteria pollutant emissions from refineries. The benefits in this table also do not include the full complement of health and environmental benefits that, if quantified and monetized, would increase the total monetized benefits. The range of benefits in CY2055 are estimated using either a 3% or 7% discount rate to account for avoided health outcomes that are expected to accrue over more than a single year.

[c] For criteria pollutant benefits included in the calculation of net benefits, PM$_{2.5}$-related benefits are averaged across the range of estimates in CY2055. For presentational clarity, the present and equivalent annualized value of net benefits for a 3% discount rate reflect benefits based on the Pope III et al. study while the present and equivalent annualized value of net benefits for a 7% discount rate reflect benefits based on the Wu et al. study.

We have also estimated the total transfers associated with the proposed CO$_2$ emission standards, as shown in Table VIII–8. The transfers consist of the IRA battery tax credit and vehicle tax credit and fuel taxes. None of these are included in the prior tables (*i.e.,* Table VIII–1, Table VIII–2, and Table VIII–6) in this section's comparison of benefits and costs.

TABLE VIII–8—TRANSFERS ASSOCIATED WITH THE PROPOSAL AND THE ALTERNATIVE

[Millions of 2021 dollars]

	Proposal				Alternative			
	Battery tax credits	Vehicle tax credits	Fuel taxes	Sum	Battery tax credits	Vehicle tax credits	Fuel taxes	Sum
2055	$0	$0	$6,600	$6,600	$0	$0	$4,700	$4,700
PV, 3%	3,300	5,900	69,000	79,000	2,300	3,900	50,000	56,000
PV, 7%	2,900	5,000	37,000	44,000	2,000	3,400	26,000	31,000
EAV, 3%	170	310	3,600	4,100	120	210	2,600	2,900
EAV, 7%	240	410	3,000	3,600	160	270	2,100	2,600

IX. Analysis of Alternative CO$_2$ Emission Standards

As discussed throughout this preamble, in developing this proposal, EPA considered and is requesting comment on a regulatory alternative that would establish less stringent CO$_2$ emission standards and, thus, would result in fewer GHG emission reductions than the CO$_2$ emission standards we are proposing. This section presents estimates of technology costs, CO$_2$ emission reductions, fuel savings, and other impacts associated with the alternative. We request comment on this analysis for the alternative set of CO$_2$ standards. See Section II.H for our request for comment regarding the alternative set of standards than those proposed.

We also are seeking comment on a more stringent set of emission standards that would be based on higher ZEV adoption rates on a national level around the same levels as the adoption rates included in the California ACT rule, as described in Section II.H.

A. Comparison of Proposal and Alternative

The alternative represents a slower phase-in option for program implementation, which represents differences in timing, costs, and benefits of a HD vehicle CO_2 emissions program. Specifically, the alternative has both a less aggressive phase-in of CO_2 emissions standards from MYs 2027 through 2031 and a less stringent standard for MYs 2032 and beyond. The alternative was modeled using the same methodologies used to model the proposal, as described in Chapters 3 and 4 of the DRIA.

1. Slower Phase-In Alternative

EPA developed and considered an alternative with a more gradual phase-in of CO_2 emission standards for MYs 2027 through MY 2031 and a less stringent final standard in MY 2032, as discussed in Section II.H. The ZEV adoption rates associated with level of stringency for MYs 2027 through 2032 under the slower phase-in alternative are shown in Table IX–1. The slower phase-in alternative ZEV adoption rates by regulatory subcategory and by MY are shown in DRIA Chapter 2.9.5. The slower phase-in alternative standards, presented in Table IX–2 through Table IX–5, are calculated using the same method as the proposed standards, as described in Preamble Sections II.F.2 and II.F.3, using the alternative ZEV adoption rates by regulatory subcategory.

TABLE IX–1—ZEV TECHNOLOGY ADOPTION RATES IN THE TECHNOLOGY PACKAGES CONSIDERED FOR THE ALTERNATIVE

	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 and later (%)
Vocational	14	20	25	30	35	40
Short-Haul Tractors	5	8	10	15	20	25
Long-Haul Tractors	0	0	0	10	15	20

TABLE IX–2—ALTERNATIVE MY 2027 THROUGH 2032+ VOCATIONAL VEHICLE CO_2 EMISSION STANDARDS

[Grams/ton-mile]

Model year	Subcategory	CI light heavy	CI medium heavy	CI heavy heavy	SI light heavy	SI medium heavy
2027	Urban	318	227	244	364	266
	Multi-Purpose	281	204	205	323	237
	Regional	242	187	164	270	216
2028	Urban	294	218	239	340	257
	Multi-Purpose	257	195	200	299	228
	Regional	218	178	159	246	207
2029	Urban	275	211	235	321	250
	Multi-Purpose	238	188	196	280	221
	Regional	199	171	155	227	200
2030	Urban	255	206	212	301	245
	Multi-Purpose	218	183	173	260	216
	Regional	179	166	132	207	195
2031	Urban	235	199	205	281	238
	Multi-Purpose	198	176	166	240	209
	Regional	159	159	125	187	188
2032 and later	Urban	215	192	195	261	231
	Multi-Purpose	178	169	156	220	202
	Regional	139	152	115	167	181

TABLE IX–3—ALTERNATIVE MY 2027 THROUGH 2032+ OPTIONAL CUSTOM CHASSIS VOCATIONAL VEHICLE CO_2 EMISSION STANDARDS

[Grams/ton-mile]

Optional custom chassis vehicle category	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032 and later
School Bus	214	203	195	190	182	173
Other Bus	286	269	252	237	223	206
Coach Bus	205	205	205	185	174	164
Refuse Hauler	265	253	241	232	221	212
Concrete Mixer	275	265	256	246	237	228
Motor home	226	226	226	226	226	226
Mixed-use vehicle	316	316	316	316	316	316
Emergency vehicle	319	319	319	319	319	319

TABLE IX–4—ALTERNATIVE MY 2027 THROUGH MY 2032+ TRACTOR CO_2 EMISSION STANDARDS

[Grams/ton-mile]

Model year	Roof height	Class 7 all cab styles	Class 8 day cab	Class 8 sleeper cab
	Low Roof	91.4	69.7	64.1
	Mid Roof	98.2	74.1	69.6
	High Roof	95.0	71.9	64.3
2028	Low Roof	88.5	67.5	64.1
	Mid Roof	95.1	71.8	69.6
	High Roof	92.0	69.6	64.3
2029	Low Roof	86.6	66.1	64.1
	Mid Roof	93.1	70.2	69.6
	High Roof	90.0	68.1	64.3
2030	Low Roof	81.8	62.4	57.7
	Mid Roof	87.9	66.3	62.6
	High Roof	85.0	64.3	57.9
2031	Low Roof	77.0	58.7	54.5
	Mid Roof	82.7	62.4	59.2
	High Roof	80.0	60.6	54.7
2032 and Later	Low Roof	72.2	55.1	51.3
	Mid Roof	77.6	58.5	55.7
	High Roof	75.0	56.8	51.4

TABLE IX–5—ALTERNATIVE MY 2027 THROUGH MY 2032+ HEAVY-HAUL TRACTOR CO_2 EMISSION STANDARDS

[Grams/ton-mile]

Model Year	CO_2 Emission standards (grams/ton-mile)
2027	48.3
2028	48.3
2029	48.3
2030	44.0
2031	43.0
2032 and Later	42.5

Based on our current analysis for each of the vocational vehicle and tractor subcategories, there appear to be technically feasible emission standards available that provide for greater CO_2 emission reductions through the proposed standards than through the slower phase-in alternative. As explained in section II.H, the proposed standards are therefore appropriate. Consequently, at this time, EPA does not believe that the slower phase-in alternative would be appropriate.

2. Proposed CO_2 Emission Standards

Details regarding MOVES modeling of these proposed standards are included in Section IV of this preamble and Chapter 4 of the DRIA. The ZEV adoption rates in the technology packages associated with the proposed level of stringency for MYs 2027 through 2032 under the proposal are shown in Table IX–6.

TABLE IX–6—ZEV TECHNOLOGY ADOPTION RATES IN THE TECHNOLOGY PACKAGES CONSIDERED FOR THE PROPOSED STANDARDS

	MY 2027 (%)	MY 2028 (%)	MY 2029 (%)	MY 2030 (%)	MY 2031 (%)	MY 2032 and later
Vocational	20	25	30	35	40	50
Short-Haul Tractors	10	12	15	20	30	35
Long-Haul Tractors	0	0	0	10	20	25

The bases for each of the proposed CO_2 emission standards by model year and industry segment are discussed more fully earlier in this preamble Section II and in Chapter 2 of the DRIA. Section II of this preamble include explanation of how EPA arrived at the proposed CO_2 emission standards, including discussion of the technologies upon which the CO_2 emission standards are based and why the standards are reasonable in light of these technologies, based on all of the information available to us at the time of this proposal.

B. Emission Inventory Comparison of Proposal and Slower Phase-In Alternative

Both the proposal and alternative were modeled in MOVES3.R3 by increasing ZEV adoption in HD vehicles, which means we model the alternative as displacing fewer HD ICE vehicles than the proposal. In general, this means the alternative has both lower downstream emission reductions and lower upstream EGU emission increases when compared to the proposal. Chapter 4.7 of the DRIA contains more discussion on the emission impacts of the alternative.

1. Downstream Emission Comparison

Our estimates of the downstream emission reductions of GHGs that would result from the alternative, relative to the reference case, are presented in Table IX–7 for calendar years 2035, 2045, and 2055. Total GHG emissions, or CO_2 equivalent (CO_2e), are calculated by summing all GHG emissions multiplied by their 100-year Global Warming Potential (GWP).

TABLE IX–7—ANNUAL DOWNSTREAM HEAVY-DUTY GHG EMISSION REDUCTIONS FROM THE ALTERNATIVE IN CALENDAR YEARS (CY) 2035, 2045, AND 2055

Pollutant	100-year GWP	CY 2035 reductions		CY 2045 reductions		CY 2055 reductions	
		Million metric tons	Percent (%)	Million metric tons	Percent (%)	Million metric tons	Percent (%)
Carbon Dioxide (CO_2)	1	36	9	73	19	90	22
Methane (CH_4)	25	0.003	5	0.011	17	0.022	22
Nitrous Oxide (N_2O)	298	0.005	9	0.009	17	0.011	20
CO_2 Equivalent (CO_2e)		38	9	76	19	94	22

Our estimated GHG emission reductions for the alternative are lower than for the proposal (see Section V of the preamble). In 2055, we estimate that the alternative would reduce emissions of CO_2 by 22 percent (the proposal's estimate is 30 percent), methane by 22 percent (the proposal's estimate is 31 percent), and N_2O by 20 percent (the proposal's estimate is 28 percent). The resulting total GHG reduction, in CO_2e, is 22 percent for the alternative versus 30 percent for the proposal.

The warming impacts of GHGs are cumulative. Table IX–8 presents the cumulative GHG reductions that would result from the proposed standards and the alternative in 2055, in billion metric tons (BMT).

TABLE IX–8—CUMULATIVE 2027–2055 DOWNSTREAM HEAVY-DUTY GHG EMISSION REDUCTIONS FROM THE PROPOSED STANDARDS AND THE ALTERNATIVE

Pollutant	Proposal GHG reductions		Alternative GHG reductions	
	BMT	Percent (%)	BMT	Percent (%)
Carbon Dioxide (CO_2)	2.2	18	1.6	13
Methane (CH_4)	0.00035	17	0.00025	12
Nitrous Oxide (N_2O)	0.00028	17	0.0002	12
CO_2 Equivalent (CO_2e)	2.3	18	1.6	13

Consistent with Table IX–7, the cumulative GHG emission reductions are smaller for the alternative than the proposal.

We anticipate an increase in the use of zero-emission technologies to meet the CO_2 emission standards for both the proposal and the alternative. Therefore, we also expect downstream emission reductions for criteria pollutants and air toxics would result from the alternative, as presented in Table IX–9.

TABLE IX–9—ANNUAL DOWNSTREAM HD CRITERIA POLLUTANT AND AIR TOXIC EMISSION REDUCTIONS FROM THE ALTERNATIVE IN CALENDAR YEARS (CYS) 2035, 2045, AND 2055

Pollutant	CY 2035 reductions		CY 2045 reductions		CY 2055 reductions	
	U.S. tons	Percent (%)	U.S. tons	Percent (%)	U.S. tons	Percent (%)
Nitrogen Oxides (NO_X)	11,471	3	40,460	15	51,027	20
Primary Exhaust $PM_{2.5}$	199	5	501	22	701	28
Volatile Organic Compounds (VOC)	4,438	8	10,366	21	15,139	27
Sulfur Dioxide (SO_2)	147	10	298	19	373	23
Carbon Monoxide (CO)	70,292	8	176,283	20	252,482	25
1,3-Butadiene	14	17	35	34	50	38
Acetaldehyde	91	8	216	22	326	26
Benzene	82	13	208	30	302	36
Formaldehyde	61	6	157	20	258	24
Naphthalene[a]	5	7	11	28	16	33
Ethylbenzene	52	9	128	22	195	30

[a] Naphthalene includes both gas and particle phase emissions.

Once again, the emission reductions in criteria pollutants and air toxics that would result from the alternative are smaller than those that would result from the proposal. For example, in 2055, we estimate the alternative would reduce NO_X emissions by 20 percent, $PM_{2.5}$ emissions by 28 percent, and VOC emissions by 27 percent. This is compared to the proposal's reductions of NO_X by 28 percent, $PM_{2.5}$ by 39 percent, and VOC by 37 percent for the proposal. Reductions in emissions for air toxics from the alternative range from 24 percent for formaldehyde (the proposal's estimate is 33 percent) to 38 percent for 1,3-butadiene (the proposal's estimate is 51 percent).

2. Upstream Emission Comparison

Our estimates of the additional CO_2 emissions from EGUs due to the proposed standards, relative to the reference case, are presented in Table IX–10 for calendar years 2035, 2045, and 2055.

TABLE IX–10—ANNUAL UPSTREAM EGU CO_2 EMISSION INCREASES FROM THE ALTERNATIVE IN CALENDAR YEARS (CYS) 2035, 2045, AND 2055

Pollutant	Additional EGU emissions (million metric tons)		
	CY 2035	CY 2045	CY 2055
Carbon Dioxide (CO_2)	15	12	8

In 2055, we estimate the alternative would increase EGU emissions of CO_2 by 8 million metric tons, compared to 11 million metric tons from the proposal. The EGU impacts decrease over time because of projected changes in the power generation mix.

In Table IX–11, we present the cumulative CO_2 increases from EGUs that we expect would result from the proposal and alternative, measured in billion metric tons (BMT).

TABLE IX–11—CUMULATIVE 2027–2055 EGU CO_2 EMISSION INCREASES REFLECTING THE PROPOSED AND ALTERNATIVE GHG STANDARDS

Pollutant	EGU CO_2 emissions increase (BMT)	
	Proposal	Alternative
Carbon Dioxide (CO_2)	0.4	0.3

We estimate the alternative would result in 0.3 billion metric tons of increased CO_2 emissions from EGUs, compared to 0.4 billion metric tons from the proposal.

Table IX–12 contains our estimates of EGU emission increases from the alternative for some criteria pollutants. In general, we expect the EGU emissions increases from the alternative to be 20 to 30 percent smaller than for the proposal.

TABLE IX–12—ANNUAL CRITERIA POLLUTANT EMISSION INCREASES FROM EGUS FROM THE ALTERNATIVE IN CALENDAR YEARS (CYS) 2035, 2045, AND 2055

Pollutant	Additional EGU emissions (U.S. tons)		
	CY 2035	CY 2045	CY 2055
Nitrogen Oxides (NO_X)	2,054	1,625	575
Primary $PM_{2.5}$	885	761	549
Volatile Organic Compounds (VOC)	458	563	551
Sulfur Dioxide (SO_2)	7,235	1,863	666

In addition to downstream and EGU emissions impacts, we also estimated impacts on select criteria pollutant emissions from refineries for calendar year 2055. This analysis assumes that the reduction in demand for liquid fuels would lead to reduced activity and emissions at refineries. The results are presented in Table IX–13. Additional detail on the refinery analysis is available in Chapter 4.3.3 of the DRIA.

TABLE IX–13—CRITERIA POLLUTANT EMISSION REDUCTIONS FROM REFINERIES FROM THE PROPOSAL AND ALTERNATIVE IN 2055

Pollutant	CY 2055 refinery emission reductions (U.S. tons)	
	Proposal	Alternative
NO_X	1,785	1,298
$PM_{2.5}$	436	318
VOC	1,227	894
SO_2	642	468

Like the downstream emission reductions and the EGU emission increases, the refinery emission impacts of the alternative are 20 to 30 percent smaller than the proposal.

3. Comparison of Net Emissions Impacts

While we present a net emissions impact of the alternative CO_2 emission standards, it is important to note that some upstream emission sources are not included in the analysis. Although we expect the alternative to reduce demand for refined fuels, we did not quantify emissions changes associated with producing or extracting crude or transporting crude or refined fuels. Also, because our analysis of refinery emissions only included select criteria pollutants, refinery emission impacts are therefore included in net criteria emission impacts for 2055 but not net CO_2 emission impacts. Therefore, this analysis likely underestimates the net emissions reductions that may result from the alternative.

Table IX–14 shows a summary of our modeled downstream, upstream, and net CO_2 emission impacts of the alternative relative to the reference case, in million metric tons, for calendar years 2035, 2045, and 2055.

Table IX–14—Annual Net CO_2 Emission Impacts [a] From the Alternative in Calendar Years (CYs) 2035, 2045, and 2055

Pollutant	CY 2035 impacts (MMT)			CY 2045 impacts (MMT)			CY 2055 impacts (MMT)		
	Downstream	EGU	Net	Downstream	EGU	Net	Downstream	EGU	Net
CO_2	−36	15	−22	−73	12	−62	−90	8	−82

[a] We present emissions reductions as negative numbers and emission increases as positive numbers.

In 2055, we estimate the alternative would result in a net decrease of 82 million metric tons of CO_2 emissions. The net reduction for the proposal is 114 million metric tons. The net decreases become larger between 2035 and 2055 as we project the HD fleet to turn over and the power grid to use less fossil fuels.

In Table IX–15, we present the cumulative net CO_2 emissions impact that we expect would result from the proposed standards and the alternative, in billion metric tons (BMT). Overall, we expect downstream reduction in CO_2 emissions to be far larger than upstream increases from EGUs, and we expect the alternative would result in a net reduction of 1.3 billion metric tons from CYs 2027 to 2055. This is about 28 percent less than the 1.8 billion metric tons of cumulative CO_2 emissions reductions we expect from the proposal.

Table IX–15—Cumulative 2027–2055 EGU CO_2 Emission Impacts [a] (in BMT) of the Alternative

Pollutant	Proposal			Alterative		
	Downstream	EGU	Net	Downstream	EGU	Net
Carbon Dioxide (CO_2)	−2.2	0.4	1.8	−1.6	0.3	1.3

[a] We present emissions reductions as negative numbers and emission increases as positive numbers.

Table IX–16 contains a summary of the modeled net impacts of the alternative CO_2 emission standards on criteria pollutant emissions considering downstream and EGUs, relative to the reference case for calendar years 2035 and 2045. Table IX–17 contains a similar summary for calendar year 2055 that includes estimates of net impacts of refinery, EGU, and downstream emissions.

Table IX–16—Annual Net Impacts [a] on Criteria Pollutant Emissions From the Alternative in Calendar Years (CYs) 2035 and 2045

Pollutant	CY 2035 impacts (U.S. tons)			CY 2045 impacts (U.S. tons)		
	Downstream	EGU	Net	Downstream	EGU	Net
NO_X	−11,471	2,054	−9,417	−40,460	1,625	−38,836
$PM_{2.5}$	−199	885	687	−501	761	260
VOC	−4,438	458	−3,980	−10,366	563	−9,802
SO_2	−147	7,235	7,088	−298	1,863	1,565

[a] We present emissions reductions as negative numbers and emission increases as positive numbers.

Table IX–17—Net Impacts [a] on Criteria Pollutant Emissions From the Alternative in CY 2055

Pollutant	CY 2055 impacts (U.S. tons)			
	Downstream	EGU	Refinery	Net
NO_X	−51,027	575	−1,298	−51,750
$PM_{2.5}$	−701	549	−318	−471
VOC	−15,139	551	−894	−15,482
SO_2	−373	666	−468	−175

[a] We present emissions reductions as negative numbers and emission increases as positive numbers.

By 2055, when considering downstream, EGU, and refinery emissions, we estimate a net decrease in emissions from all pollutants modeled (*i.e.,* NO_X, $PM_{2.5}$, VOC, and SO_2). In earlier years, when considering only downstream and EGU emissions, we estimate net decreases of NO_X and VOC emissions, but net increases of $PM_{2.5}$ and SO_2 emissions. These increases become smaller over time. All net emission impacts for the alternative, whether they are positive or negative, are smaller in magnitude than for the proposal.

C. Program Costs Comparison of Proposal and Alternative

Using the cost elements outlined in Sections IV.B, IV.C, and IV.D, we have estimated the costs associated with the proposal and alternative relative to the reference case, as shown in Table IX–18. Costs are presented in more detail in Chapter 3 of the DRIA. As noted earlier, costs are presented in 2021 dollars in undiscounted annual values along with net present values at both 3- and 7-percent discount rates with values discounted to the 2027 calendar year.

As shown in Table IX–18, our analysis shows that the proposal scenario would have the lowest cost.

TABLE IX–18—TOTAL TECHNOLOGY, OPERATING COST AND EVSE COST IMPACTS OF THE PROPOSED OPTION RELATIVE TO THE REFERENCE CASE AND THE ALTERNATIVE OPTION RELATIVE TO THE REFERENCE CASE, ALL REGULATORY CLASSES AND ALL FUELS,

[Millions of 2021 dollars] [a]

Calendar year	Proposal				Alternative			
	Total technology costs	Total operating costs	Total EVSE costs	Total program cost	Total technology costs	Total operating costs	Total EVSE costs	Total program cost
2027	$2,000	−$330	$1,300	$3,000	$920	−$180	$710	$1,400
2028	1,800	−790	1,600	2,500	1,100	−490	1,100	1,600
2029	1,700	−1,400	1,900	2,200	1,000	−920	1,300	1,400
2030	2,000	−2,100	2,000	1,900	1,400	−1,400	1,500	1,400
2031	2,300	−2,800	2,200	1,700	1,400	−2,000	1,700	1,100
2032	2,000	−3,800	2,600	860	1,400	−2,700	1,900	510
2033	1,500	−4,900	2,600	−820	960	−3,500	1,800	−710
2034	1,300	−6,100	2,600	−2,200	810	−4,300	1,800	−1,700
2035	1,000	−7,400	2,500	−3,800	620	−5,200	1,700	−2,900
2036	750	−8,700	2,500	−5,500	440	−6,200	1,700	−4,000
2037	620	−10,000	2,500	−7,000	350	−7,200	1,700	−5,100
2038	410	−12,000	2,500	−8,700	200	−8,200	1,700	−6,300
2039	220	−13,000	2,600	−10,000	70	−9,100	1,800	−7,300
2040	140	−14,000	2,600	−12,000	9	−10,000	1,800	−8,400
2041	−40	−16,000	2,600	−13,000	−120	−11,000	1,800	−9,400
2042	−200	−17,000	2,600	−15,000	−230	−12,000	1,800	−10,000
2043	−360	−18,000	2,700	−16,000	−340	−13,000	1,800	−12,000
2044	−410	−20,000	2,700	−18,000	−370	−14,000	1,900	−13,000
2045	−550	−21,000	2,700	−19,000	−480	−15,000	1,900	−13,000
2046	−690	−22,000	2,700	−20,000	−570	−16,000	1,900	−14,000
2047	−820	−23,000	2,700	−22,000	−670	−17,000	1,900	−15,000
2048	−850	−24,000	2,700	−22,000	−680	−17,000	1,900	−16,000
2049	−970	−25,000	2,800	−23,000	−770	−18,000	1,900	−17,000
2050	−1,100	−26,000	2,800	−24,000	−850	−18,000	1,900	−17,000
2051	−1,100	−27,000	2,800	−25,000	−860	−19,000	2,000	−18,000
2052	−1,200	−28,000	2,900	−26,000	−940	−20,000	2,000	−19,000
2053	−1,300	−29,000	2,900	−27,000	−1,000	−21,000	2,000	−20,000
2054	−1,400	−30,000	2,900	−28,000	−1,100	−21,000	2,000	−20,000
2055	−1,500	−31,000	2,900	−29,000	−1,200	−22,000	2,100	−21,000
PV, 3%	9,000	−250,000	47,000	−190,000	4,000	−180,000	33,000	−140,000
PV, 7%	10,000	−120,000	29,000	−85,000	5,400	−87,000	20,000	−62,000
EAV, 3%	470	−13,000	2,500	−10,000	210	−9,100	1,700	−7,200
EAV, 7%	820	−10,000	2,300	−6,900	440	−7,100	1,600	−5,100

[a] Values show 2 significant digits; negative cost values denote savings; calendar year values are undiscounted, present values are discounted to 2027. Program Cost is the sum of Total Tech Cost, Total Operating Cost, and total EVSE costs.

D. Benefits

1. Social Cost of GHGs

Our estimates of the climate benefits from the GHG emissions reductions associated with the alternative are similar to those discussed for the proposal in Section VII of this preamble. Table IX–19 presents the estimated annual, undiscounted climate benefits (*i.e.,* total GHG benefits), and consequently the annual quantified benefits (*i.e.,* total GHG benefits), for each of the four interim social cost of GHG (SC–GHG) values estimated by the Interagency Working Group on Social Cost of Greenhouse Gases [1007] for the years beginning with the first year of rule implementation, 2027, through 2055 for the proposed program. Also shown are the present values and equivalent annualized values associated with each of the four interim SC–GHG values. For more detailed information about the climate benefits analysis conducted for the proposed and alternative programs, please refer to Section 7.1 of the draft RIA. Our analysis includes CO_2 emission increases from EGUs (see Section V and Section IX.B); however, it does not include upstream emissions impacts associated with liquid fuel refining.

[1007] Interagency Working Group on Social Cost of Greenhouse Gases (IWG). 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990. February. United States Government. Available at: *https://www.whitehouse.gov/briefing-room/blog/2021/02/26/a-return-to-science-evidence-based-estimates-of-the-benefits-of-reducing-climate-pollution/.*

Table IX–19—Climate Benefits From Reduction in GHG Emissions Associated With the Proposal and Alternative, Millions of 2021 Dollars

Calendar year	Proposal				Alternative			
	Total technology costs	Total operating costs	Total EVSE costs	Total program cost	Total technology costs	Total operating costs	Total EVSE costs	Total program cost
5% Average	3% Average	2.5% Average	3% 95th Percentile	5% Average	3% Average	2.5% Average	3% 95th Percentile	
2027	33	$110	$160	$320	$17	$57	$83	$170
2028	74	240	350	710	45	140	210	430
2029	120	400	580	1,200	80	250	370	760
2030	190	610	880	1,800	130	420	610	1,300
2031	290	900	1,300	2,700	200	630	910	1,900
2032	410	1,300	1,800	3,800	290	890	1,300	2,700
2033	530	1,600	2,300	4,900	380	1,200	1,700	3,500
2034	660	2,000	2,800	6,000	470	1,400	2,000	4,300
2035	780	2,300	3,300	7,100	550	1,700	2,400	5,000
2036	940	2,800	4,000	8,500	670	2,000	2,800	6,000
2037	1,100	3,300	4,700	9,900	790	2,300	3,300	7,100
2038	1,300	3,800	5,400	12,000	920	2,700	3,800	8,200
2039	1,500	4,300	6,100	13,000	1,100	3,100	4,400	9,400
2040	1,700	4,900	6,900	15,000	1,200	3,500	4,900	11,000
2041	1,900	5,400	7,600	16,000	1,400	3,900	5,400	12,000
2042	2,100	5,900	8,300	18,000	1,500	4,200	5,900	13,000
2043	2,300	6,500	9,000	20,000	1,700	4,600	6,500	14,000
2044	2,500	7,000	9,800	21,000	1,800	5,000	7,000	15,000
2045	2,700	7,500	10,000	23,000	2,000	5,400	7,500	16,000
2046	2,900	8,000	11,000	24,000	2,100	5,700	7,900	17,000
2047	3,100	8,400	12,000	26,000	2,200	6,000	8,300	18,000
2048	3,300	8,800	12,000	27,000	2,300	6,300	8,700	19,000
2049	3,500	9,200	13,000	28,000	2,500	6,600	9,100	20,000
2050	3,700	9,700	13,000	30,000	2,600	7,000	9,600	21,000
2051	3,800	10,000	14,000	30,000	2,700	7,200	9,900	22,000
2052	4,000	10,000	14,000	31,000	2,900	7,400	10,000	22,000
2053	4,100	11,000	15,000	32,000	3,000	7,600	10,000	23,000
2054	4,300	11,000	15,000	32,000	3,100	7,800	11,000	23,000
2055	4,400	11,000	15,000	33,000	3,200	8,000	11,000	24,000
PV	22,000	87,000	130,000	260,000	16,000	62,000	96,000	190,000
EAV	1,400	4,600	6,500	14,000	1,000	3,300	4,700	9,900

2. Criteria Pollutant Reductions

Table IX–20 presents the total annual, undiscounted $PM_{2.5}$-related health benefits estimated for the stream of years beginning with the first year of rule implementation, 2027, through calendar year 2055 for the proposed and alternative programs. The range of benefits in Table IX–20 reflects the range of premature mortality estimates based on risk estimates reported from two different long-term exposure studies using different cohorts to account for uncertainty in the benefits associated with avoiding PM-related premature deaths.[1008] [1009] Although annual benefits presented in the table are not discounted for the purposes of present value or annualized value calculations, annual benefits do reflect the use of 3-percent and 7-percent discount rates to account for avoided health outcomes that are expected to accrue over more than a single year (the ''cessation lag'' between the change in PM exposures and the total realization of changes in health effects). The table also displays the present and annualized value of estimated benefits that occur from 2027 to 2055, discounted using both 3-percent and 7-percent discount rates and reported in 2021 dollars. We estimate that the present value of benefits for the alternative program is $11 to $21 billion at a 3 percent discount rate and $4.2 to $8.2 billion at a 7 percent discount rate (2021 dollars), which is less than that of the proposed program. For more detailed information about the benefits analysis conducted for the proposed and alternative programs, please refer to Chapter 7 of the draft RIA.

Table IX—20-Year-Over-Year Monetized $PM_{2.5}$-Related Health Benefits Associated With the Proposal and Alternative

[Millions of 2021 Dollars]

	Proposal		Alternative	
	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate
2027	$6.4–13	$5.7–12	$4.7–9.6	$4.2–8.7
2028	15–31	13–28	12–25	11–22
2029	26–53	23–48	22–44	19–40
2030	16–33	14–30	12–24	11–21
2031	(22)–(45)	(20)–(40)	(6.8)–(18)	(6.2)–(16)

[1008] Wu, X, Braun, D, Schwartz, J, Kioumourtzoglou, M and Dominici, F (2020). Evaluating the impact of long-term exposure to fine particulate matter on mortality among the elderly. Science advances 6(29): eaba5692.

[1009] Pope III, CA, Lefler, JS, Ezzati, M, Higbee, JD, Marshall, JD, Kim, S–Y, Bechle, M, Gilliat, KS, Vernon, SE and Robinson, AL (2019). Mortality risk and fine particulate air pollution in a large, representative cohort of US adults. Environmental health perspectives 127(7): 077007.

TABLE IX—20-YEAR-OVER-YEAR MONETIZED $PM_{2.5}$-RELATED HEALTH BENEFITS ASSOCIATED WITH THE PROPOSAL AND ALTERNATIVE—Continued

[Millions of 2021 Dollars]

	Proposal		Alternative	
	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate
2032	(70)–(140)	(64)–(130)	(37)–(82)	(34)–(74)
2033	(120)–(240)	(110)–(210)	(67)–(150)	(61)–(130)
2034	(160)–(330)	(150)–(300)	(97)–(210)	(88)–(190)
2035	(210)–(410)	(190)–(370)	(120)–(260)	(110)–(240)
2036	(110)–(220)	(100)–(200)	(57)–(130)	(53)–(110)
2037	31–62	27–57	42–76	37–67
2038	220–440	200–400	180–340	160–310
2039	440–880	400–790	340–660	300–590
2040	700–1,400	630–1,300	520–1,000	470–920
2041	870–1,700	780–1,500	630–1,200	570–1,100
2042	1,000–2,100	940–1,900	750–1,500	680–1,300
2043	1,200–2,400	1,100–2,200	880–1,700	790–1,600
2044	1,400–2,800	1,300–2,500	1,000–2,000	920–1,800
2045	1,600–3,100	1,400–2,800	1,200–2,300	1,000–2,000
2046	1,700–3,400	1,600–3,100	1,300–2,400	1,100–2,200
2047	1,900–3,600	1,700–3,300	1,300–2,600	1,200–2,400
2048	2,000–3,900	1,800–3,500	1,400–2,800	1,300–2,500
2049	2,100–4,100	1,900–3,700	1,500–3,000	1,400–2,700
2050	2,300–4,400	2,000–3,900	1,600–3,100	1,500–2,800
2051	2,300–4,500	2,100–4,100	1,700–3,300	1,500–2,900
2052	2,400–4,700	2,200–4,200	1,800–3,400	1,600–3,000
2053	2,500–4,800	2,300–4,400	1,800–3,500	1,600–3,100
2054	2,600–5,000	2,300–4,500	1,900–3,600	1,700–3,200
2055	2,700–5,200	2,400–4,600	1,900–3,700	1,700–3,300
PV	15,000–29,000	5,800–11,000	11,000–21,000	4,200–8,200
EAV	780–1,500	470–910	570–1,100	340–670

Notes: The range of benefits in this table reflect the range of premature mortality estimates derived from the Medicare study (Wu et al., 2020) and the NHIS study (Pope et al., 2019). All benefits estimates are rounded to two significant figures. Annual benefit values presented here are not discounted. Negative values in parentheses are health disbenefits related to increases in estimated emissions. The present value of benefits is the total aggregated value of the series of discounted annual benefits that occur between 2027–2055 (in 2021 dollars) using either a 3% or 7% discount rate. The benefits associated with the standards presented here do not include health benefits associated with reduced criteria pollutant emissions from refineries. The benefits in this table also do not include the full complement of health and environmental benefits that, if quantified and monetized, would increase the total monetized benefits.

3. Energy Security

In Table IX–21, EPA presents the macroeconomic oil security premiums and the energy security benefits for the alternative CO_2 emission standards for the years 2027 through 2055. The oil security premiums and the energy security benefits for the proposed CO_2 emission standards can be found in Section VII.

TABLE IX—21 OIL SECURITY PREMIUMS (2021$/BARREL) AND THE ENERGY SECURITY BENEFITS (MILLIONS OF 2021$) FROM 2027–2055 FOR ALTERNATIVE GHG EMISSION STANDARDS[1010]

Calendar year	Oil security premium (range)	Benefits	
		Proposal	Alternative
2027	$3.57 ($0.79–$6.65)	$15	$8
2028	$3.65 ($0.80–$6.79)	33	20
2029	$3.72 ($0.80–$6.92)	55	35
2030	$3.79 ($0.81–$7.06)	91	63
2031	$3.87 ($0.85–$7.22)	140	100
2032	$3.96 ($0.89–$7.38)	210	150
2033	$4.04 ($0.92–$7.53)	280	200
2034	$4.13 ($0.96–$7.69)	350	250

[1010] ORNL's oil security premium methodology provides estimates through 2050. For years 2051–2055 we use the value of the 2050 oil security premium.

TABLE IX—21 OIL SECURITY PREMIUMS (2021$/BARREL) AND THE ENERGY SECURITY BENEFITS (MILLIONS OF 2021$) FROM 2027–2055 FOR ALTERNATIVE GHG EMISSION STANDARDS [1010]—Continued

Calendar year	Oil security premium (range)	Benefits	
		Proposal	Alternative
2035	$4.21 ($1.00–$7.85)	420	300
2036	$4.29 ($1.03–$7.98)	490	350
2037	$4.36 ($1.06–$8.11)	560	400
2038	$4.44 ($1.10–$8.24)	620	450
2039	$4.51 ($1.13–$8.37)	690	490
2040	$4.59 ($1.16–$8.50)	750	530
2041	$4.65 ($1.19–$8.62)	800	570
2042	$4.71 ($1.21–$8.73)	850	610
2043	$4.76 ($1.24–$8.85)	900	650
2044	$4.82 ($1.26–$8.96)	940	680
2045	$4.88 ($1.29–$9.08)	990	710
2046	$4.94 ($1.32–$9.18)	1,000	740
2047	$5.00 ($1.35–$9.28)	1,100	760
2048	$5.06 ($1.37–$9.37)	1,100	790
2049	$5.12 ($1.40–$9.46)	1,100	810
2050	$5.18 ($1.43–$9.56)	1,200	840
2051	$5.18 ($1.43–$9.56)	1,200	850
2052	$5.18 ($1.43–$9.56)	1,200	870
2053	$5.18 ($1.43–$9.56)	1,200	890
2054	$5.18 ($1.43–$9.56)	1,300	900
2055	$5.18 ($1.43–$9.56)	1,300	910
PV, 3%		12,000	8,500
PV, 7%		6,000	4,300
EAV, 3%		620	440
EAV, 7%		490	350

E. How do the proposal and alternative compare in overall benefits and costs?

Table IX–22 shows the net benefits for the proposal and alternative relative to the baseline, at 3 percent and 7 percent discount rates, respectively. Section VIII.B of this preamble and Chapter 7 of the DRIA present more detailed results. These net benefits include benefits associated with reduced vehicle GHG and non-GHG emissions and EGU CO2 emissions, but do not include any impacts associated with petroleum extraction, transportation or liquid fuel refining.

TABLE IX–22—NET BENEFITS ASSOCIATED WITH THE PROPOSAL AND ALTERNATIVE

[Millions of 2021 dollars]

	Proposal				Alternative			
	5% Average	3% Average	2.5% Average	3% 95th Percentile	5% Average	3% Average	2.5% Average	3% 95th Percentile
2055	$39,000	$46,000	$50,000	$68,000	$28,000	$33,000	$36,000	$49,000
PV, 3%	260,000	320,000	370,000	500,000	180,000	230,000	260,000	360,000
PV, 7%	120,000	180,000	230,000	360,000	86,000	130,000	170,000	260,000
EAV, 3%	14,000	17,000	19,000	26,000	9,800	12,000	13,000	19,000

TABLE IX–22—NET BENEFITS ASSOCIATED WITH THE PROPOSAL AND ALTERNATIVE—Continued

[Millions of 2021 dollars]

	Proposal				Alternative			
	5% Average	3% Average	2.5% Average	3% 95th Percentile	5% Average	3% Average	2.5% Average	3% 95th Percentile
EAV, 7%	9,300	12,000	14,000	22,000	6,800	9,000	10,000	16,000

Notes: Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC–CO_2), the social cost of methane (SC–CH_4), and the social cost of nitrous oxide (SC–N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC–CO_2, SC–CH_4, and SC–N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts. The same discount rate used to discount the value of damages from future emissions (SC–GHG at 5, 3, 2.5 percent) is used to calculate present value of SC–GHGs for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent. Annual costs and benefits in 2055 shown are undiscounted values. Note that the non-GHG impacts associated with the standards included here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure. For the purposes of presentational clarity in the calculation of net benefits, $PM_{2.5}$-related benefits are averaged across the range of alternative estimates for 2055. For PV and EAV estimated with a 3 percent discount rate, we calculate net benefits using $PM_{2.5}$-related benefits based on the Pope III et al., 2019 study of premature mortality. For PV and EAV estimated with a 7 percent discount rate, net benefits reflect $PM_{2.5}$-related benefits based on the Wu et al., 2020 study.

X. Preemption of State Standards and Requirements for New Locomotives or New Engines Used in Locomotives

A. Overview

In April of 1998, EPA adopted its first-ever regulations addressing air pollutant emissions from new locomotives and new locomotive engines (including freshly built and remanufactured) under CAA section 213(a)(5), 42 U.S.C. 7547(a)(5).[1011] As part of the 1998 final rule EPA also promulgated regulations designed to codify the nonroad preemption provisions of section 209(e) of the CAA and to clarify the prohibition on certain new nonroad engines or nonroad vehicles standards by states or political subdivisions and other requirements relating to the control of emissions, including from new locomotives or new engines used in locomotives. EPA adopted a regulation that set a period equivalent in length to 133 percent of the regulatory useful life of a new locomotive or engine during which certain non-Federal requirements are preempted from applying to locomotives or engines used in locomotives.[1012] EPA also adopted regulations to implement the CAA provisions allowing California to request authorization for other non-Federal requirements on non-new locomotives and engines used in locomotives not otherwise prohibited.[1013]

CAA section 209(e)(2)(B) requires EPA to promulgate regulations implementing subsection 209(e), which addresses the prohibition of state standards regarding certain classes of nonroad engines or vehicles and potential EPA authorization of state standards for other nonroad engines or vehicles. The prohibited state standards or other requirements relating to the control of emissions include, under CAA section 209(e)(1)(B), those affecting new locomotives or new engines used in locomotives. Such state requirements cannot be authorized by EPA under section 209(b), pursuant to the final sentence of section 209(e)(1), or under section 209(e)(2). However, section 209(e)(2) requires EPA to authorize, subject to certain criteria, California's adoption and enforcement of standards and other requirements relating to control of emissions from nonroad vehicles or engines other than those referred to in paragraph 209(e)(1), which would include non-new locomotives and non-new engines used in locomotives.

EPA is concerned that our preemption regulations as adopted, particularly in extending preemption well beyond the CAA language of prohibiting the state regulation of new locomotives and new engines used in locomotives and to an extended point at which locomotives and engines are no longer new, may no longer be appropriate.[1014] Specifically, our existing regulations may have the unintended effect of both exceeding Congress' prescribed prohibition on state regulation of new locomotives and engines in section 209(e)(1) and impeding states from adopting innovative programs to reduce locomotive emissions that may be permissible under CAA section 209(e)(2). In this rule, EPA proposes to revise our locomotive preemption regulations to better align with the precise language Congress provided in section 209(e) and the Congressional directive to EPA to implement the prohibition of state regulation of new locomotives and new engines used in locomotives while ensuring that states are not impeded from adopting programs as allowed by the CAA to address the contribution of air pollutant emissions from non-new locomotives and engines to their air quality issues. In this section, EPA outlines the reasons that its previous extension of the categorical prohibition of state regulations applicable to locomotives and engines up to 133 percent of the regulatory useful life is not required by the CAA and may no longer be appropriate considering developments since the 1998 rule. We believe it is necessary to better align our regulatory text with the plain language of the CAA to provide regulatory space for state controls that do not inappropriately affect the design and manufacture of new locomotives or new engines used in locomotives.

B. Background

1. EPA's New Locomotive and Engine Standards and the Regulated Fleet[1015]

The Clean Air Act amendments of 1990 called on EPA to adopt emission

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[1011] Emission Standards for Locomotives and Locomotive Engines, 63 FR 18978 (April 16, 1998), codified at 40 CFR parts 85, 89 and 92.

[1012] For purely informational purposes, EPA notes that it is not aware that its regulations addressing the scope of preemption of state regulation of other types of nonroad engines and nonroad vehicles present the concerns described here relating to locomotives. Moreover, EPA's regulations do not set an equivalent period of preemption for any other class of nonroad engines (other than locomotives). EPA has issued several authorizations of California regulations relating to other non-new nonroad standards. See 80 FR 76468 (December 9, 2015); 78 FR 58090 (September 20, 2013). This action does not reopen any aspect of EPA's preemption regulations, policies, or actions regarding any other nonroad engines or vehicles, or regarding any other topics besides those expressly described in the text of the preamble and the proposed regulations.

[1013] To avoid confusion of the term ''used'' sometimes meaning ''placed or mounted,'' we employ the term ''non-new'' to describe engines that do not meet the definition of ''new'' in section 1074.5.

[1014] EPA announced an intent to review this issue in November 2022. See *https://www.epa.gov/regulations-emissions-vehicles-and-engines/petitions-address-harmful-emissions-locomotives.*

[1015] EPA provides this discussion of the Federal locomotive requirements under the CAA for standards for new locomotives and new locomotive engines to achieve the greatest degree of emission reduction achievable through the application of technology which EPA determines will be available for the locomotives or engines, giving appropriate consideration to the cost of applying such technology within the period of time available to manufacturers and to associated noise, energy, and safety factors. CAA section 213(a)(5), 42 U.S.C. 7547(a)(5). From the beginning, EPA's new locomotive emission control program identified two ways by which locomotives and engines would be deemed ''new'' and thus subject to the standards: EPA imposed emission standards for so-called ''freshly manufactured'' locomotives that have increasing stringency levels based on which ''Tier'' the new locomotive belongs to, and We applied emission standards for older locomotives built beginning in 1973 that would apply when those older locomotives are ''remanufactured'' (all of the power assemblies are either replaced or are inspected and requalified either all at once or within a 5-year period) according to their original Tier. This approach was necessary due to the very long service lives of locomotives. As we explained in the 1998 rule, the service life of a locomotive can extend to 40 years and beyond, during which period the engine and the locomotive undergo several extensive remanufacturing operations that EPA has determined makes the locomotive or engine ''new'' again. These remanufacturing operations generally consist of, at a minimum, the replacement of the power assemblies (*i.e.,* pistons, piston rings, cylinder liners, cylinder heads, fuel injectors, valves, etc.) with new components (or components that are in new condition) to restore the locomotive to the condition it was in when originally manufactured with respect to performance, durability, and emissions. Because they are designed to be rebuilt on a regular schedule, locomotives can remain in service as long as the main engine block remains serviceable. EPA's locomotive remanufacture program reduces emissions from these older locomotives, which are fitted with better parts and systems when they are remanufactured and become ''new'' again. However, the stringency of the remanufacture standards has been limited by the extent to which new emission control technology can be retrofit on these older designs.

Not surprisingly, recent fleet profile data shows that the in-service locomotive fleet continues to be dominated by Tier 2 and earlier locomotives subject to EPA's less stringent emission standards.[1016] According to data supporting EPA's 2020 National Emission Inventory, there are 16,787 locomotives in the Class I line-haul fleet.[1017] Of these, about 26 percent are Tier 3 or Tier 4 locomotives subject to more stringent emission standards.[1018] The other 74 percent are Tier 2 or earlier locomotives, broken down as follows: About 62 percent are remanufactured to the revised remanufacture standards adopted in 2008; 11 percent have not been remanufactured and continue to have the higher emissions of their original certification tier; and a small number, about 1 percent, are unregulated (pre-1973) locomotives. Class II and III[1019] railroads are not generally subject to remanufacturing obligations. To the extent one of these railroads purchases a locomotive that was previously certified to EPA's standards, then the railroad must ensure the locomotive continues to comply with those standards. The Class II and III line-haul fleet consists of 3,447 locomotives. Of these, about 7 percent are Tier 3 or 4 locomotives. The other 93 percent are Tier 2 or earlier, broken down as follows: About 39 percent of the locomotives are unregulated (pre-1973); 48 percent are Tier 0; and The other six percent are Tier 1 or Tier 2.

Given the large share of older locomotives in the Class I, II and III railroad fleets, and their emissions contribution to ambient concentrations of air pollution that may cause violations of national ambient air quality standards (NAAQS), states and local entities who must develop state implementation plans (SIPs) demonstrating attainment of NAAQS have expressed interest in obtaining greater emissions reductions from this sector, including possibly adopting programs to achieve greater emission reductions from non-new locomotives beyond those achieved by EPA's standards applicable to new locomotives. States and local entities have expressed particular interest in addressing emissions from non-new locomotives for areas located along high traffic rail lines and/or in communities with environmental justice concerns. However, notwithstanding Congress' provision in section 209(e)(2) for EPA to authorize such state efforts, subject to certain criteria, the agency now believes that the pre-emption regulation for locomotives adopted in the 1998 rule might preclude states (following California as described Section X.B.2) from exploring some innovative local programs.

2. EPA's Regulatory Preemption of State Control of Locomotive and Engine Emissions

As part of the 1998 locomotive rule EPA established regulations that prohibited state regulation of new locomotives and new engines used in locomotives. This is currently reflected in the regulatory text of 40 CFR 1074.12(a), and reflects Congress' command in CAA section 209(e)(1)(B). In addition, to provide certainty to state, localities, and industry regarding the period when certain state controls would be prohibited under 209(e)(1)(B), EPA also provided that such prohibition would last for a period equal to 133 percent of the useful life of a new locomotive or new engine used in a locomotive—even after the locomotive or engine was placed into service and ceased to be ''new.''[1020] This is currently reflected at section 1074.12(b) of EPA's rule, along with several specific types of standards or other requirements that EPA then concluded are preempted. This decision to codify a prohibition period extending beyond when locomotives are new and to enumerate several preempted types of requirements was based on EPA's understanding of the nature of the locomotive industry, the regulatory landscape, and the then-existing emission control technologies considering the CAA and other relevant legal considerations.[1021]

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background purposes only. In this proposal, EPA is not reopening the Federal locomotive requirements, and any comments on such will be deemed beyond the scope of the action.

[1016] 2020 National Emissions Inventory Locomotive Methodology Prepared for U.S. Environmental Protection Agency by Eastern Research Group, Inc. (May 19, 2022). *https://gaftp.epa.gov/air/nei/2020/doc/supporting_data/nonpoint/Rail/2020_NEI_Rail_062722.pdf.*

[1017] The current classification of railroads adopted by the Surface Transportation Board (STB) in 2021 is based on annual carrier operating revenue, as follows: Class I railroads, greater than $943.9 million; Class II railroads, $42.4 to $943.9 million; Class III railroads less than $42.4 million. See 49 CFR 1201 (1–1 Classification of Carriers).

[1018] EPA took action to set additional emission standards for new locomotives and engines in 2008; see final rule published at 73 FR 37096 (June 30, 2008), Control of Emissions of Air Pollution From Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder.

[1019] *Ibid.*

[1020] Proposed Rule: Emission Standards for Locomotives and Locomotive Engines, 62 FR 6366 (February 11, 1997)

[1021] These considerations included: The language of the CAA and its legislative history (62 FR 6397–6398; Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission

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In 1998, the locomotive manufacturers and remanufacturers were anticipating a need to develop emission technologies to apply to their locomotive engines with uncontrolled emissions to comply with the first three Tiers of locomotive emission standards (Tiers 0, 1, and 2). They would eventually need to apply technology to meet Tiers 3 and 4, adopted in 2008 and fully phased-in by 2015. As EPA explained in 1998, there was a risk that some state regulations could have affected the design and manufacture of new locomotives and new engines used in locomotives (including freshly manufactured and remanufactured), and additional certainty was determined to be beneficial for all interested parties.[1022] At the same time, in the 1998 rulemaking EPA explained that states may regulate the use and operation of locomotives in a manner that does not significantly affect the design or manufacture of a new (including remanufactured) locomotive or engine, potentially allowing states to control nuisances, and that California (and other states following California) may obtain an EPA authorization (waiver of Federal preemption) for standards and other requirements relating to the control of emissions from non-new locomotives and non-new engines used in locomotives, provided they did not significantly affect the design and manufacture of new locomotives or engines.[1023] This allowance is currently reflected in EPA's rules at section 1074.101 through 1074.115. However, to date California has not sought EPA authorization under section 209(e) of any program to address emissions from non-new locomotives or engines.

By defining the period of preemption to be 133 percent of the useful life of a new locomotive or engine EPA intended to preclude certain forms of potential state regulation of non-new locomotives due to the concern they could significantly impact the design and manufacture of new locomotives and new engines used in locomotives. EPA's intention to preclude some but not all forms of state regulation is clearly discussed in the 1997 NPRM,[1024] in the Summary and Analysis of Comments,[1025] and in the final 1998 rulemaking[1026] where we explained that ''The list of state controls that are explicitly preempted under today's regulation is not intended to be exclusive''[1027] and ''. . . all state requirements relating to the control of emissions from in-use locomotives and locomotive engines, including state requirements not listed as preempted [. . .], are subject to section 209(e)(2)'s waiver requirement.''[1028] This preemption language was recodified in the sections of 40 CFR part 1074, in October of 2008, as part of EPA's final rule establishing standards for the Control of Emissions from Nonroad Spark-Ignition Engines and Equipment.[1029]

C. Evaluation of Impact of Regulatory Preemption

In EPA's final 1998 action, EPA adopted regulations preempting certain state and local controls of locomotives and engines used in locomotives, which we determined to be appropriate based on our understanding of the information at the time.[1030] The intent of these regulations was to provide ''certainty with respect to when state controls would be preempted'' (62 FR 6398) and determine that ''certain categories of potential state requirements would be preempted under the proposed approach'' (62 FR 6398).

EPA's explanation for the preemptions was particularly focused on specific types of controls listed in 40 CFR 1074.12(b), which we deemed categorically preempted for locomotives and engines up to 133 percent of the regulatory useful life.[1031] For all other types of controls, the 1998 Locomotive final rulemaking stated that ''. . . all state requirements relating to the control of emissions from in-use locomotives and locomotive engines, including state requirements not listed as preempted in 40 CFR 85.1603(c)(1), are subject to section 209(e)(2)'s waiver requirement.''[1032] Further, in our response to comments regarding preemption of state regulations we explained, ''states may regulate the use and operation of locomotives in a manner that does not significantly affect the design or manufacture of a new (including remanufactured) locomotive or engine, potentially allowing states to control nuisances.''[1033] As an example, the final rule deviated from the proposal by excluding state in-use testing programs using the Federal test procedure from the list of preempted controls because EPA could not determine that it would violate 209(e)(1)(B).[1034] While these aspects of the 1998 rule make a case that there are opportunities for California to obtain authorization under CAA 209(e)(2) for eligible measures, we are concerned that the effect of our 1998 regulation has been to discourage consideration of all such opportunities.

At the same time, locomotive emission controls have developed significantly since the 1998 rule, and some of these developments call into question the factual underpinnings of EPA's prior decision to categorially preempt certain controls up to 133 percent of the regulatory useful life. It has been 15 years since EPA's 2008 rule was finalized and eight years since the first compliance year of the locomotive Tier 4 emissions standards. With the certainty provided by the long lead time prior to implementation of Tier 4 and the stability provided by a long period of unchanged standards, the emission control technologies for new diesel locomotives are now well established. In developing this proposal, we reviewed the technical basis for the types of controls in 40 CFR 1074.12(b) established in 1998 and evaluated currently available technologies and practices to investigate the extent to which our reasoning in 1998 still holds today, following more recent technological developments and the extent to which emissions control tools may be employed for existing locomotives without necessarily presenting significant effects on the

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Standards for Locomotives and Locomotive Engines, 1998), p. 12; court rulings (see 62 FR 6397, *see also Allway Taxi, Inc.* v. *City of New York,* 340 F. Supp. 1120, 1124 (S.D.N.Y. 1972)); Constitutional concerns (Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission Standards for Locomotives and Locomotive Engines, 1998, pp. 13, 17, 18); and Technical challenges of states regulating non-new locomotives and engines used in locomotives (Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission Standards for Locomotives and Locomotive Engines, 1998, Chapter 1 Section C).

[1022] 63 FR 18979 and 18993–18994.

[1023] Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission Standards for Locomotives and Locomotive Engines, EPA, EPA–420–R–97–101, pp. 17–18.

[1024] See 62 FR 6366, 6398, and 6399.

[1025] Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission Standards for Locomotives and Locomotive Engines, EPA, EPA–420–R–97–101, pp. 15–19.

[1026] See 63 FR 18978.

[1027] 63 FR 18994.

[1028] *Ibid.*

[1029] Oct 8, 2008, 73 FR 59033, Control of Emissions from Nonroad Spark-Ignition Engines & Equipment.

[1030] See, 63 FR at 18993–18994, codified at 40 CFR 85.1603 Application of definitions; scope of preemption. This was later recodified at 40 CFR 1074.12; see 73 FR 59034 (Oct. 8, 2008).

[1031] Including but not limited to emission standards, mandatory fleet average standards, certification requirements, retrofit and aftermarket equipment requirements, and non-Federal in-use testing requirements.

[1032] See, 63 FR 18994.

[1033] Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission Standards for Locomotives and Locomotive Engines, EPA, EPA–420–R–97–101, p. 18.

[1034] 63 FR 18993–18994.

design and manufacture of new locomotives and engines.

We have identified two examples of post-1998 emission controls that states would be prohibited from requiring for non-new locomotives under the language of 40 CFR 1074.12(b), but that initially appear would not significantly affect the design or manufacture of a new locomotive or locomotive engine and in fact have in some cases been voluntarily applied. Although we have not received any submission of an actual regulation addressing controls of this nature, which would need to be evaluated on its own basis under CAA section 209(e)(2), we discuss these possible measures that might not be preempted as requirements applying to new locomotives or new engines used in locomotives if evaluated on a case-by-case basis. Our evaluation suggests that the 1998 regulatory provisions categorically preempting certain controls up to 133 percent of the useful life may be overly restrictive in precluding state consideration of potential measures to reduce emissions from existing locomotives.

One example of a post-1998 control measure that we have identified as potentially not significantly affecting the design or manufacture of a new locomotive or engine is the retrofitting of an auxiliary power unit (APU) to support engine shutdown for idle reduction. In this scenario, installation of such an APU on a locomotive with an engine shutdown timer can enable the main engine to shut down while maintaining power to auxiliary functions such as air brake pressure and battery state of charge. There may be sufficient space and fluids onboard to accommodate this component without disrupting the existing equipment or the design of new remanufacturing kits. Under the terms of current 40 CFR 1074.12(b) this is an example of a requirement that may be categorically preempted because current section 1074.12(b) preempts state retrofit and aftermarket equipment requirements. Without evaluating the technical drawbacks or merits of any specific state requirement for such a retrofitting on existing locomotives, we observe that such a requirement could potentially be consistent with the statutory authorization criteria and be allowed if evaluated on its own merits under 40 CFR 1074.101 through 1074.115. As further evidence that such a retrofit requirement would not likely have an adverse effect on the design of new locomotives, this type of technology retrofit project is often pursued by locomotive operators on a voluntary basis.[1035]

A second example of a post-1998 emission control measure that may not significantly affect the design or manufacture of a new locomotive or engine is the installation of a new load control calibration strategy that better manages load on the main engine while the locomotive is in line haul service. Such technology is utilized today and may be installed on units already in service[1036] and is available as an upgrade in some certified remanufacture kits.[1037] In this scenario, a locomotive would have certain software installed that governs how the engine is used during the route, which helps save fuel and reduces emissions. Because the components involved include minimal hardware, we do not believe implementation of this measure would result in a significant effect on the design of new locomotives. Therefore, a state imposing a requirement that existing locomotives employ it would not necessarily constitute a control of new locomotive emissions. Nonetheless, under the existing regulations, such a control may be categorically preempted. Without evaluating the technical drawbacks or merits of such a state's specific action to impose such a requirement for this kind of more recent technological measure, we believe that our 1998 regulatory text may inappropriately restrict whether a state can request authorization under CAA section 209(e)(2) to impose such a requirement. Therefore, EPA believes that there are in fact reasonable examples of readily available technologies that if included as part of a state regulatory program could be considered for authorization under CAA section 209(e)(2) and our rules at 40 CFR 1074.101 through 1074.115, but that under our 1998 regulatory text in 40 CFR 1074.12(b)—adopted in advance of the development of these newer technological measures—California is currently discouraged from exploring. Any such program should be evaluated on its own terms, if submitted, rather than be assumed to significantly affect design and manufacture of new locomotives under a categorical regulatory preemption provision that did not account for more recent technological measures.

While EPA's adoption of its regulations in 1998 helped facilitate a smooth regulatory progression from uncontrolled to regulated locomotives, the more recent technological developments of pollution control measures, such as those briefly discussed in this Section X, indicate that there may be instances now where the general conclusions reached in 1998 may no longer be supportable, and instead may result in our 1998 preemption rules inappropriately reaching beyond the scope of section 209(e)(1)'s prohibition on requirements that relate to new locomotives and new engines used in locomotives. Although EPA has discussed only some examples of potential control measures that might be considered for application under a state program for existing locomotives without significantly affecting the design and manufacture of new locomotives, the very nature of rapid technological development suggests that it is not necessary or possible for EPA to prejudge, as under the current text of 40 CFR 1074.12, all potential forms of state control of existing locomotives regarding whether they should remain preempted with no possibility of authorization under CAA section 209(e)(2).

EPA further believes that the examples discussed show there is sufficient information available to more generally call into question the conclusion that all the forms of state control explicitly preempted by the current text in 40 CFR 1074.12(b) would necessarily affect how manufacturers and remanufacturers design new locomotives and new engines used in locomotives. Based on these examples, along with the fact that any request from California (for its regulatory and technological approaches) under 40 CFR 1074.101 through 1074.115 would be evaluated on a case-by-case basis, we observe that by removing the language in 40 CFR 1074.12(b) EPA would still be required to evaluate any submission from California under CAA section 209(e)(1) and (2), providing the opportunity for public comment by all interested stakeholders. EPA seeks comment on this assessment and to what extent there would be public benefit if we were to retain the current regulatory text.

While EPA can no longer say, for certain, that our conclusions in 1998 about state imposition of in-use requirements will always be true for

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[1035] See, for example, Railway Age, BNSF, Hotstart partner on locomotive retrofit, November 19, 2014. *https://www.railwayage.com/freight/class-i/bnsf-hotstart-partner-on-locomotive-retrofit/* accessed January 2023.

[1036] See, for example, *https://www.nyabproducts.com/leader/* and *https://www.wabteccorp.com/digital-electronics/train-performance-and-automation/trip-optimizer*, accessed January 2023.

[1037] See, for example, Wabtec's certified remanufacture families PGETK0668T1Y and PGETK0668T0C, which are Tier 1 and Tier 0 systems, respectively, that include the Trip Optimizer software as an energy saving design.

those listed forms of standards or requirements, we are also not saying that such measures can or will be authorized under CAA section 209(e)(2) (even for the examples provided). EPA is not concluding in this document that any of these forms of standards, if submitted, would be authorized, or that these forms of standards would not contravene CAA section 209(e)(1). Rather this action to revise 40 CFR 1074.12, if finalized, would better allow California the opportunity to explore, develop, and justify in a program-specific submission for authorization why a certain form of state regulation should be allowed under CAA section 209(e)(2) and our rules at 40 CFR 1074.101 through 1074.115, and allow EPA to evaluate such a submission on a case-by-case basis evaluating its specific merits rather than being categorically preempted without the benefit of an actual administrative record regarding the specific state regulation.

The scope of this proposal includes the types of state measures preempted as well as the period of preemption. EPA's assessment that our previous general conclusions regarding what types of measures must be preempted at the outset may no longer be supportable necessarily extends to the period of preemption imposed by our regulations. The current text at 40 CFR 1074.12(b) preempts the state control of in-use locomotives for the categories of regulations listed for a period of 133 percent of useful life of a new locomotive or engine. Since we now believe it is inappropriate to prejudge that all the listed types of measures would have such an effect, we likewise cannot say that the fixed period of preemption of such measures must still apply. EPA therefore proposes to remove the specified period of preemption in 40 CFR 1074.12(b). In place of this, the EPA would include evaluation of the temporal nature of any submitted state controls as part of its evaluation of any authorization request under 40 CFR 1074.101 through 1074.115.

D. What is EPA proposing?

We believe the current preemption language may impede California's exploration of regulations of non-new locomotives and locomotive engines beyond what is required by CAA section 209(e). To address this, EPA is proposing to make several revisions in part 1074, including sections 1074.10, 1074.12, and 1074.101.

In 40 CFR 1074.10, we propose to revise subsection (b) to contain text that is currently located in section 1074.12(a), and move the current text of subsection (b) into a new subsection (c). This would solely be a housekeeping measure, as no revisions to the content of the text or current subsection 1074.12(a) are proposed.

In 40 CFR 1074.12, we are proposing to delete 40 CFR 1074.12 in its entirety. We believe the removal of the explicit period of preemption as well as the listed categories of state control measures would signal that not all state regulations are intended to be preempted and would better align the scope of the regulation with the CAA. We seek comment on these proposed revisions and whether they adequately align our regulations with the CAA, and whether they achieve the intended purpose of not impeding California from pursuing state-level standards or control measures that may be considered for authorization according to the procedures outlined in 40 CFR 1074.101 through 1074.115. We note that under the proposal, California rules addressing non-new locomotives or engines would still need to go through the authorization process at 40 CFR 1074.101 through 1074.105, which would ensure compliance with the statutory authorization criteria: California's determination that its standards will be, in the aggregate, at least as protective of public health and welfare as otherwise applicable Federal standards is not arbitrary and capricious; Any opponents of the authorization have not met their burdens to demonstrate that California does not need such standards to meet compelling and extraordinary conditions; and Any such opponents have not demonstrated that such standards and accompanying enforcement procedures are not consistent with section 209 of the CAA (including section 209(e)(1)).[1038]

EPA notes that we would still have concerns related to authorization requests that included forms of state controls that would significantly affect the design or manufacture of a new locomotive or engine. However, EPA recognizes that significant advances in technology have occurred in the intervening years since 1998, along with innovative forms of regulations. Any state authorization application received by EPA would need to demonstrate why the submitted control measure would not significantly affect the design or manufacture of a new locomotive. As required by the CAA, the EPA would evaluate any such application on a case-by-case basis to determine if the controls may be authorized under section 209(e)(2).

Note that certain categories of potential state requirements, while not expressly preempted by section 209(e)(1) or EPA's regulations implementing section 209(e)(1), may be preempted if they would create a conflict with other provisions of the Act. For example, section 203(a)(3) of the Act prohibits tampering, and certain requirements to modify engines might constitute tampering. Analysis of such possible conflicts would be incorporated into the evaluation of EPA's review of an authorization request under 40 CFR 1074.101 through 1074.115.

In 40 CFR 1074.101, we propose a minor housekeeping edit to paragraph (a) of this section, to refer to the relocated text in 1074.10(b) that is being moved out of 1074.12.

None of the proposed changes to our preemption regulations would have any impact on the regulation of new locomotives or engines used in locomotives (including freshly built and remanufactured) under 40 CFR part 1033. We are not reopening any aspect of the regulation of new locomotives or engines, and any comments on these topics will be deemed beyond the scope.

XI. Statutory and Executive Order Reviews

Additional information about these statutes and Executive Orders can be found at *http://www.epa.gov/laws-regulations/laws-and-executive-orders.*

A. Executive Order 12866: Regulatory Planning and Review and Executive Order 13563: Improving Regulation and Regulatory Review

Under section 3(f)(1) of Executive Order 12866, this action is a significant regulatory action that was submitted to the Office of Management and Budget (OMB) for review. Any changes made in response to recommendations received as part of Executive Order 12866 review have been documented in the docket. EPA prepared an analysis of the potential costs and benefits associated with this action. This analysis, the draft ''Regulatory Impact Analysis—Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles-Phase 3—Notice of Proposed Rulemaking,'' is available in the docket. The analyses contained in this document are also summarized in Sections II, IV, V, VI, VII, VIII and IX of this preamble.

[1038] 40 CFR 1074.105(b). Adopted at Part 85.1603(c)(1) in 1998 and recodified in Part 1074 as part of the Control of Emissions From Nonroad Spark-Ignition Engines and Equipment, October 8, 2008, 73 FR 59033.

B. Paperwork Reduction Act (PRA)

The information collection activities in this proposed rule have been submitted for approval to the Office of Management and Budget (OMB) under the PRA. The Information Collection Request (ICR) that EPA prepared has been assigned EPA ICR Number 2734.1. You can find a copy of the Supporting Statement in the docket for this rule, and it is briefly summarized here.

This proposed rulemaking consists of targeted updates to the existing GHG emission standards for heavy-duty vehicles beginning with MY 2027 in consideration of zero-emission technology. The information collection activities for EPA's Phase 2 GHG program would not change as a result of this proposed rule, although manufacturers would experience a cost associated with reviewing the new requirements.

- *Respondents/affected entities:* Manufacturers of heavy-duty onroad vehicles.
- *Respondent's obligation to respond:* Regulated entities must respond to the collection if they wish to sell their products in the United States, as prescribed by CAA section 203(a). Participation in some programs is voluntary; but once a manufacturer has elected to participate, it must submit the required information.
- *Estimated number of respondents:* Approximately 77 heavy-duty vehicle manufacturers.
- *Frequency of response:* One-time burden associated with reviewing the new requirements for all manufacturers; for EV manufacturers, one-time burden associated with new battery health monitor provisions, warranty reporting requirements, and associated revisions to owners manuals
- *Total estimated burden:* 7,411 hours. Burden is defined at 5 CFR 1320.03(b)
- *Total estimated cost:* $1.622 million; includes an estimated $936,500 maintenance and operational costs.

An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations in 40 CFR are listed in 40 CFR part 9.

Submit your comments on the Agency's need for this information, the accuracy of the provided burden estimates and any suggested methods for minimizing respondent burden to EPA using the docket identified at the beginning of this rule. You may also send your ICR-related comments to OMB's Office of Information and Regulatory Affairs using the interface at *www.reginfo.gov/public/do/PRAMain.* Find this particular information collection by selecting "Currently under Review—Open". Since OMB is required to make a decision concerning the ICR between 30 and 60 days after receipt, OMB must receive comments no later than June 26, 2023. The EPA will respond to any ICR-related comments in the final rule.

C. Regulatory Flexibility Act (RFA)

I certify that this action will not have a significant economic impact on a substantial number of small entities under the RFA. As explained elsewhere in this preamble, EPA is proposing to exempt small entities from the proposed revisions to EPA's Phase 2 GHG requirements for MY 2027 and the proposed additional GHG requirements for MYs 2028 through 2032 and later. Small EV manufacturers would be subject to new battery health monitor provisions and warranty provisions, which include making associated revisions to owners manuals. There are 10 small companies that would be affected by the proposal. The estimated burden is not expected to exceed 3 percent of annual revenue for any small entity, and is expected to be between 1 and 3 percent of annual revenue for only one company. We have therefore concluded that this action will have minimal impact on small entities within the regulated industries. More information concerning the small entities and our decision is presented in Chapter 9 of the draft RIA.

D. Unfunded Mandates Reform Act (UMRA)

This proposed rule contains no Federal mandates under UMRA, 2 U.S.C. 1531–1538, for State, local, or Tribal governments. The proposed rule would impose no enforceable duty on any State, local or Tribal government. This proposed rule would contain a Federal mandate under UMRA that may result in expenditures of $100 million or more for the private sector in any one year. Accordingly, the costs and benefits associated with the proposed rule are discussed in Section VIII and in the draft RIA, which are in the docket for this rule.

This action is not subject to the requirements of section 203 of UMRA because it contains no regulatory requirements that might significantly or uniquely affect small governments.

E. Executive Order 13132: Federalism

The action we are proposing for HD Phase 3 CO_2 emission standards and related regulations does not have federalism implications. The proposed HD Phase 3 CO_2 emission standards will not have substantial direct effects on the states, on the relationship between the national government and the states, or on the distribution of power and responsibilities among the various levels of government.

The action we are proposing with regard to preemption of State control of air pollutant emissions from new locomotives and new engines used in locomotives (described in Section X), however, does have federalism implications because the proposed revisions to part 1074 involve existing regulations that preempt State law under CAA section 209(e)(1). This action proposes revisions to current regulatory provisions in order to better align EPA's rules with CAA section 209(e)'s statutory requirements. Today's action proposes to remove regulatory language that extended the preemption period beyond the point at which locomotives and engines are new. In this rule, EPA proposes to revise our locomotive preemption regulations to better align with precise language Congress provided in section 209(e) and the Congressional directive to EPA to implement the prohibition of state regulation of new locomotives and new engines used in locomotives while ensuring that states are not impeded from adopting programs as allowed by the CAA to address the contribution of air pollutant emissions from non-new locomotives and engines to their air quality issues. EPA consulted with representatives of various State and local governments in developing this proposed rule. We met with representatives from the National Association of State Energy Officials, the National Association of Clean Air Agencies, the Northeast States for Coordinated Air Use Management, the Ozone Transport Commission, and the Association of Air Pollution Control Agencies in a joint meeting on April 21, 2022. We met with representatives from CARB periodically from September to December 2022, and we met with representatives from the National Association of Clean Air Agencies, the Northeast States for Coordinated Air Use Management, and the Ozone Transport Commission in a joint meeting on December 13, 2022. In the spirit of Executive Order 13132, and consistent with EPA policy to promote communications between EPA and State and local governments, EPA specifically solicits comment on this proposed rule revision from State and local officials.

F. Executive Order 13175: Consultation and Coordination With Indian Tribal Governments

This action does not have Tribal implications as specified in Executive Order 13175. Thus, Executive Order 13175 does not apply to this action.

This action does not have substantial direct effects on one or more Indian tribes, on the relationship between the Federal Government and Indian tribes, or on the distribution of power and responsibilities between the Federal Government and Indian tribes. However, EPA plans to continue engaging with Tribal stakeholders in the development of this rulemaking by offering a Tribal workshop and offering government-to-government consultation upon request.

G. Executive Order 13045: Protection of Children From Environmental Health and Safety Risks

This action is subject to Executive Order 13045 because it is a significant regulatory action under section 3(f)(1) of Executive Order 12866, and EPA believes that the environmental health risks or safety risks of the pollutants addressed by this action may have a disproportionate effect on children. The 2021 Policy on Children's Health also applies to this action.[1039] Accordingly, we have evaluated the environmental health or safety effects of air pollutants affected by the proposed program on children. The results of this evaluation are described in Section VI of the preamble and Chapter 5 of the DRIA. The protection offered by these standards may be especially important for children because childhood represents a life stage associated with increased susceptibility to air pollutant-related health effects.

This proposed rule would reduce emissions of GHGs, which would reduce the effects of climate change on children. GHGs contribute to climate change and the GHG emissions reductions resulting from implementation of this proposed rule would further improve children's health. The assessment literature cited in EPA's 2009 and 2016 Endangerment Findings concluded that certain populations and life stages, including children, the elderly, and the poor, are most vulnerable to climate-related health effects. The assessment literature since 2016 strengthens these conclusions by providing more detailed findings regarding these groups' vulnerabilities and the projected impacts they may experience. These assessments describe how children's unique physiological and developmental factors contribute to making them particularly vulnerable to climate change. Impacts to children are expected from heat waves, air pollution, infectious and waterborne illnesses, and mental health effects resulting from extreme weather events. In addition, children are among those especially susceptible to most allergic diseases, as well as health effects associated with heat waves, storms, and floods. Additional health concerns may arise in low-income households, especially those with children, if climate change reduces food availability and increases prices, leading to food insecurity within households. More detailed information on the impacts of climate change to human health and welfare is provided in Section VI.A of this preamble.

Children make up a substantial fraction of the U.S. population, and often have unique factors that contribute to their increased risk of experiencing a health effect from exposures to ambient air pollutants because of their continuous growth and development. Children are more susceptible than adults to many air pollutants because they have (1) a developing respiratory system, (2) increased ventilation rates relative to body mass compared with adults, (3) an increased proportion of oral breathing, particularly in boys, relative to adults, and (4) behaviors that increase chances for exposure. Even before birth, the developing fetus may be exposed to air pollutants through the mother that affect development and permanently harm the individual when the mother is exposed.

In addition to reducing GHGs, this proposed rule would also reduce onroad emissions of criteria pollutants and air toxics. Section V of this preamble presents the estimated onroad emissions reductions from the proposed rule. Certain motor vehicle emissions present greater risks to children. Early lifestages (*e.g.,* children) are thought to be more susceptible to tumor development than adults when exposed to carcinogenic chemicals that act through a mutagenic mode of action.[1040] Exposure at a young age to these carcinogens could lead to a higher risk of developing cancer later in life. Chapter 5.2.8 of the DRIA describes a systematic review and meta-analysis conducted by the U.S. Centers for Disease Control and Prevention that reported a positive association between proximity to traffic and the risk of leukemia in children.

The adverse effects of individual air pollutants may be more severe for children, particularly the youngest age groups, than adults. As described in Section VI.B of this preamble and Chapter 5 of the DRIA, the Integrated Science Assessments for a number of pollutants affected by this rule, including those for SO_2, NO2, PM, ozone and CO, describe children as a group with greater susceptibility. Also, Section VI.B of this preamble and Chapter 5 of the DRIA discuss a number of childhood health outcomes associated with proximity to roadways, including evidence for exacerbation of asthma symptoms and suggestive evidence for new onset asthma.

There is substantial evidence that people who live or attend school near major roadways are more likely to be people of color, Hispanic ethnicity, and/or low socioeconomic status. Within these highly exposed groups, children's exposure and susceptibility to health effects is greater than adults due to school-related and seasonal activities, behavior, and physiological factors.

Children are not expected to experience greater ambient concentrations of air pollutants than the general population. However, because of their greater susceptibility to air pollution, including the impacts of a changing climate, and their increased time spent outdoors, it is likely that the emissions reductions associated with the proposed standards would have particular benefits for children's health.

H. Executive Order 13211: Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use

This action is not a ‘‘significant energy action’’ because it is not likely to have a significant adverse effect on the supply, distribution, or use of energy. EPA has outlined the energy effects in Section VI of this preamble and Chapter 5 of the draft RIA, which is available in the docket for this action and is briefly summarized here.

This action proposes to reduce CO_2 emissions from heavy-duty vehicles under revised GHG standards, which would result in significant reductions in the consumption of petroleum, would achieve energy security benefits, and would have no adverse energy effects. Because the GHG emission standards result in fuel savings, this rule encourages more efficient use of fuels. Section VI.F of this preamble describes our projected fuel savings due to the proposed standards.

[1039] U.S. Environmental Protection Agency (2021). 2021 Policy on Children's Health. Washington, DC. *https://www.epa.gov/system/files/documents/2021-10/2021-policy-on-childrens-health.pdf.*

[1040] U.S. Environmental Protection Agency. (2005). Supplemental guidance for assessing susceptibility from early-life exposure to carcinogens. Washington, DC: Risk Assessment Forum. EPA/630/R–03/003F. *https://www3.epa.gov/airtoxics/childrens_supplement_final.pdf.*

I. National Technology Transfer and Advancement Act (NTTAA) and 1 CFR Part 51

This rulemaking involves technical standards. Except for the standards discussed in this Section XI.I, the standards included in the regulatory text as incorporated by reference were all previously approved for IBR and no change is included in this action.

In accordance with the requirements of 1 CFR 51.5, we are proposing to incorporate by reference the use of standards and test methods from the United Nations. The referenced standards and test methods may be obtained from the UN Economic Commission for Europe, Information Service at Palais des Nations, CH–1211 Geneva 10, Switzerland; *unece_info@un.org*; *www.unece.org*. We are incorporating by reference the following UN Economic Commission for Europe document:

Standard or test method	Regulation	Summary
Addendum 22: United Nations Global Technical Regulation No. 22, United Nations Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles, Adopted April 14, 2022.	40 CFR 1037.115 and 1037.810	GTR 22 establishes design protocols and procedures for measuring durability and performance for batteries used with electric vehicles and plug-in hybrid-electric vehicles.

J. Executive Order 12898: Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations

Executive Order 12898 (59 FR 7629, February 16, 1994) directs Federal agencies, to the greatest extent practicable and permitted by law, to make environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority populations (people of color and/or indigenous peoples) and low-income populations.

EPA believes that the human health or environmental conditions that exist prior to this action result in or have the potential to result in disproportionate and adverse human health or environmental effects on people of color, low-income populations and/or indigenous peoples. EPA provides a summary of the evidence for potentially disproportionate and adverse effects among people of color and low-income populations in Section VI.D of the preamble for this rule.

EPA believes that this action is likely to reduce existing disproportionate and adverse effects on people of color, low-income populations and/or indigenous peoples.

Section VI.D.1 discusses the environmental justice issues associated with climate change. People of color, low-income populations and/or indigenous peoples may be especially vulnerable to the impacts of climate change. The GHG emission reductions from this proposal would contribute to efforts to reduce the probability of severe impacts related to climate change.

In addition to reducing GHGs, this proposed rule would also reduce onroad emissions of criteria pollutants and air toxics. Section V of this preamble presents the estimated impacts from the proposed rule on onroad and EGU emissions. These non-GHG emission reductions from vehicles would improve air quality for the people who reside in close proximity to major roadways and who are disproportionately represented by people of color and people with low income, as described in Section VI.D.2 of this preamble. We expect that increases in criteria and toxic pollutant emissions from EGUs and reductions in petroleum-sector emissions could lead to changes in exposure to these pollutants for people living in the communities near these facilities. Analyses of communities in close proximity to these sources (such as EGUs and refineries) have found that a higher percentage of communities of color and low-income communities live near these sources when compared to national averages.

EPA is additionally identifying and addressing environmental justice concerns by providing fair treatment and meaningful involvement with Environment Justice groups in developing this proposed action and soliciting input for this notice of proposed rulemaking.

The information supporting this Executive Order review is contained in Section VI.D of the preamble for this rule, and all supporting documents have been placed in the public docket for this action.

XII. Statutory Authority and Legal Provisions

Statutory authority for the proposed GHG standards is found in CAA section 202(a)(1)–(2), 42 U.S.C. 7521 (a)(1)–(2), which requires EPA to establish standards applicable to emissions of air pollutants from new motor vehicles and engines which cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. Statutory authority for this proposed rule overall is found at 42 U.S.C. 7401–7675.

List of Subjects

40 CFR Part 1036

Environmental protection, Administrative practice and procedure, Air pollution control, Confidential business information, Greenhouse gases, Incorporation by reference, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements, Warranties.

40 CFR Part 1037

Environmental protection, Administrative practice and procedure, Air pollution control, Confidential business information, Incorporation by reference, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements, Warranties.

40 CFR Part 1054

Environmental protection, Administrative practice and procedure, Air pollution control, Confidential business information, Imports, Labeling, Penalties, Reporting and recordkeeping requirements, Warranties.

40 CFR Part 1065

Environmental protection, Administrative practice and procedure, Air pollution control, Incorporation by reference, Reporting and recordkeeping requirements, Research.

40 CFR Part 1074

Environmental protection, Administrative practice and procedure, Air pollution control, Locomotives, Nonroad engines, Scope of preemption.

Michael S. Regan,
Administrator.

For the reasons set out in the preamble, we are proposing to amend title 40, chapter I of the Code of Federal Regulations as set forth below.

PART 1036—CONTROL OF EMISSIONS FROM NEW AND IN-USE HEAVY-DUTY HIGHWAY ENGINES

■ 1. The authority citation for part 1036 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

■ 2. Amend § 1036.101 by revising the introductory text and paragraph (a)(1) to read as follows:

§ 1036.101 Overview of exhaust emission standards.

This part contains standards and other regulations applicable to the emission of the air pollutant defined as the aggregate group of six greenhouse gases: carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

(a) * * *

(1) Criteria pollutant standards for NO_X, HC, PM, and CO apply as described in § 1036.104. These pollutants are sometimes described collectively as ''criteria pollutants'' because they are either criteria pollutants under the Clean Air Act or precursors to the criteria pollutants ozone and PM.

* * * * *

§ 1036.104— [Amended]

■ 3. Amend § 1036.104 by removing paragraph (c)(2)(iii).

■ 4. Amend § 1036.108 by revising paragraphs (a)(1)(iii) introductory text and (e) to read as follows:

§ 1036.108 Greenhouse gas emission standards—CO_2, CH_4, and N_2O.

* * * * *

(a) * * *

(1) * * *

(iii) The following Phase 2 and Phase 3 CO_2 standards apply for compression-ignition engines and all Heavy HDE (in g/hp·hr):

* * * * *

(e) Applicability for testing. The emission standards in this subpart apply as specified in this paragraph (e) to all duty-cycle testing (according to the applicable test cycles) of testable configurations, including certification, selective enforcement audits, and in-use testing. The CO_2 FCLs serve as the CO_2 emission standards for the engine family with respect to certification and confirmatory testing instead of the standards specified in paragraph (a)(1) of this section. The FELs serve as the emission standards for the engine family with respect to all other duty-cycle testing. See §§ 1036.235 and 1036.241 to determine which engine configurations within the engine family are subject to testing. Note that engine fuel maps and powertrain test results also serve as standards as described in §§ 1036.535, 1036.540, 1036.545, and 1036.630.

■ 5. Amend § 1036.110 by revising paragraphs (b)(6), (b)(9) introductory text, (b)(11)(ii) and (c)(1) to read as follows:

§ 1036.110 Diagnostic controls.

* * * * *

(b) * * *

(6) The provisions related to verification of in-use compliance in 13 CCR 1971.1(l)(4) do not apply. The provisions related to manufacturer self-testing in 13 CCR 1971.5(c) also do not apply.

* * * * *

(9) Design compression-ignition engines to make the following additional data-stream signals available on demand with a generic scan tool according to 13 CCR 1971.1(h)(4.2), if the engine is so equipped with the relevant components and OBD monitoring is required for those components:

* * * * *

(11) * * *

(ii) Send us results from any testing you performed for certifying engine families (including equivalent engine families) with the California Air Resources Board, including the results of any testing performed under 13 CCR 1971.1(l) for verification of in-use compliance and 13 CCR 1971.5(c) for manufacturer self-testing within the deadlines set out in 13 CCR 1971.1 and 1971.5.

* * * * *

(c) * * *

(1) For inducements specified in § 1036.111 and any other AECD that derates engine output related to SCR or DPF systems, indicate the fault code for the detected problem, a description of the fault code, and the current speed restriction. For inducement faults under § 1036.111, identify whether the fault condition is for DEF level, DEF quality, or tampering; for other faults, identify whether the fault condition is related to SCR or DPF systems. If there are additional derate stages, also indicate the next speed restriction and the time remaining until starting the next restriction. If the derate involves something other than restricting vehicle speed, such as a torque derate, adjust the information to correctly identify any current and pending restrictions.

* * * * *

■ 6. Amend § 1036.111 by revising paragraphs (a)(2), (b) introductory text, (d), and (e) to read as follows:

§ 1036.111 Inducements related to SCR.

* * * * *

(a) * * *

(2) The provisions of this section apply differently based on an individual vehicle's speed history. A vehicle's speed category is based on the OBD system's recorded value for average speed for the preceding 30 hours of non-idle engine operation. The vehicle speed category applies at the point that the engine first detects an inducement triggering condition identified under paragraph (b) of this section and continues to apply until the inducement triggering condition is fully resolved as specified in paragraph (e) of this section. Non-idle engine operation includes all operating conditions except those that qualify as idle based on OBD system controls as specified in 13 CCR 1971.1(h)(5.4.10). Apply speed derates based on the following categories:

TABLE 1 TO PARAGRAPH (a)(2) OF § 1036.111—VEHICLE CATEGORIES

Vehicle category [a]	Average speed (mi/hr)
Low-speed	speed <15.
Medium-speed	15< speed <25.
High-speed	speed >25.

[a] A vehicle is presumed to be a high-speed vehicle if it has not yet logged 30 hours of non-idle operation.

* * * * *

(b) Inducement triggering conditions. Create derate strategies that monitor for and trigger an inducement based on the following conditions:

* * * * *

(d) Derate schedule. Engines must follow the derate schedule described in this paragraph (d) if the engine detects an inducement triggering condition identified in paragraph (b) of this section. The derate takes the form of a maximum drive speed for the vehicle. This maximum drive speed decreases over time based on hours of non-idle engine operation without regard to engine starting.

(1) Apply speed-limiting derates according to the following schedule:

TABLE 2 TO PARAGRAPH (d)(1) OF § 1036.111—DERATE SCHEDULE FOR DETECTED INDUCEMENT TRIGGERING CONDITIONS [a]

High-speed vehicles		Medium-speed vehicles		Low-speed vehicles	
Hours of non-idle engine operation	Maximum speed (mi/hr)	Hours of non-idle engine operation	Maximum speed (mi/hr)	Hours of non-idle engine operation	Maximum speed (mi/hr)
0	65	0	55	0	45
6	60	6	50	5	40
12	55	12	45	10	35
20	50	45	40	30	25
86	45	70	35		
119	40	90	25		
144	35				
164	25				

[a] Hours start counting when the engine detects an inducement triggering condition specified in paragraph (b) of this section. For DEF supply, you may program the engine to reset the timer to three hours when the engine detects an empty DEF tank.

(2) You may design and produce engines that will be installed in motorcoaches with an alternative derate schedule that starts with a 65 mi/hr derate when an inducement triggering condition is first detected, steps down to 50 mi/hr after 80 hours, and concludes with a final derate speed of 25 mi/hr after 180 hours of non-idle operation.

(e) *Deactivating derates.* Program the engine to deactivate derates as follows:

(1) Evaluate whether the detected inducement triggering condition continues to apply. Deactivate derates if the engine confirms that the detected inducement triggering condition is resolved.

(2) Allow a generic scan tool to deactivate inducement triggering codes while the vehicle is not in motion.

(3) Treat any detected inducement triggering condition that recurs within 40 hours of engine operation as the same detected inducement triggering condition, which would restart the derate at the same point in the derate schedule that the system last deactivated the derate.

■ 7. Amend § 1036.120 by revising paragraph (c) to read as follows:

§ 1036.120 Emission-related warranty requirements.

* * * * *

(c) *Components covered.* The emission-related warranty covers all components listed in 40 CFR part 1068, appendix A, and components from any other system you develop to control emissions. Note that this includes hybrid system components when a manufacturer's certified configuration includes hybrid system components. The emission-related warranty covers any components, regardless of the company that produced them, that are the original components or the same design as components from the certified configuration.

* * * * *

■ 8. Amend § 1036.125 by revising paragraph (h)(8)(iii) to read as follows:

§ 1036.125 Maintenance instructions and allowable maintenance.

* * * * *

(h) * * *

(8) * * *

(iii) A description of the three types of SCR-related derates (DEF level, DEF quality and tampering) and that further information on the inducement cause (*e.g.,* trouble codes) is available using the OBD system.

* * * * *

■ 9. Amend § 1036.150 by:

■ a. Revising paragraph (d);

■ b. Adding paragraph (f);

■ c. Revising paragraphs (j), and (k); and

■ d. Adding paragraph (aa).

The additions and revisions read as follows:

§ 1036.150 Interim provisions.

* * * * *

(d) *Small manufacturers.* The greenhouse gas standards of this part apply on a delayed schedule for manufacturers meeting the small business criteria specified in 13 CFR 121.201. Apply the small business criteria for NAICS code 336310 for engine manufacturers with respect to gasoline-fueled engines and 333618 for engine manufacturers with respect to other engines; the employee limits apply to the total number employees together for affiliated companies. Qualifying small manufacturers are not subject to the greenhouse gas emission standards in § 1036.108 for engines with a date of manufacture on or after November 14, 2011 but before January 1, 2022. In addition, qualifying small manufacturers producing engines that run on any fuel other than gasoline, E85, or diesel fuel may delay complying with every later greenhouse gas standard under this part by one model year; however, small manufacturers may generate emission credits only by certifying all their engine families within a given averaging set to standards that apply for the current model year. Note that engines not yet subject to standards must nevertheless supply fuel maps to vehicle manufacturers as described in paragraph (n) of this section. Note also that engines produced by small manufacturers are subject to criteria pollutant standards.

162 HEI Panel on the Health Effects of Long-Term Exposure to Traffic-Related Air Pollution (2022) Systematic review and meta-analysis of selected health effects of long-term exposure to traffic-related air pollution. Health Effects Institute Special Report 23. [Online at *https://www.healtheffects.org/publication/systematic-review-and-meta-analysis-selected-health-effects-long-term-exposure-traffic*] This more recent review focused on health outcomes related to birth effects, respiratory effects, cardiometabolic effects, and mortality.

* * * * *

(f) *Testing exemption for qualifying engines.* Tailpipe CO_2, CH_4, HC, and CO emissions from engines fueled with neat hydrogen are deemed to be zero. No fuel mapping, and no testing for CO_2, CH_4, HC, or CO is required under this part for these engines.

* * * * *

(j) *Alternate standards under 40 CFR part 86.* This paragraph (j) describes alternate emission standards that apply for model year 2023 and earlier loose engines certified under 40 CFR 86.1819–14(k)(8). The standards of § 1036.108 do not apply for these engines. The standards in this paragraph (j) apply for emissions measured with the engine installed in a complete vehicle consistent with the provisions of 40 CFR 86.1819–14(k)(8)(vi). The only requirements of this part that apply to these engines are those in this paragraph (j), §§ 1036.115 through 1036.135, 1036.535, and 1036.540.

(k) *Limited production volume allowance under ABT.* You may produce a limited number of Heavy HDE that continue to meet the standards that applied under 40 CFR 86.007–11 in model years 2027 through 2029. The maximum number of engines you may produce under this limited production allowance is 5 percent of the annual average of your actual production volume of Heavy HDE in model years 2023–2025 for calculating emission credits under § 1036.705. Engine certification under this paragraph (k) is subject to the following conditions and requirements:

* * * * *

(aa) *Correcting credit calculations.* If you notify us by October 1, 2024 that errors mistakenly decreased your balance of emission credits for 2020 or any earlier model years, you may correct the errors and recalculate the balance of emission credits after applying a 10 percent discount to the credit correction.

■ 10. Amend § 1036.205 by revising paragraph (v) to read as follows:

§ 1036.205 Requirements for an application for certification.

* * * * *

(v) Include good-faith estimates of U.S.-directed production volumes. Include a justification for the estimated production volumes if they are substantially different than actual production volumes in earlier years for similar models.

* * * * *

■ 11. Amend § 1036.240 by revising paragraph (c)(3) to read as follows:

§ 1036.240 Demonstrating compliance with criteria pollutant emission standards.

* * * * *

(c) * * *

(3) *Sawtooth and other nonlinear deterioration patterns.* The deterioration factors described in paragraphs (c)(1) and (2) of this section assume that the highest useful life emissions occur either at the end of useful life or at the low-hour test point. The provisions of this paragraph (c)(3) apply where good engineering judgment indicates that the highest useful life emissions will occur between these two points. For example, emissions may increase with service accumulation until a certain maintenance step is performed, then return to the low-hour emission levels and begin increasing again. Such a pattern may occur with battery-based hybrid engines or hybrid powertrains. Base deterioration factors for engines with such emission patterns on the difference between (or ratio of) the point at which the highest emissions occur and the low-hour test point. Note that this applies for maintenance-related deterioration only where we allow such critical emission-related maintenance.

* * * * *

■ 12. Amend § 1036.241 by revising paragraph (c)(3) to read as follows:

§ 1036.241 Demonstrating compliance with greenhouse gas emission standards.

* * * * *

(c) * * *

(3) *Sawtooth and other nonlinear deterioration patterns.* The deterioration factors described in paragraphs (c)(1) and (2) of this section assume that the highest useful life emissions occur either at the end of useful life or at the low-hour test point. The provisions of this paragraph (c)(3) apply where good engineering judgment indicates that the highest useful life emissions will occur between these two points. For example, emissions may increase with service accumulation until a certain maintenance step is performed, then return to the low-hour emission levels and begin increasing again. Such a pattern may occur with battery-based hybrid engines or hybrid powertrains. Base deterioration factors for engines with such emission patterns on the difference between (or ratio of) the point at which the highest emissions occur and the low-hour test point. Note that this applies for maintenance-related deterioration only where we allow such critical emission-related maintenance.

* * * * *

■ 13. Amend § 1036.245 by revising paragraphs (c)(3) introductory text and (c)(3)(ii) introductory text to read as follows:

§ 1036.245 Deterioration factors for exhaust emission standards.

* * * * *

(c) * * *

(3) Perform service accumulation in the laboratory by operating the engine or hybrid powertrain repeatedly over one of the following test sequences, or a different test sequence that we approve in advance:

* * * * *

(ii) Duty-cycle sequence 2 is based on operating over the LLC and the vehicle-based duty cycles from 40 CFR part 1037. Select the vehicle subcategory and vehicle configuration from § 1036.540 or § 1036.545 with the highest reference cycle work for each vehicle-based duty cycle. Operate the engine as follows for duty-cycle sequence 2:

* * * * *

■ 14. Amend § 1036.250 by revising paragraph (a) to read as follows:

§ 1036.250 Reporting and recordkeeping for certification.

(a) By September 30 following the end of the model year, send the Designated Compliance Officer a report including the total U.S.-directed production volume of engines you produced in each engine family during the model year (based on information available at the time of the report). Report the production by serial number and engine configuration. You may combine this report with reports required under subpart H of this part. We may waive the reporting requirements of this paragraph (a) for small manufacturers.

* * * * *

■ 15. Amend § 1036.301 by revising paragraph (c) to read as follows:

§ 1036.301 Measurements related to GEM inputs in a selective enforcement audit.

* * * * *

(c) If your certification includes powertrain testing as specified in 40 CFR 1036.630, these selective enforcement audit provisions apply with respect to powertrain test results as specified in 40 CFR part 1037, subpart D, and § 1036.545. We may allow manufacturers to instead perform the engine-based testing to simulate the powertrain test as specified in 40 CFR 1037.551.

* * * * *

■ 16. Amend § 1036.405 by revising paragraphs (a)(1), (a)(3) and (d) to read as follows:

§ 1036.405 Overview of the manufacturer-run field-testing program.

(a) * * *

(1) We may select up to 25 percent of your engine families in any calendar year, calculated by dividing the number of engine families you certified in the model year corresponding to the calendar year by four and rounding to the nearest whole number. We will consider only engine families with annual U.S.-directed production volumes above 1,500 units in calculating the number of engine families subject to testing each calendar year under the annual 25 percent engine family limit. If you have only three or fewer families that each exceed an annual U.S.-directed production volume of 1,500 units, we may select one engine family per calendar year for testing.

* * * * *

(3) We will not select engine families for testing under this subpart from a

given model year if your total U.S.-directed production volume was less than 100 engines.

* * * * *

(d) You must complete all the required testing and reporting under this subpart (for all ten test engines, if applicable), within 18 months after we direct you to test a particular engine family. We will typically select engine families for testing and notify you in writing by June 30 of the applicable calendar year. If you request it, we may allow additional time to send us this information.

* * * * *

■ 17. Amend § 1036.420 by revising paragraph (a) to read as follows:

§ 1036.420 Pass criteria for individual engines.

* * * * *

(a) Determine the emission standard for each regulated pollutant for each bin by adding the following accuracy margins for PEMS to the off-cycle standards in § 1036.104(a)(3):

TABLE 1 TO PARAGRAPH (a) OF § 1036.420—ACCURACY MARGINS FOR IN-USE TESTING

	NO_X	HC	PM	CO
Bin 1	0.4 g/hr			
Bin 2	5 mg/hp·hr	10 mg/hp·hr	6 mg/hp·hr	0.25 g/hp·hr.

* * * * *

■ 18. Amend § 1036.501 by adding paragraph (g) to read as follows:

§ 1036.501 General testing provisions.

* * * * *

(g) For testing engines that use regenerative braking through the crankshaft to only power an electric heater for aftertreatment devices, you may use the fuel mapping procedure in § 1036.505(b)(1) or (2) and the nonhybrid engine testing procedures in §§ 1036.510, 1036.512, and 1036.514, as long as the recovered energy is less than 10 percent of the total positive work for each applicable transient duty cycle. Otherwise, use powertrain testing procedures specified for hybrid engines or hybrid powertrains to create fuel maps and measure emissions. For engines that power an electric heater with a battery, you must meet the requirements related to charge-sustaining operation as described in 40 CFR 1066.501.

■ 19. Amend § 1036.505 by revising paragraphs (a), (b) introductory text, and (b)(3) and (4) to read as follows:

§ 1036.505 Engine data and information to support vehicle certification.

* * * * *

(a) Identify engine make, model, fuel type, combustion type, engine family name, calibration identification, and engine displacement. Also identify whether the engines meet CO_2 standards for tractors, vocational vehicles, or both. When certifying vehicles with GEM, for any fuel type not identified in Table 1 of § 1036.550, select fuel type as diesel fuel for engines subject to compression-ignition standards, and select fuel type as gasoline for engines subject to spark-ignition standards.

(b) This paragraph (b) describes four different methods to generate engine fuel maps. For engines without hybrid components and for mild hybrid engines where you do not include hybrid components in the test, generate fuel maps using either paragraph (b)(1) or (2) of this section. For other hybrid engines, generate fuel maps using paragraph (b)(3) of this section. For hybrid powertrains and nonhybrid powertrains and for vehicles where the transmission is not automatic, automated manual, manual, or dual-clutch, generate fuel maps using paragraph (b)(4) of this section.

* * * * *

(3) Determine fuel consumption at idle as described in § 1036.535(c) and (d) and determine cycle-average engine fuel maps as described in § 1036.545, including cycle-average engine fuel maps for highway cruise cycles. Set up the test to apply accessory load for all operation by primary intended service class as described in the following table:

TABLE 1 TO PARAGRAPH (b)(3) OF § 1036.505—ACCESSORY LOAD

Primary intended service class	Power representing accessory load (kW)
Light HDV	1.5
Medium HDV	2.5
Heavy HDV	3.5

(4) Generate powertrain fuel maps as described in § 1036.545 instead of fuel mapping under § 1036.535 or § 1036.540. Note that the option in § 1036.545(b)(2) is allowed only for hybrid engine testing. Disable stop-start systems and automatic engine shutdown systems when conducting powertrain fuel map testing using § 1036.545.

* * * * *

■ 20. Amend § 1036.510 by:

■ a. Revising paragraphs (b)(2) introductory text, (b)(2)(vii), and (b)(2)(viii);

■ b. Removing paragraph (b)(2)(ix);

■ c. Revising paragraphs (c)(2)(i) introductory text, (d) introductory text, and (d)(1) and (2)(ii);

■ d. Removing the period in the heading in Figure 1 to paragraph (d)(4); and

■ e. Revising paragraphs (e), (f), and (g).

The revisions read as follows:

§ 1036.510 Supplemental Emission Test.

* * * * *

(b) * * *

(2) Test hybrid engines and hybrid powertrains as described in § 1036.545, except as specified in this paragraph (b)(2). Do not compensate the duty cycle for the distance driven as described in § 1036.545(g)(4). For hybrid engines, select the transmission from Table 1 of § 1036.540, substituting ''engine'' for ''vehicle'' and ''highway cruise cycle'' for ''SET''. Disregard duty cycles in § 1036.545(j). For cycles that begin with idle, leave the transmission in neutral or park for the full initial idle segment. Place the transmission into drive no earlier than 5 seconds before the first nonzero vehicle speed setpoint. For SET testing only, place the transmission into park or neutral when the cycle reaches the final idle segment. Use the following vehicle parameters instead of those in § 1036.545 to define the vehicle model in § 1036.545(a)(3):

* * * * *

(vii) Select a combination of drive axle ratio, ka, and a tire radius, r, that represents the worst-case combination of final gear ratio, drive axle ratio, and tire size for CO_2 expected for vehicles in which the hybrid engine or hybrid powertrain will be installed. This is typically the highest axle ratio and smallest tire radius. In selecting a drive axle ratio and tire radius, if representative, ensure that the maximum vehicle speed is no less than 60 mi/hr. Manufacturers may request preliminary approval for selected drive axle ratio and tire radius consistent with the provisions of § 1036.210. If the hybrid engine or hybrid powertrain is used exclusively in vehicles which are not capable of reaching 60 mi/hr, follow the provisions of 40 CFR 1066.425(b)(5).

Note for hybrid engines the final gear ratio can change depending on the duty-cycle, which will change the selection of the drive axle ratio and tire size. For example, § 1036.520 prescribes a different top gear ratio than paragraph (b)(2) of this section.

(viii) If you are certifying a hybrid engine, use a default transmission efficiency of 0.95 and create the vehicle model along with its default transmission shift strategy as described in § 1036.545(a)(3)(ii). Use the transmission parameters defined in Table 1 of § 1036.540 to determine transmission type and gear ratio. For Light HDV and Medium HDV, use the Light HDV and Medium HDV parameters for FTP, LLC, and SET duty cycles. For Tractors and Heavy HDVs, use the Tractor and Heavy HDV transient cycle parameters for the FTP and LLC duty cycles and the Tractor and Heavy HDV highway cruise cycle parameters for the SET duty cycle.

(c) * * *

(2) * * *

(i) Determine road grade at each point based on the continuous rated power of the hybrid powertrain, $P_{\mathrm{contrated}}$, in kW determined in § 1036.520, the vehicle speed (A, B, or C) in mi/hr for a given SET mode, $v_{\mathrm{ref[speed]}}$, and the specified road-grade coefficients using the following equation:

* * * * *

(d) Determine criteria pollutant emissions for plug-in hybrid engines and plug-in hybrid powertrains as follows:

(1) Precondition the engine or powertrain in charge-sustaining mode. Perform testing as described in this section for hybrid engines or hybrid powertrains in charge-sustaining mode.

(2) * * *

(ii) Operate the engine or powertrain continuously over repeated SET duty cycles until you reach the end-of-test criterion defined in 40 CFR 1066.501(a)(3).

* * * * *

(e) Determine greenhouse gas pollutant emissions for plug-in hybrid engines and plug-in hybrid powertrains using the emissions results for all the SET test intervals for both charge-depleting and charge-sustaining operation from paragraph (d)(2) of this section. Calculate the utility factor-weighted composite mass of emissions from the charge-depleting and charge-sustaining test results, $e_{\mathrm{UF[emission]comp}}$, using the following equation:

$$e_{\mathrm{UF[emission]comp}} = \sum_{i=1}^{N}\left[e_{\mathrm{[emission][int]CD}i}\cdot\left(UF_{\mathrm{DCD}i}-UF_{\mathrm{DCD}i-1}\right)\right] + \sum_{j=1}^{M}\left[e_{\mathrm{[emission][int]CS}j}\right]\cdot\frac{\left(1-UF_{\mathrm{RCD}}\right)}{M}$$

Eq. 1036.510-10

Where:

i = an indexing variable that represents one test interval.

N = total number of charge-depleting test intervals.

$e_{\mathrm{[emission][int]CDi}}$ = total mass of emissions in the charge-depleting portion of the test for each test interval, i, starting from i = 1, including the test interval(s) from the transition phase.

UF_{DCDi} = utility factor fraction at distance $_{\mathrm{DCD}i}$ from Eq. 1036.510–11, as determined by interpolating the approved utility factor curve for each test interval, i, starting from i = 1. Let UFDCD0 = 0.

j = an indexing variable that represents one test interval.

M = total number of charge-sustaining test intervals.

$e_{\mathrm{[emission][int]CSj}}$ = total mass of emissions in the charge-sustaining portion of the test for each test interval, j, starting from j = 1.

UF_{RCD} = utility factor fraction at the full charge-depleting distance, RCD, as determined by interpolating the approved utility factor curve. RCD is the cumulative distance driven over N charge-depleting test intervals.

$$D_{\mathrm{CD}i} = \sum_{k=1}^{Q}\left(v_k \cdot \Delta t\right)$$

Eq. 1036.510-11

Where:

k = an indexing variable that represents one recorded velocity value.

Q = total number of measurements over the test interval.

v = vehicle velocity at each time step, k, starting from k = 1. For tests completed under this section, v is the vehicle velocity from the vehicle model in § 1036.545. Note that this should include charge-depleting test intervals that start when the engine is not yet operating.

$\Delta t = 1/f_{\mathrm{record}}$

frecord = the record rate.

Example using the charge-depletion test in Figure 1 of § 1036.510 for the SET for CO₂ emission determination:

Q = 24000

$v1$ = 0 mi/hr

$v2$ = 0.8 mi/hr

$v3$ = 1.1 mi/hr

f_{record} = 10 Hz

Δt = 1/10 Hz = 0.1 s

$$D_{\mathrm{CD1}} = \sum_{k=1}^{24000}\left(0\cdot 0.1 + 0.8\cdot 0.1 + 1.1\cdot 0.1 + v_{24000}\cdot \Delta t\right)$$

D_{CD1} = 30.1 mi

D_{CD2} = 30.0 mi

D_{CD3} = 30.1 mi

D_{CD4} = 30.2 mi

D_{CD5} = 30.1 mi

N = 5

UF_{DCD1} = 0.11

UF_{DCD2} = 0.23

UF_{DCD3} = 0.34

UF_{DCD4} = 0.45

UF_{DCD5} = 0.53

$e_{\mathrm{CO2SETCD1}}$ = 0 g/hp·hr

$e_{\mathrm{CO2SETCD2}}$ = 0 g/hp·hr

$e_{\mathrm{CO2SETCD3}}$ = 0 g/hp·hr

$e_{\mathrm{CO2SETCD4}}$ = 0 g/hp·hr

$e_{\mathrm{CO2SETCD5}}$ = 174.4 g/hp·hr

M = 1

e_{CO2SETCS} = 428.1 g/hp·hr

UFRCD = 0.53

$$e_{\mathrm{UFCO2comp}} = [0 \cdot (0.11 - 0) + 0 \cdot (0.23 - 0.11) + 0 \cdot (0.34 - 0.23) + 0 \cdot (0.45 - 0.34) + 174.4 \cdot (0.53 - 0.45)] + 428.1 \cdot \frac{(1 - 0.53)}{1}$$

$e_{\mathrm{UFCO2comp}} = 215.2$ g/hp·hr

(f) Calculate and evaluate cycle statistics as specified in 40 CFR 1065.514 for nonhybrid engines and § 1036.545 for hybrid engines and hybrid powertrains.

(g) Calculate the total emission mass of each constituent, *m,* over the test interval as described in 40 CFR 1065.650. For nonhybrid engines, calculate the total work, *W,* over the test interval as described in 40 CFR 1065.650(d). For hybrid engines and hybrid powertrains, calculate total positive work over the test interval using system power, Psys. Determine Psys, using § 1036.520(f).

■ 21. Amend § 1036.512 by:

■ a. Revising paragraphs (b)(2)(v), (c), (d) introductory text, (d)(1) and (2)(ii);

■ b. Removing the period in the heading in Figure 1 to paragraph (d)(4); and

■ c. Revising paragraph (f).

The revisions read as follows:

§ 1036.512 Federal Test Procedure.

* * * * *

(b) * * *

(2) * * *

(v) For plug-in hybrid engines and plug-in hybrid powertrains, test over the FTP in both charge-sustaining and charge-depleting operation for both criteria and greenhouse gas pollutant determination.

(c) The FTP duty cycle consists of an initial run through the test interval from a cold start as described in 40 CFR part 1065, subpart F, followed by a (20 ±1) minute hot soak with no engine operation, and then a final hot start run through the same transient test interval. Engine starting is part of both the cold-start and hot-start test intervals. Calculate the total emission mass of each constituent, *m,* over each test interval as described in 40 CFR 1065.650. For nonhybrid engines, calculate the total work, *W,* over the test interval as described in 40 CFR 1065.650(d). For hybrid engines and hybrid powertrains, calculate total positive work over each test interval using system power, $P_{\mathrm{sys.}}$ Determine P_{sys} using § 1036.520(f). For powertrains with automatic transmissions, account for and include the work produced by the engine from the CITT load. Calculate the official transient emission result from the cold-start and hot-start test intervals using the following equation:

$$Official\ transient\ emission\ result = \frac{cold\ start\ emissions\ (g) + 6 \cdot hot\ start\ emissions\ (g)}{cold\ start\ work\ (hp \cdot hr) + 6 \cdot hot\ start\ work\ (hp \cdot hr)}$$

Eq. 1036.512-1

(d) Determine criteria pollutant emissions for plug-in hybrid engines and plug-in hybrid powertrains as follows:

(1) Precondition the engine or powertrain in charge-sustaining mode. Perform testing as described in this section for hybrid engines or hybrid powertrains in charge-sustaining mode.

(2) * * *

(ii) Operate the engine or powertrain over one FTP duty cycle followed by alternating repeats of a 20-minute soak and a hot start test interval until you reach the end-of-test criteria defined in 40 CFR 1066.501.

* * * * *

(f) Calculate and evaluate cycle statistics as specified in 40 CFR 1065.514 for nonhybrid engines and § 1036.545 for hybrid engines and hybrid powertrains.

■ 22. Revise § 1036.514 to read as follows:

§ 1036.514 Low Load Cycle.

(a) Measure emissions using the transient Low Load Cycle (LLC) as described in this section to determine whether engines meet the LLC emission standards in § 1036.104.

(b) The LLC duty cycle is described in paragraph (d) of appendix B of this part. The following procedures apply differently for testing nonhybrid engines, hybrid engines, and hybrid powertrains:

(1) For nonhybrid engine testing, use the following procedures:

(i) Use the normalized speed and torque values for engine testing in the LLC duty cycle described in paragraph (d) of appendix B of this part.

(ii) Denormalize speed and torque values as described in 40 CFR 1065.512 and 1065.610 with the following additional requirements:

(A) The accessory load at idle described in paragraph (c) of this section must be applied using the optional declared idle power in 40 CFR 1065.510(f)(6). Use of the optional declared idle torque in 40 CFR 1065.510(f)(5)(iii) is not allowed and must be zero.

(B) Replace paragraph 40 CFR 1065.610(d)(3)(vi) with the following:

(*1*) For all other idle segments less than or equal to 200 s in length, set the reference speed and torque values to the warm-idle-in-drive values. This is to represent the transmission operating in drive.

(*2*) For idle segments more than 200 s in length, set the reference speed and torque values to the warm-idle-in-drive values for the first three seconds and the last three seconds of the idle segment. For all other points in the idle segment set the reference speed and torque values to the warm-idle-in-neutral values. This is to represent the transmission being manually shifted from drive to neutral near the beginning of the idle segment and back to drive near the end of the idle segment.

(iii) Calculate and evaluate cycle statistics as described in 40 CFR 1065.514. For testing spark-ignition gaseous-fueled engines with fuel delivery at a single-point in the intake manifold, you may apply the statistical criteria in Table 1 in this section to validate the LLC.

TABLE 1 TO PARAGRAPH (b)(1)(III) OF § 1036.514—STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES FOR GASEOUS-FUELED SPARK-IGNITION ENGINES [a]

Parameter	Speed	Torque	Power
Slope, a_1		0.800 ≤a1 ≤1.030	0.800 ≤a1 ≤1.030.
Absolute value of intercept, $\|a^0\|$			
Standard error of the estimate, *SEE*.			≤15% of maximum mapped power.
Coefficient of determination, r^2		≥0.650	≥0.650.

[a] Statistical criteria apply as specified in 40 CFR 1065.514 unless otherwise specified.

(2) Test hybrid engines and hybrid powertrains as described in § 1036.510(b)(2), with the following exceptions:

(i) Replace $P_{\text{contrated}}$ with P_{rated}, which is the peak rated power determined in § 1036.520.

(ii) Keep the transmission in drive for all idle segments 200 seconds or less. For idle segments more than 200 seconds, leave the transmission in drive for the first 3 seconds of the idle segment, place the transmission in park or neutral immediately after the 3rd second in the idle segment, and shift the transmission into drive again 3 seconds before the end of the idle segment which is defined by the first nonzero vehicle speed setpoint.

(iii) For hybrid engines, select the transmission from Table 1 of § 1036.540, substituting ''engine'' for ''vehicle''.

(iv) For hybrid engines, you may request to change the GEM-generated engine reference torque at idle to better represent curb idle transmission torque (CITT).

(v) For plug-in hybrid engines and plug-in hybrid powertrains, determine criteria pollutant and greenhouse gas emissions as described in § 1036.510(d) and (e), replacing ''SET'' with ''LLC''.

(vi) Calculate and evaluate cycle statistics as specified in § 1036.545.

(c) Apply a vehicle accessory load for each idle point in the cycle based on a constant power. Use the power values in Table 2 to paragraph (c)(3) of this section based on primary intended service class. For nonhybrid engine testing, this is in addition to any applicable CITT. Additional provisions related to vehicle accessory load apply for the following special cases:

(1) For engines with stop-start technology, account for the loss of mechanical work due to the lack of any idle accessory load during engine-off conditions by determining the total loss of mechanical work from idle accessory load during all engine-off intervals over the entire test interval and distributing that work over the engine-on intervals of the entire test interval based on a calculated average power. You may determine the engine-off time by running practice cycles or through engineering analysis.

(2) Apply vehicle accessory power loads on idle points for hybrid powertrain testing where torque is measured at the axle input shaft or wheel hubs either as a mechanical or electrical load.

(3) Table 2 follows:

TABLE 2 TO PARAGRAPH (c)(3) OF § 1036.514—ACCESSORY LOAD AT IDLE

Primary intended service class	Power representing accessory load (kW)
Light HDE	1.5
Medium HDE	2.5
Heavy HDE	3.5

(d) The test sequence consists of preconditioning the engine by running one or two FTPs with each FTP followed by (20 ±1) minutes with no engine operation and a hot start run through the LLC. You may start any preconditioning FTP with a hot engine. Perform testing as described in 40 CFR 1065.530 for a test interval that includes engine starting. Calculate the total emission mass of each constituent, m, over the test interval as described in 40 CFR 1065.650. For nonhybrid engines, calculate the total work, W, over the test interval as described in 40 CFR 1065.650(d). For hybrid engines and hybrid powertrains, calculate total positive work over the test interval using system power, Psys. Determine Psys using § 1036.520(f). For powertrains with automatic transmissions, account for and include the work produced by the engine from the CITT load.

■ 23. Amend § 1036.520 by revising the introductory text, paragraphs (b) introductory text, (d)(2) and (3), (h), and (i)(2) to read as follows:

§ 1036.520 Determining power and vehicle speed values for powertrain testing.

This section describes how to determine the system peak power and continuous rated power of hybrid and nonhybrid powertrain systems and the vehicle speed for carrying out duty-cycle testing under this part and § 1036.545.

* * * * *

(b) Set up the powertrain test according to § 1036.545, with the following exceptions:

* * * * *

(d) * * *

(2) Set maximum driver demand for a full load acceleration at 6.0% road grade with an initial vehicle speed of 0 mi/hr, continuing for 268 seconds. You may decrease the road grade in the first 30 seconds or increase initial vehicle speed up to 5 mi/hr as needed to mitigate clutch slip.

(3) Linearly ramp the grade from 6.0% down to 0.0% over 300 seconds. Stop the test after the acceleration is less than 0.02 m/s².

* * * * *

(h) Determine rated power, Prated, as the maximum measured power from the data collected in paragraph (d)(2) of this section where the COV determined in paragraph (g) of this section is less than 2%.

(i) * * *

(2) For hybrid powertrains, Pcontrated is the maximum measured power from the data collected in paragraph (d)(3) of this section where the COV determined in paragraph (g) of this section is less than 2%.

* * * * *

■ 24. Amend § 1036.525 by revising the introductory text to read as follows:

§ 1036.525 Clean Idle test.

Measure emissions using the procedures described in this section to determine whether engines and hybrid powertrains meet the clean idle emission standards in § 1036.104(b). For plug-in hybrid engines and plug-in hybrid powertrains, perform the test with the hybrid function disabled.

* * * * *

■ 25. Amend § 1036.530 by adding paragraph (j) to read as follows:

§ 1036.530 Test procedures for off-cycle testing.

* * * * *

(j) *Fuel other than carbon-containing.* The following procedures apply for testing engines using at least one fuel that is not a carbon-containing fuel:

(1) Use the following equation to determine $m_{\mathrm{CO2,norm,testinterval}}$ instead of Eq. 1036.530–2:

$$m_{\mathrm{CO2,norm,testinterval}} = \frac{W_{\mathrm{testinterval}}}{P_{\max} \cdot t_{\mathrm{testinterval}}}$$

Eq. 1036.530-6

Where:

$W_{\mathrm{testinterval}}$ = total positive work over the test interval as determined in 40 CFR 1065.650.

$P_{\max}$ = the highest value of rated power for all the configurations included in the engine family.

$t_{\mathrm{testinterval}}$ = duration of the test interval. Note that the nominal value is 300 seconds.

Example:

$W_{\mathrm{testinterval}}$ = 8.95 hp·hr

$P_{\max}$ = 406.5 hp

$t_{\mathrm{testinterval}}$ = 300.01 s = 0.08 hr

$$m_{\mathrm{CO2,norm,testinterval}} = \frac{8.95}{406.5 \cdot 0.08}$$

$m_{\mathrm{CO2,norm,testinterval}}$ = 0.2722

$m_{\mathrm{CO2,norm,testinterval}}$ = 27.22%

(2) Determine off-cycle emissions quantities as follows:

(i) For engines subject to spark-ignition standards, use the following equation instead of Eq. 1036.530–3:

$$e_{\mathrm{[emissions],offcycle}} = \frac{m_{\mathrm{[emission]}}}{W_{\mathrm{testinterval}}}$$

Eq. 1036.530-7

Where:

$m_{\mathrm{[emission]}}$ = total emission mass for a given pollutant over the test interval as determined in paragraph (d)(2) of this section.

$W_{\mathrm{testinterval}}$ = total positive work over the test interval as determined in 40 CFR 1065.650.

Example:

m_{NOx} = 1.337 g

$W_{\mathrm{testinterval}}$ = 38.2 hp·hr

$$e_{\mathrm{NOx,offcycle}} = \frac{1.337}{38.2}$$

$e_{\mathrm{NOx,offcycle}}$ = 0.035 g/hp·hr

(ii) For engines subject to compression-ignition standards, use Eq. 1036.530–4 to determine the off-cycle emission quantity for bin 1.

(iii) For engines subject to compression-ignition standards, use the following equation instead of Eq. 1036.530–5 to determine the off-cycle emission quantity for bin 2:

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

Eq. 1036.530-8

Where:

i = an indexing variable that represents one 300 second test interval.

N = total number of 300 second test intervals in bin 2.

$m_{\mathrm{[emission],testinterval,i}}$ = total emission mass for a given pollutant over the test interval i in bin 2 as determined in paragraph (d)(2) of this section.

$W_{\mathrm{testinterval,i}}$ = total positive work over the test interval i in bin 2 as determined in 40 CFR 1065.650.

Example:

N = 15439

m_{NOx1} = 0.546 g

m_{NOx2} = 0.549 g

m_{NOx3} = 0.556 g

$W_{\mathrm{testinterval1}}$ = 8.91 hp·hr

$W_{\mathrm{testinterval2}}$ = 8.94 hp·hr

$W_{\mathrm{testinterval3}}$ = 8.89 hp·hr

$$e_{\mathrm{NOx,offcycle,bin2}} = \frac{\left(0.546 + 0.549 + 0.556 \ldots + m_{\mathrm{NOx,testinterval,15439}}\right)}{\left(8.91 + 8.94 + 8.89 \ldots + W_{\mathrm{testinterval,15439}}\right)}$$

$e_{\mathrm{NOx,offcycle,bin2}}$ = 0.026 g/hp·hr

■ 26. Amend § 1036.535 by revising paragraphs (b)(1)(ii) introductory text, (b)(1)(ii)(B), (b)(1)(iii), and (b)(10) to read as follows:

§ 1036.535 Determining steady-state engine fuel maps and fuel consumption at idle.

* * * * *

(b) * * *

(1) * * *

(ii) Select the following required torque setpoints at each of the selected speed setpoints: zero (T = 0), maximum mapped torque, Tmax mapped, and eight (or more) equally spaced points between T = 0 and Tmax mapped. Select the maximum torque setpoint at each speed to conform to the torque map as follows:

* * * * *

(B) Select $T_{\max}$ at each speed setpoint as a single torque value to represent all the default torque setpoints above the value determined in paragraph (b)(1)(ii)(A) of this section. All of the other default torque setpoints less than T_{max} at a given speed setpoint are required torque setpoints.

(iii) You may select any additional speed and torque setpoints consistent with good engineering judgment. For example you may need to select additional points if the engine's fuel consumption is nonlinear across the torque map. Avoid creating a problem with interpolation between narrowly spaced speed and torque setpoints near T_{max}. For each additional speed setpoint, we recommend including a torque setpoint of T_{max}; however, you may select torque setpoints that properly represent in-use operation. Increments for torque setpoints between these minimum and maximum values at an additional speed setpoint must be no more than one-ninth of $T_{\mathrm{max,mapped}}$. Note that if the test points were added for the child rating, they should still be reported in the parent fuel map. We will test with at least as many points as you. If you add test points to meet testing requirements for child ratings, include those same test points as reported values for the parent fuel map. For our testing, we will use the same normalized speed and torque test points you use, and we may select additional test points.

* * * * *

(10) Correct the measured or calculated mean fuel mass flow rate, at each of the operating points to account for mass-specific net energy content as described in paragraph (e) of this section.

* * * * *

■ 27. Amend § 1036.540 by revising paragraph (b) to read as follows:

§ 1036.540 Determining cycle-average engine fuel maps.

* * * * *

(b) *General test provisions.* The following provisions apply for testing under this section:

(1) Measure $\mathrm{NO_X}$ emissions for each specified sampling period in grams. You may perform these measurements using a $\mathrm{NO_X}$ emission-measurement system that meets the requirements of 40 CFR part 1065, subpart J. Include these measured $\mathrm{NO_X}$ values any time you report to us your fuel-consumption values from testing under this section. If a system malfunction prevents you from measuring $\mathrm{NO_X}$ emissions during a test under this section but the test otherwise gives valid results, you may consider this a valid test and omit the $\mathrm{NO_X}$ emission measurements; however, we may require you to repeat the test if we determine that you inappropriately voided the test with respect to $\mathrm{NO_X}$ emission measurement.

(2) The provisions related to carbon balance error verification in § 1036.543 apply for all testing in this section. These procedures are optional, but we will perform carbon balance error verification for all testing under this section.

(3) Correct fuel mass to a mass-specific net energy content of a reference fuel as described in paragraph (d)(13) of this section.

(4) This section uses engine parameters and variables that are consistent with 40 CFR part 1065.

* * * * *

■ 28. Revise § 1036.543 to read as follows:

§ 1036.543 Carbon balance error verification.

The optional carbon balance error verification in 40 CFR 1065.543 compares independent assessments of the flow of carbon through the system (engine plus aftertreatment). This procedure applies for each individual interval in §§ 1036.535(b), (c), and (d), 1036.540, and 1036.545.

■ 29. Add § 1036.545 to read as follows:

§ 1036.545 Powertrain testing.

This section describes the procedure to measure fuel consumption and create engine fuel maps by testing a powertrain that includes an engine coupled with a transmission, drive axle, and hybrid components or any assembly with one or more of those hardware elements. Engine fuel maps are part of demonstrating compliance with Phase 2 and Phase 3 vehicle standards under 40 CFR part 1037; the powertrain test procedure in this section is one option for generating this fuel-mapping information as described in § 1036.505. Additionally, this powertrain test procedure is one option for certifying hybrid engines and hybrid powertrains to the engine standards in §§ 1036.104 and 1036.108.

(a) *General test provisions.* The following provisions apply broadly for testing under this section:

(1) Measure $\mathrm{NO_X}$ emissions as described in paragraph (k) of this section. Include these measured $\mathrm{NO_X}$ values any time you report to us your greenhouse gas emissions or fuel consumption values from testing under this section.

(2) The procedures of 40 CFR part 1065 apply for testing in this section except as specified. This section uses engine parameters and variables that are consistent with 40 CFR part 1065.

(3) Powertrain testing depends on models to calculate certain parameters. You can use the detailed equations in this section to create your own models, or use the GEM HIL model contained within GEM Phase 2, Version 4.0 (incorporated by reference, see § 1036.810) to simulate vehicle hardware elements as follows:

(i) Create driveline and vehicle models that calculate the angular speed setpoint for the test cell dynamometer, $f_{\mathrm{nref,dyno}}$, based on the torque measurement location. Use the detailed equations in paragraph (f) of this section, the GEM HIL model's driveline and vehicle submodels, or a combination of the equations and the submodels. You may use the GEM HIL model's transmission submodel in paragraph (f) of this section to simulate a transmission only if testing hybrid engines.

(ii) Create a driver model or use the GEM HIL model's driver submodel to simulate a human driver modulating the throttle and brake pedals to follow the test cycle as closely as possible.

(iii) Create a cycle-interpolation model or use the GEM HIL model's cycle submodel to interpolate the duty-cycles and feed the driver model the duty-cycle reference vehicle speed for each point in the duty-cycle.

(4) The powertrain test procedure in this section is designed to simulate operation of different vehicle configurations over specific duty cycles. See paragraphs (h) and (j) of this section.

(5) For each test run, record engine speed and torque as defined in 40 CFR 1065.915(d)(5) with a minimum sampling frequency of 1 Hz. These engine speed and torque values represent a duty cycle that can be used for separate testing with an engine mounted on an engine dynamometer under 40 CFR 1037.551, such as for a selective enforcement audit as described in 40 CFR 1037.301.

(6) For hybrid powertrains with no plug-in capability, correct for the net energy change of the energy storage device as described in 40 CFR 1066.501. For plug-in hybrid electric powertrains, follow 40 CFR 1066.501 to determine End-of-Test for charge-depleting operation. You must get our approval in advance for your utility factor curve; we will approve it if you can show that you created it, using good engineering judgment, from sufficient in-use data of vehicles in the same application as the vehicles in which the plug-in hybrid electric powertrain will be installed. You may use methodologies described in SAE J2841 to develop the utility factor curve.

(7) The provisions related to carbon balance error verification in § 1036.543 apply for all testing in this section. These procedures are optional if you are only performing direct or indirect fuel-flow measurement, but we will perform carbon balance error verification for all testing under this section.

(8) Do not apply accessory loads when conducting a powertrain test to generate inputs to GEM if torque is measured at the axle input shaft or wheel hubs.

(9) If you test a powertrain over the duty cycle specified in § 1036.514, control and apply the electrical accessory loads using one of the following systems:

(i) An alternator with dynamic electrical load control.

(ii) A load bank connected directly to the powertrain's electrical system.

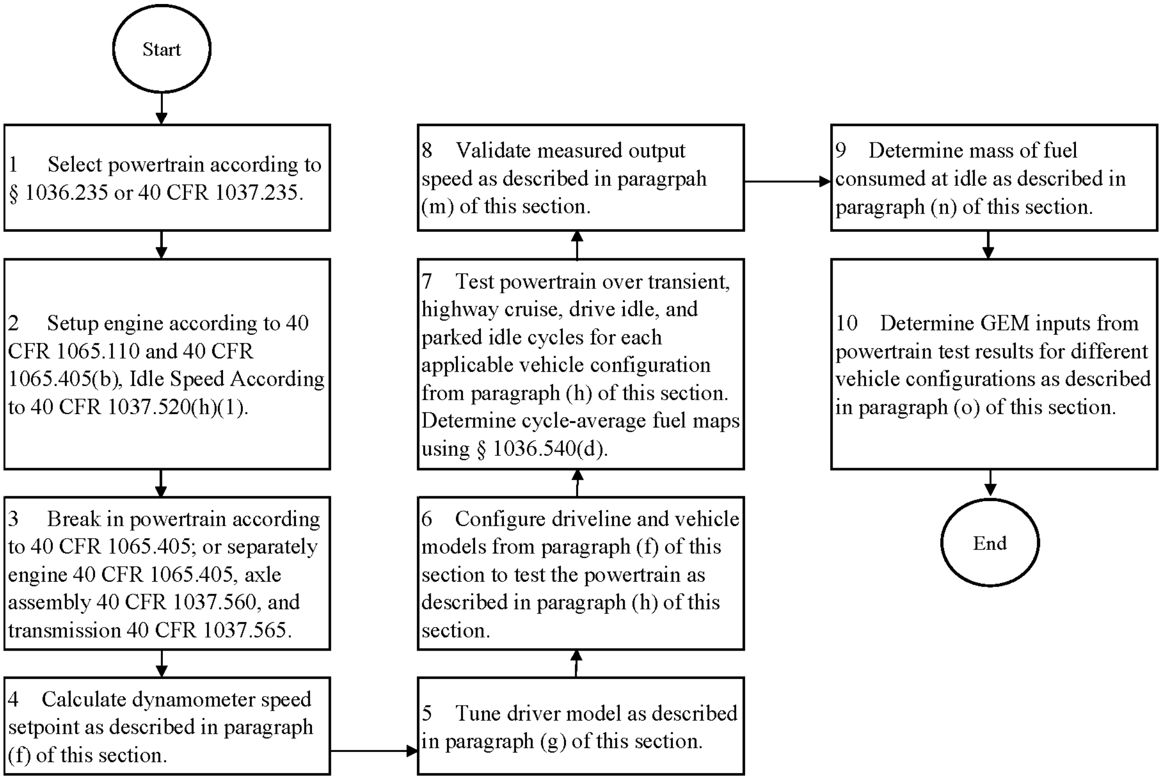
(10) The following instruments are required with plug-in hybrid systems to determine required voltages and currents during testing and must be installed on the powertrain to measure these values during testing:

(i) Measure the voltage and current of the battery pack directly with a DC wideband power analyzer to determine power. Measure all current entering and leaving the battery pack. Do not measure voltage upstream of this measurement point. The maximum integration period for determining amp-hours is 0.05 seconds. The power analyzer must have an accuracy for measuring current and voltage of 1% of point or 0.3% of maximum, whichever is greater. The power analyzer must not be susceptible to offset errors while measuring current.

(ii) If safety considerations do not allow for measuring voltage, you may determine the voltage directly from the powertrain ECM.

(11) The following figure provides an overview of the steps involved in carrying out testing under this section:

Figure 1 to Paragraph (a)(11) of § 1036.545—Overview of Powertrain Testing



Duty Cycle Exceptions	Note
SET, FTP, LLC	1) Do not compensate the duty cycle for the distance driven in step 5 2) Disregard duty cycles in step 7. 3) For cycles that begin with idle, leave the transmission in neutral or park for the full initial idle segment. Place the transmission into drive no earlier than 5 seconds before the first nonzero vehicle speed setpoint. 4) Use the vehicle parameters in § 1036.505(b)(2)(i) to (ix) to define the vehicle model in § 1036.545(a)(3)
SET Specific	1) For SET testing only, place the transmission into park or neutral when the cycle reaches the final idle segment. 2) Select the transmission from Table 1 of § 1036.540, substituting “engine” for “vehicle” and “highway cruise cycle” for “SET”.
FTP Specific	1) Replace Pcontrated with Prated, which is the peak rated power determined in § 1036.527 2) Keep the transmission in drive for all idle segments after the initial idle segment 3) For hybrid engines, select the transmission from Table 1 of § 1036.540, substituting “engine” for “vehicle”. 4) For hybrid engines, you may request to change the engine-commanded torque at idle to better represent curb idle transmission torque (CITT)
LLC Specific	1) Replace Pcontrated with Prated, which is the peak rated power determined in § 1036.527. 2) Keep the transmission in drive for all idle segments 200 seconds or less. For idle segments more than 200 seconds, place the transmission in park or neutral at the start of the idle segment and place the transmission into drive again no earlier than 5 seconds before the first nonzero vehicle speed setpoint. 3) For hybrid engines, you may request to change the engine-commanded torque at idle to better represent curb idle transmission torque (CITT). 4) For plug-in hybrid engines and powertrains, determine criteria pollutant and greenhouse gas emissions as described in § 1036.505(d) and (e), replacing “SET” with “LLC”.

(b) *Test configuration.* Select a powertrain for testing as described in 40 CFR 1037.235 or § 1036.235 as applicable. Set up the engine according to 40 CFR 1065.110 and 40 CFR 1065.405(b). Set the engine's idle speed to idle speed defined in 40 CFR 1037.520(h)(1).

(1) The default test configuration consists of a powertrain with all components upstream of the axle. This involves connecting the powertrain's output shaft directly to the dynamometer or to a gear box with a fixed gear ratio and measuring torque at the axle input shaft. You may instead set up the dynamometer to connect at the wheel hubs and measure torque at that location. The preceding sentence may apply if your powertrain configuration requires it, such as for hybrid powertrains or if you want to represent the axle performance with powertrain test results. Alternately you may test the powertrain with a chassis dynamometer as long as you measure speed and torque at the powertrain's output shaft or wheel hubs.

(2) For testing hybrid engines, connect the engine's crankshaft directly to the dynamometer and measure torque at that location.

(c) *Powertrain temperatures during testing.* Cool the powertrain during testing so temperatures for oil, coolant, block, head, transmission, battery, and power electronics are within the manufacturer's expected ranges for normal operation. You may use electronic control module outputs to comply with this paragraph (c). You may use auxiliary coolers and fans.

(d) *Engine break in.* Break in the engine according to 40 CFR 1065.405, the axle assembly according to 40 CFR 1037.560, and the transmission according to 40 CFR 1037.565. You may instead break in the powertrain as a complete system using the engine break in procedure in 40 CFR 1065.405.

(e) *Dynamometer setup.* Set the dynamometer to operate in speed-control mode (or torque-control mode for hybrid engine testing at idle, including idle portions of transient duty cycles). Record data as described in 40 CFR 1065.202. Command and control the dynamometer speed at a minimum of 5 Hz, or 10 Hz for testing hybrid engines. Run the vehicle model to calculate the dynamometer setpoints at a rate of at least 100 Hz. If the dynamometer's command frequency is less than the vehicle model dynamometer setpoint frequency, subsample the calculated setpoints for commanding the dynamometer setpoints.

(f) *Driveline and vehicle model.* Use the GEM HIL model's driveline and vehicle submodels or the equations in this paragraph (f) to calculate the dynamometer speed setpoint, $f_{\text{nref,dyno}}$, based on the torque measurement location. For all powertrains, configure GEM with the accessory load set to zero. For hybrid engines, configure GEM with the applicable accessory load as specified in §§ 1036.505 and 1036.514. For all powertrains and hybrid engines, configure GEM with the tire slip model disabled.

(1) *Driveline model with a transmission in hardware.* For testing with torque measurement at the axle input shaft or wheel hubs, calculate, fnref,dyno, using the GEM HIL model's driveline submodel or the following equation:

$$f_{\text{nref}i,\text{dyno}} = \frac{k_{\text{a[speed]}} \cdot v_{\text{ref}i}}{2 \cdot \pi \cdot r_{\text{[speed]}}}$$

Eq. 1036.545-1

Where:

$k_{\text{a[speed]}}$ = drive axle ratio as determined in paragraph (h) of this section. Set $k_{\text{a[speed]}}$ equal to 1.0 if torque is measured at the wheel hubs.

$v_{\text{ref}i}$ = simulated vehicle reference speed as calculated in paragraph (f)(3) of this section.

$r_{\text{[speed]}}$ = tire radius as determined in paragraph (h) of this section.

(2) *Driveline model with a simulated transmission.* For testing with the torque measurement at the engine's crankshaft, $f_{\text{nref,dyno}}$ is the dynamometer target speed from the GEM HIL model's transmission submodel. You may request our approval to change the transmission submodel, as long as the changes do not affect the gear selection logic. Before testing, initialize the transmission model with the engine's measured torque curve and the applicable steady-state fuel map from the GEM HIL model. You may request our approval to input your own steady-state fuel map. For example, this request for approval could include using a fuel map that represents the combined performance of the engine and hybrid components. Configure the torque converter to simulate neutral idle when using this procedure to generate engine fuel maps in § 1036.505 or to perform the Supplemental Emission Test (SET) testing under § 1036.510. You may change engine commanded torque at idle to better represent CITT for transient testing under § 1036.512. You may change the simulated engine inertia to match the inertia of the engine under test. We will evaluate your requests under this paragraph (f)(2) based on your demonstration that that the adjusted testing better represents in-use operation.

(i) The transmission submodel needs the following model inputs:

(A) Torque measured at the engine's crankshaft.

(B) Engine estimated torque determined from the electronic control module or by converting the instantaneous operator demand to an instantaneous torque in N·m.

(C) Dynamometer mode when idling (speed-control or torque-control).

(D) Measured engine speed when idling.

(E) Transmission output angular speed, fni,transmission, calculated as follows:

$$f_{\text{n}i,\text{transmission}} = \frac{k_{\text{a[speed]}} \cdot v_{\text{ref}i}}{2 \cdot \pi \cdot r_{\text{[speed]}}}$$

Eq. 1036.545-2

Where:

$k_{\text{a[speed]}}$ = drive axle ratio as determined in paragraph (h) of this section.

$v_{\text{ref}i}$ = simulated vehicle reference speed as calculated in paragraph (f)(3) of this section.

$r_{\text{[speed]}}$ = tire radius as determined in paragraph (h) of this section.

(ii) The transmission submodel generates the following model outputs:

(A) Dynamometer target speed.

(B) Dynamometer idle load.

(C) Transmission engine load limit.

(D) Engine speed target.

(3) *Vehicle model.* Calculate the simulated vehicle reference speed, $v_{\text{ref}i}$, using the GEM HIL model's vehicle submodel or the equations in this paragraph (f)(3):

$$v_{\mathrm{ref}i} = \left(\frac{k_{\mathrm{a}} \cdot T_{i\text{-}1}}{r} \cdot (Eff_{\mathrm{axle}}) - \left(M \cdot g \cdot C_{\mathrm{rr}} \cdot \cos(\operatorname{atan}(G_{i\text{-}1})) + \frac{\rho \cdot C_{\mathrm{d}}A}{2} \cdot v_{\mathrm{ref},i\text{-}1}^{2} \right) - F_{\mathrm{brake},i\text{-}1} - F_{\mathrm{grade},i\text{-}1} \right) \cdot \frac{\Delta t_{i\text{-}1}}{M + M_{\mathrm{rotating}}} + v_{\mathrm{ref},i\text{-}1}$$

Eq. 1036.545-3

Where:

i = a time-based counter corresponding to each measurement during the sampling period.

Let $v_{\mathrm{ref}1} = 0$; start calculations at $i = 2$. A 10-minute sampling period will generally involve 60,000 measurements.

T = instantaneous measured torque at the axle input, measured at the wheel hubs, or simulated by the GEM HIL model's transmission submodel. For configurations with multiple torque measurements, for example when measuring torque at the wheel hubs, T is the sum of all torque measurements.

Eff_{axle} = axle efficiency. Use $Eff_{\mathrm{axle}} = 0.955$ for $T \geq 0$, and use $Eff_{\mathrm{axle}} = 1/0.955$ for $T < 0$. Use $Eff_{\mathrm{axle}} = 1.0$ if torque is measured at the wheel hubs.

M = vehicle mass for a vehicle class as determined in paragraph (h) of this section.

g = gravitational constant = 9.80665 m/s².

C_{rr} = coefficient of rolling resistance for a vehicle class as determined in paragraph (h) of this section.

G_{i-1} = the percent grade interpolated at distance, D_{i-1}, from the duty cycle in appendix D to this part corresponding to measurement (i–1).

$$D_{i\text{-}1} = \sum_{i=1}^{N} \left(v_{\mathrm{ref},i\text{-}1} \cdot \Delta t_{i\text{-}1} \right)$$

Eq. 1036.545-4

ρ = air density at reference conditions. Use $\rho = 1.1845$ kg/m³.

$C_{\mathrm{d}}A$ = drag area for a vehicle class as determined in paragraph (h) of this section.

$F_{\mathrm{brake,i-1}}$ = instantaneous braking force applied by the driver model.

$$F_{\mathrm{grade},i\text{-}1} = M \cdot g \cdot \sin(\operatorname{atan}(G_{i\text{-}1}))$$

Eq. 1036.545-5

Δt = the time interval between measurements. For example, at 100 Hz, $\Delta t = 0.0100$ seconds.

M_{rotating} = inertial mass of rotating components. Let $M_{\mathrm{rotating}} = 340$ kg for vocational Light HDV or vocational Medium HDV. See paragraph (h) of this section for tractors and for vocational Heavy HDV.

(4) *Example.* The following example illustrates a calculation of $f_{\mathrm{nref,dyno}}$ using paragraph (f)(1) of this section where torque is measured at the axle input shaft. This example is for a vocational Light HDV or vocational Medium HDV with 6 speed automatic transmission at B speed (Test 4 in Table 1 to paragraph (h)(2)(ii) of this section).

$k_{aB} = 4.0$

$r_B = 0.399\ \mathrm{m}$

$T_{999} = 500.0\ \mathrm{N{\cdot}m}$

$C_{rr} = 7.7\ \mathrm{N/kN} = 7.7{\cdot}10^{-3}\ \mathrm{N/N}$

$M = 11408\ \mathrm{kg}$

$C_dA = 5.4\ \mathrm{m}^2$

$G_{999} = 0.39\ \% = 0.0039$

$$D_{999} = \sum_{i=0}^{998}\left(19.99 \cdot 0.01 + 20.0 \cdot 0.01 + \ldots + v_{\mathrm{ref},998} \cdot \Delta t_{998}\right) = 1792\ \mathrm{m}$$

$F_{\mathrm{brake},999} = 0\ \mathrm{N}$

$v_{\mathrm{ref},999} = 20.0\ \mathrm{m/s}$

$F_{\mathrm{grade},999} = 11408 \cdot 9.81 \cdot \sin(\mathrm{atan}(0.0039)) = 436.5\ \mathrm{N}$

$\Delta t = 0.0100\ \mathrm{s}$

$M_{\mathrm{rotating}} = 340\ \mathrm{kg}$

$$v_{\mathrm{ref}1000} = \left(\frac{4.0{\cdot}500.0}{0.399} \cdot (0.955) - \left(11408 \cdot 9.80665 \cdot 7.7 \cdot 10^{-3} \cdot cos(atan(0.0039)) + \frac{1.1845{\cdot}5.4}{2} \cdot 20.0^2\right) - 0 - 436.5\right) \cdot \frac{0.0100}{11408+340} + 20.0 v_{\mathrm{ref}1000}$$

$v_{\mathrm{ref}1000} = 20.00189\ \mathrm{m/s}$

$$f_{\mathrm{nref}1000,\mathrm{dyno}} = \frac{4.0 \cdot 20.00189}{2 \cdot 3.14 \cdot 0.399}$$

$f_{\mathrm{nref}1000,\mathrm{dyno}} = 31.93\ \mathrm{r/s} = 1915.8\ \mathrm{r/min}$

(g) *Driver model.* Use the GEM HIL model's driver submodel or design a driver model to simulate a human driver modulating the throttle and brake pedals. In either case, tune the model to follow the test cycle as closely as possible meeting the following specifications:

(1) The driver model must meet the following speed requirements:

(i) For operation over the highway cruise cycles, the speed requirements described in 40 CFR 1066.425(b) and (c).

(ii) For operation over the transient cycle specified in appendix A of this part, the SET as defined § 1036.510, the Federal Test Procedure (FTP) as defined in § 1036.512, and the Low Load Cycle (LLC) as defined in § 1036.514, the speed requirements described in 40 CFR 1066.425(b) and (c).

(iii) The exceptions in 40 CFR 1066.425(b)(4) apply to the highway cruise cycles, the transient cycle specified in appendix A of this part, SET, FTP, and LLC.

(iv) If the speeds do not conform to these criteria, the test is not valid and must be repeated.

(2) Send a brake signal when operator demand is zero and vehicle speed is greater than the reference vehicle speed from the test cycle. Include a delay before changing the brake signal to prevent dithering, consistent with good engineering judgment.

(3) Allow braking only if operator demand is zero.

(4) Compensate for the distance driven over the duty cycle over the course of the test. Use the following equation to perform the compensation in real time to determine your time in the cycle:

$$t_{\mathrm{cycle}i} = \sum_{i=1}^{N}\left(\left(\frac{v_{\mathrm{vehicle},i-1}}{v_{\mathrm{cycle},i-1}}\right) \cdot \Delta t_{i-1}\right)$$

Eq. 1036.545-6

Where:

v_{vehicle} = measured vehicle speed.

v_{cycle} = reference speed from the test cycle. If $v_{\mathrm{cycle},i\text{-}1} < 1.0$ m/s, set $v_{\mathrm{cycle},i\text{-}1} = v_{\mathrm{vehicle}i\text{-}1}$

(h) *Vehicle configurations to evaluate for generating fuel maps as defined in § 1036.505.* Configure the driveline and vehicle models from paragraph (f) of this section in the test cell to test the powertrain. Simulate multiple vehicle configurations that represent the range of intended vehicle applications using one of the following options:

(1) For known vehicle configurations, use at least three equally spaced axle ratios or tire sizes and three different road loads (nine configurations), or at least four equally spaced axle ratios or tire sizes and two different road loads (eight configurations). Select axle ratios to represent the full range of expected vehicle installations. Select axle ratios and tire sizes such that the ratio of

engine speed to vehicle speed covers the range of ratios of minimum and maximum engine speed to vehicle speed when the transmission is in top gear for the vehicles in which the powertrain will be installed. Note that you do not have to use the same axle ratios and tire sizes for each GEM regulatory subcategory. You may determine appropriate C_{rr}, $C_{\text{d}}A$, and mass values to cover the range of intended vehicle applications or you may use the C_{rr}, $C_{\text{d}}A$, and mass values specified in paragraph (h)(2) of this section.

(2) If vehicle configurations are not known, determine the vehicle model inputs for a set of vehicle configurations as described in § 1036.540(c)(3) with the following exceptions:

(i) In the equations of § 1036.540(c)(3)(i), k_{topgear} is the actual top gear ratio of the powertrain instead of the transmission gear ratio in the highest available gear given in Table 1 in § 1036.540.

(ii) Test at least eight different vehicle configurations for powertrains that will be installed in Spark-ignition HDE, vocational Light HDV, and vocational Medium HDV using the following table instead of Table 2 in § 1036.540:

Table 1 to Paragraph (h)(2)(ii) of § 1036.545—Vehicle Configurations for Testing Spark-ignition HDE, Light HDE, and Medium HDE

Parameter	1	2	3	4	5	6	7	8
C_{rr} (N/kN)	6.2	7.7	6.2	7.7	6.2	7.7	6.2	7.7
$C_{\text{d}}A$	3.4	5.4	3.4	5.4	3.4	5.4	3.4	5.4
CI engine speed for $\frac{f_{\text{ntire}}}{v_{\text{vehicle}}}$ and k_{a}	f_{nrefA}	f_{nrefA}	f_{nrefB}	f_{nrefB}	f_{nrefC}	f_{nrefC}	f_{ntest}	f_{ntest}
SI engine speed for $\frac{f_{\text{ntire}}}{v_{\text{vehicle}}}$ and k_{a}	f_{nrefD}	f_{nrefD}	f_{nrefA}	f_{nrefA}	f_{nrefB}	f_{nrefB}	f_{nrefC}	f_{nrefC}
M (kg)	7,257	11,408	7,257	11,408	7,257	11,408	7,257	11,408
M_{rotating} (kg)	340	340	340	340	340	340	340	340
Drive axle configuration[a]	4x2	4x2	4x2	4x2	4x2	4x2	4x2	4x2
GEM regulatory subcategory[a]	LHD	MHD	LHD	MHD	LHD	MHD	LHD	MHD

[a]Drive axle configuration and GEM regulatory subcategory are not used if using the equations in paragraph (f)(3) of this section.

(iii) Select and test vehicle configurations as described in § 1036.540(c)(3)(iii) for powertrains that will be installed in vocational Heavy HDV and tractors using the following tables instead of Table 3 and Table 4 in § 1036.540:

Table 2 to Paragraph (h)(2)(iii) of § 1036.545—Vehicle Configurations for Testing General Purpose Tractors and Vocational Heavy HDV

Parameter	1	2	3	4	5	6	7	8	9
C_{rr} (N/kN)	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
$C_{\text{d}}A$	5.4	4.7	4.0	5.4	4.7	4.0	5.4	4.7	4.0
Engine speed for $\frac{f_{\text{ntire}}}{v_{\text{vehicle}}}$ and k_{a}	f_{nrefD}	f_{nrefD}	f_{nrefD}	f_{nrefB}	f_{nrefB}	f_{nrefB}	f_{ntest}	f_{ntest}	f_{ntest}
M (kg)	31,978	25,515	19,051	31,978	25,515	19,051	31,978	25,515	19,051
M_{rotating} (kg)	1,021	794	794	1,021	794	794	1,021	794	794
Drive axle Cconfiguration[a]	6x4	6x4	4x2	6x4	6x4	4x2	6x4	6x4	4x2
GEM regulatory subcategory[a]	C8_SC_HR	C8_DC_MR	C7_DC_MR	C8_SC_HR	C8_DC_MR	C7_DC_MR	C8_SC_HR	C8_DC_MR	C7_DC_MR
Vehicle weight reduction (pounds)	0	13,275	6,147	0	13,275	6,147	0	13,275	6,147

[a]Drive axle configuration and GEM regulatory subcategory are not used if using the equations in paragraph (f)(3) of this section.

Table 3 to Paragraph (h)(2)(iii) of § 1036.545—Vehicle Configurations for Testing Heavy HDE Installed in Heavy-Haul Tractors

Parameter	1	2	3	4	5	6
C_{rr} (N/kN)	6.9	6.9	6.9	6.9	6.9	6.9
C_dA	5.0	5.4	5.0	5.4	5.0	5.4
Engine speed for $\frac{f_{ntire}}{v_{vehicle}}$ and k_a	f_{nrefD}	f_{nrefD}	f_{nrefB}	f_{nrefB}	f_{ntest}	f_{ntest}
M (kg)	53,751	31,978	53,751	31,978	53,751	31,978
$M_{rotating}$ (kg)	1,021	1,021	1,021	1,021	1,021	1,021
Drive axle configuration[a]	6x4	6x4	6x4	6x4	6x4	6x4
GEM regulatory subcategory[a]	C8_HH	C8_SC_HR	C8_HH	C8_SC_HR	C8_HH	C8_SC_HR

[a] Drive axle configuration and GEM regulatory subcategory are not used if using the equations in paragraph (f)(3) of this section.

(3) For hybrid powertrain systems where the transmission will be simulated, use the transmission parameters defined in § 1036.540(c)(2) to determine transmission type and gear ratio. Use a fixed transmission efficiency of 0.95. The GEM HIL transmission model uses a transmission parameter file for each test that includes the transmission type, gear ratios, lockup gear, torque limit per gear from § 1036.540(c)(2), and the values from § 1036.505(b)(4) and (c).

(i) [Reserved]

(j) *Duty cycles to evaluate.* Operate the powertrain over each of the duty cycles specified in 40 CFR 1037.510(a)(2), and for each applicable vehicle configuration from paragraph (h) of this section. Determine cycle-average powertrain fuel maps by testing the powertrain using the procedures in § 1036.540(d) with the following exceptions:

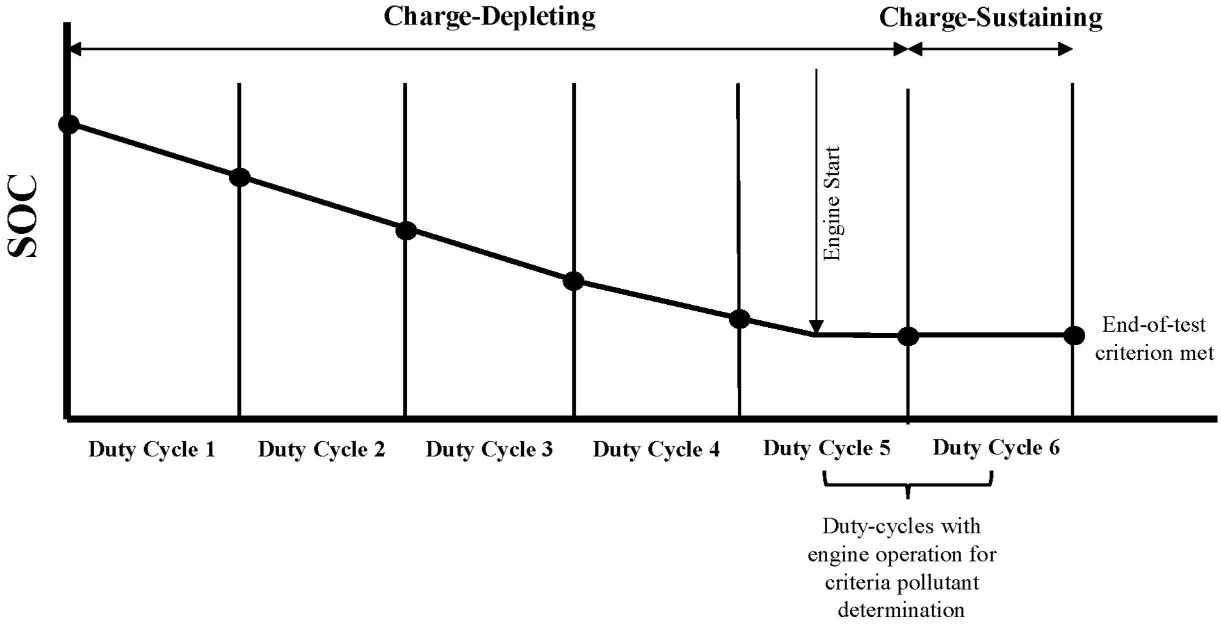
(1) Understand ‘‘engine’’ to mean ‘‘powertrain’’.

(2) Warm up the powertrain as described in § 1036.520(c)(1).

(3) Within 90 seconds after concluding the warm-up, start the transition to the preconditioning cycle as described in paragraph (j)(5) of this section.

(4) For plug-in hybrid engines, precondition the battery and then complete all back-to-back tests for each vehicle configuration according to 40 CFR 1066.501 before moving to the next vehicle configuration. Figure 2 of this section provides an example of a charge-depleting test sequence where there are two test intervals that contain engine operation. Figure 2 follows:

Figure 2 to Paragraph (j)(4) of § 1036.545—Generic Duty-Cycle Cycle Charge-Depleting Test Sequence



(5) If the preceding duty cycle does not end at 0 mi/hr, transition between duty cycles by decelerating at a rate of 2 mi/hr/s at 0% grade until the vehicle reaches zero speed. Shut off the powertrain. Prepare the powertrain and test cell for the next duty-cycle.

(6) Start the next duty-cycle within 60 to 180 seconds after shutting off the powertrain.

(i) To start the next duty-cycle, for hybrid powertrains, key on the vehicle and then start the duty-cycle. For conventional powertrains key on the vehicle, start the engine, wait for the engine to stabilize at idle speed, and then start the duty-cycle.

(ii) If the duty-cycle does not start at 0 mi/hr, transition to the next duty cycle by accelerating at a target rate of 1 mi/hr/s at 0% grade. Stabilize for 10 seconds at the initial duty cycle conditions and start the duty-cycle.

(7) Calculate cycle work using GEM or the speed and torque from the driveline and vehicle models from paragraph (f) of this section to determine the sequence of duty cycles.

(8) Calculate the mass of fuel consumed for idle duty cycles as described in paragraph (n) of this section.

(k) *Measuring NO_X emissions.* Measure NO_X emissions for each sampling period in grams. You may perform these measurements using a NO_X emission-measurement system that meets the requirements of 40 CFR part 1065, subpart J. If a system malfunction prevents you from measuring NO_X emissions during a test under this section but the test otherwise gives valid results, you may consider this a valid test and omit the NO_X emission measurements; however, we may require you to repeat the test if we determine that you inappropriately voided the test with respect to NO_X emission measurement.

(l) [Reserved]

(m) *Measured output speed validation.* For each test point, validate the measured output speed(s) with the corresponding reference values. For test setups where speed is measured at multiple locations, each location must meet the requirements in this paragraph (m). If the range of reference speed is less than 10 percent of the mean reference speed, you need to meet only the standard error of the estimate in Table 1 of this section. You may delete points when the vehicle is stopped. If your speed measurement is not at the location of fnref, correct your measured speed using the constant speed ratio between the two locations. Apply cycle-validation criteria for each separate transient or highway cruise cycle based on the following parameters:

TABLE 4 TO PARAGRAPH (m) OF § 1036.545—STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES

Parameter[a]	Speed control
Slope, a_1	0.990 ≤ a_1 ≤ 1.010.
Absolute value of intercept, $\lvert a_0 \rvert$.	≤2.0% of maximum f_{nref} speed.
Standard error of the estimate, *SEE*.	≤2.0% of maximum f_{nref} speed.
Coefficient of determination, r^2.	≥0.990.

[a] Determine values for specified parameters as described in 40 CFR 1065.514(e) by comparing measured and reference values for $f_{nref,dyno}$.

(n) *Fuel consumption at idle.* Record measurements using direct and/or indirect measurement of fuel flow. Determine the fuel-consumption rates at idle for the applicable duty cycles described in 40 CFR 1037.510(a)(2) as follows:

(1) *Direct fuel flow measurement.* Determine the corresponding mean values for mean idle fuel mass flow rate, $\bar{\dot{m}}_{\text{fuelidle}}$, for each duty cycle, as applicable. Use of redundant direct fuel-flow measurements require our advance approval.

(2) *Indirect fuel flow measurement.* Record speed and torque and measure emissions and other inputs needed to run the chemical balance in 40 CFR 1065.655(c). Determine the corresponding mean values for each duty cycle. Use of redundant indirect fuel-flow measurements require our advance approval. Measure background concentration as described in § 1036.535(b)(4)(ii). We recommend setting the CVS flow rate as low as possible to minimize background, but without introducing errors related to insufficient mixing or other operational considerations. Note that for this testing 40 CFR 1065.140(e) does not apply, including the minimum dilution ratio of 2:1 in the primary dilution stage. Calculate the idle fuel mass flow rate for each duty cycle, $\bar{\dot{m}}_{\text{fuelidle}}$, for each set of vehicle settings, as follows:

$$\bar{\dot{m}}_{\text{fuelidle}} = \frac{M_{\text{C}}}{w_{\text{Cmeas}}} \cdot \left(\bar{\dot{n}}_{\text{exh}} \cdot \frac{\bar{x}_{\text{Ccombdry}}}{1 + \bar{x}_{\text{H2Oexhdry}}} - \frac{\bar{\dot{m}}_{\text{CO2DEF}}}{M_{\text{CO2}}} \right)$$

Eq. 1036.545-7

Where:

M_C = molar mass of carbon.

w_{Cmeas} = carbon mass fraction of fuel (or mixture of test fuels) as determined in 40 CFR 1065.655(d), except that you may not use the default properties in Table 2 of 40 CFR 1065.655 to determine α, β, and w_C for liquid fuels.

$\bar{\dot{n}}_{\text{exh}}$ = the mean raw exhaust molar flow rate from which you measured emissions according to 40 CFR 1065.655.

$\bar{x}_{\text{Ccombdry}}$ = the mean concentration of carbon from fuel and any injected fluids in the exhaust per mole of dry exhaust.

$\bar{x}_{\text{H2Oexhdry}}$ = the mean concentration of H_2O in exhaust per mole of dry exhaust.

$\bar{\dot{m}}_{\text{CO2DEF}}$ = the mean CO_2 mass emission rate resulting from diesel exhaust fluid decomposition over the duty cycle as determined in § 1036.535(b)(9). If your engine does not use diesel exhaust fluid, or if you choose not to perform this correction, set equal to 0.

M_{CO2} = molar mass of carbon dioxide.

Example:

$M_C = 12.0107$ g/mol

$w_{\text{Cmeas}} = 0.867$

$\bar{\dot{n}}_{\text{exh}} = 25.534$ mol/s

$\bar{x}_{\text{Ccombdry}} = 2.805 \cdot 10^{-3}$ mol/mol

$\bar{x}_{\text{H2Oexhdry}} = 3.53 \cdot 10^{-2}$ mol/mol

$\bar{\dot{m}}_{\text{CO2DEF}} = 0.0726$ g/s

$M_{\text{CO2}} = 44.0095$

$$\bar{\dot{m}}_{\text{fuelidle}} = \frac{12.0107}{0.867} \cdot \left(25.534 \cdot \frac{2.805 \cdot 10^{-3}}{1 + 3.53 \cdot 10^{-2}} - \frac{0.0726}{44.0095}\right)$$

$\bar{\dot{m}}_{\text{fuelidle}} = 0.405$ g/s $= 1458.6$ g/hr

(o) *Create GEM inputs.* Use the results of powertrain testing to determine GEM inputs for the different simulated vehicle configurations as follows:

(1) Correct the measured or calculated fuel masses, $m_{\text{fuel[cycle]}}$, and mean idle fuel mass flow rates, $\bar{\dot{m}}_{\text{fuelidle}}$, if applicable, for each test result to a mass-specific net energy content of a reference fuel as described in § 1036.535(e), replacing mean fuel with $\bar{\dot{m}}_{\text{fuelidle}}$ with $m_{\text{fuel[cycle]}}$ where applicable in Eq. 1036.535–4.

(2) Declare fuel masses, $m_{\text{fuel[cycle]}}$ and $\bar{\dot{m}}_{\text{fuelidle}}$. Determine $m_{\text{fuel[cycle]}}$ using the calculated fuel mass consumption values described in § 1036.540(d)(12). In addition, declare mean fuel mass flow rate for each applicable idle duty cycle, $\bar{\dot{m}}_{\text{fuelidle}}$. These declared values may not be lower than any corresponding measured values determined in this section. If you use both direct and indirect measurement of fuel flow, determine the corresponding declared values as described in § 1036.535(g)(2) and (3). These declared values, which serve as emission standards, collectively represent the powertrain fuel map for certification.

(3) For engines designed for plug-in hybrid electric vehicles, the mass of fuel for each cycle, $m_{\text{fuel[cycle]}}$, is the utility factor-weighted fuel mass, $m_{\text{fuelUF[cycle]}}$. This is determined by calculating m_{fuel} for the full charge-depleting and charge-sustaining portions of the test and weighting the results, using the following equation:

$$m_{\text{fuelUF[cycle]}} = \sum_{i=1}^{N} \left[m_{\text{fuel[cycle]CD}i} \cdot \left(UF_{\text{DCD}i} - UF_{\text{DCD}i-1}\right)\right] + \sum_{j=1}^{M} \left[m_{\text{fuel[cycle]CS}j}\right] \cdot \frac{(1 - UF_{\text{RCD}})}{M}$$

Eq. 1036.545-8

Where:

i = an indexing variable that represents one test interval.

N = total number of charge-depleting test intervals.

$m_{\text{fuel[cycle]CDi}}$ = total mass of fuel in the charge-depleting portion of the test for each test interval, i, starting from i = 1, including the test interval(s) from the transition phase.

UF_{DCDi} = utility factor fraction at distance D_{CDi} from Eq. 40 CFR 1037.505–9 as determined by interpolating the approved utility factor curve for each test interval, i, starting from i = 1.

Let $UF_{\text{DCD0}} = 0$

j = an indexing variable that represents one test interval.

M = total number of charge-sustaining test intervals.

$m_{\text{fuel[cycle]CSj}}$ = total mass of fuel over the charge-sustaining portion of the test for each test interval, j, starting from j = 1.

UF_{RCD} = utility factor fraction at the full charge-depleting distance, RCD, as determined by interpolating the approved utility factor curve. RCD is the cumulative distance driven over N charge-depleting test intervals.

$$D_{\text{CD}i} = \sum_{k=1}^{Q} (v_k \cdot \Delta t)$$

Eq. 1036.545-9

Where:

k = an indexing variable that represents one recorded velocity value.

Q = total number of measurements over the test interval.

v = vehicle velocity at each time step, k, starting from k = 1. For tests completed under this section, v is the vehicle velocity as determined by Eq. 1036.545–1. Note that this should include charge-depleting test intervals that start when the engine is not yet operating.

$\Delta t = 1/f_{\text{record}}$

f_{record} = the record rate.

Example for the 55 mi/hr cruise cycle:

Q = 8790

$v_1 = 55.0$ mi/hr

$v_2 = 55.0$ mi/hr

$v_3 = 55.1$ mi/hr

$f_{\text{record}} = 10$ Hz

$\Delta t = 1/10$ Hz $= 0.1$ s

$$D_{\mathrm{CD1}} = \sum_{k=1}^{8790}\left(55.0 \cdot 0.1 + 55.0 \cdot 0.1 + 55.1 \cdot 0.1 + v_{8790} \cdot \Delta t\right) = 13.4\ \mathrm{mi}$$

$D_{\mathrm{CD2}} = 13.4$ mi
$D_{\mathrm{CD3}} = 13.4$ mi
$N = 3$
$UF_{\mathrm{DCD1}} = 0.05$
$UF_{\mathrm{DCD2}} = 0.11$
$UF_{\mathrm{DCD3}} = 0.21$
$m_{\mathrm{fuel55cruiseCD1}} = 0$ g
$m_{\mathrm{fuel55cruiseCD2}} = 0$ g
$m_{\mathrm{fuel55cruiseCD3}} = 1675.4$ g
$M = 1$
$m_{\mathrm{fuel55cruiseCS}} = 4884.1$ g
$UF_{\mathrm{RCD}} = 0.21$

$$m_{\mathrm{fuelUF55cruise}} = [0 \cdot (0.05 - 0) + 0 \cdot (0.11 - 0.05) + 1675.4 \cdot (0.21 - 0.11)] + 4884.1 \cdot \frac{(1 - 0.21)}{1}$$

$m_{\mathrm{fuelUF55cruise}} = 4026.0$ g

(4) For the transient cycle specified in 40 CFR 1037.510(a)(2)(i), calculate powertrain output speed per unit of vehicle speed,

$$\left[\frac{\bar{f}_{\mathrm{npowertrain}}}{\bar{v}_{\mathrm{powertrain}}}\right]_{[\mathrm{cycle}]}$$

using one of the following methods:

(i) For testing with torque measurement at the axle input shaft:

$$\left[\frac{\bar{f}_{\mathrm{npowertrain}}}{\bar{v}_{\mathrm{powertrain}}}\right]_{[\mathrm{cycle}]} = \frac{k_a}{2 \cdot \pi \cdot r_{[\mathrm{speed}]}}$$

Eq. 1036.545-10

Example:

$k_{\mathrm{a}} = 4.0$
$r_{\mathrm{B}} = 0.399$ m

$$\left[\frac{\bar{f}_{\mathrm{npowertrain}}}{\bar{v}_{\mathrm{powertrain}}}\right]_{\mathrm{transienttest4}} = \frac{4.0}{2 \cdot 3.14 \cdot 0.399}$$

$$\left[\frac{\bar{f}_{\mathrm{npowertrain}}}{\bar{v}_{\mathrm{powertrain}}}\right]_{\mathrm{transienttest4}} = 1.596\ \mathrm{r/m}$$

(ii) For testing with torque measurement at the wheel hubs, use Eq. 1036.545–8 setting ka equal to 1.

(iii) For testing with torque measurement at the engine's crankshaft:

$$\left[\frac{\bar{f}_{\mathrm{npowertrain}}}{\bar{v}_{\mathrm{powertrain}}}\right]_{[\mathrm{cycle}]} = \frac{\bar{f}_{\mathrm{nengine}}}{\bar{v}_{\mathrm{ref}}}$$

Eq. 1036.545-11

Where:

$\bar{f}_{\mathrm{nengine}}$ = average engine speed when vehicle speed is at or above 0.100 m/s.

$\bar{v}_{\mathrm{ref}}$ = average simulated vehicle speed at or above 0.100 m/s.

Example:

$\bar{f}_{\mathrm{nengine}} = 1870\ \mathrm{r/min} = 31.17\ \mathrm{r/s}$

$\bar{v}_{\mathrm{ref}} = 19.06\ \mathrm{m/s}$

$$\left[\frac{\bar{f}_{\mathrm{npowertrain}}}{\bar{v}_{\mathrm{powertrain}}}\right]_{\mathrm{transienttest4}} = \frac{31.17}{19.06}$$

$$\left[\frac{\bar{f}_{\mathrm{npowertrain}}}{\bar{v}_{\mathrm{powertrain}}}\right]_{\mathrm{transienttest4}} = 1.635\ \mathrm{r/m}$$

(5) Calculate engine idle speed, by taking the average engine speed measured during the transient cycle test while the vehicle speed is below 0.100 m/s. (**Note:** Use all the charge-sustaining test intervals when determining engine idle speed for plug-in hybrid engines and plug-in hybrid powertrains.)

(6) For the cruise cycles specified in 40 CFR 1037.510(a)(2)(ii), calculate the average powertrain output speed, $\bar{f}_{\mathrm{npowertrain}}$, and the average powertrain output torque (positive torque only), $\bar{T}_{\mathrm{powertrain}}$ at vehicle speed at or above 0.100 m/s. (**Note:** Use all the charge-sustaining and charge-depleting test intervals when determining $\bar{f}_{\mathrm{npowertrain}}$ and $\bar{T}_{\mathrm{powertrain}}$ for plug-in hybrid engines and plug-in hybrid powertrains.)

(7) Calculate positive work, $W_{[\mathrm{cycle}]}$, as the work over the duty cycle at the axle input shaft, wheel hubs, or the engine's crankshaft, as applicable, when vehicle speed is at or above 0.100 m/s. For plug-in hybrid engines and plug-in hybrid powertrains, calculate $W_{[\mathrm{cycle}]}$ by calculating the positive work over each of the charge-sustaining and charge-depleting test intervals and then averaging them together. For test setups where speed and torque are measured at multiple locations, determine $W_{[\mathrm{cycle}]}$ by integrating the sum of the power measured at each location.

(8) The following tables illustrate the GEM data inputs corresponding to the different vehicle configurations for a given duty cycle:

(i) For the transient cycle:

Table 5 to Paragraph (o)(8)(i) of § 1036.545 –Example of Output Matrix for Transient Cycle Vehicle Configurations

Parameter	**Configuration**					
	1	**2**	**3**	**4**	**…**	***n***
$m_{\text{fuel[cycle]}}$						
$\left[\frac{\bar{f}_{\text{npowertrain}}}{\bar{v}_{\text{powertrain}}}\right]_{\text{[cycle]}}$						
$W_{\text{[cycle]}}$						
$\bar{f}_{\text{nidle}}$						

(ii) For the cruise cycles:

TABLE 6 TO PARAGRAPH (o)(8)(ii) OF § 1036.545—GENERIC EXAMPLE OF OUTPUT MATRIX FOR CRUISE CYCLE VEHICLE CONFIGURATIONS

Parameter	Configuration								
	1	2	3	4	5	6	7	. . .	*n*
$m_{\text{fuel[cycle]}}$. $\bar{f}_{\text{powertrain[cycle]}}$. $\bar{T}_{\text{powertrain[cycle]}}$. $W_{\text{[cycle]}}$.									

(p) *Determining useable battery energy.* Useable battery energy (UBE) is defined as the total DC discharge energy, E_{DCDtotal}, measured in DC Watt hours, over the charge-depleting portion of the test sequence determined in paragraph (p)(2) of this section for the Heavy-duty Transient Test Cycle in 40 CFR part 1037, appendix A. Select a representative vehicle configuration from paragraph (h) of this section for determination of UBE. UBE represents the total deliverable energy the battery is capable of providing while a powertrain is following a duty cycle on a dynamometer.

(1) *Measure DC discharge energy,* E_{DCD}, in watt-hours and DC discharge current per hour, C_{D}, for the charge-depleting portion of the test sequence. The measurement points must capture all the current flowing into and out of the battery pack during powertrain operation, including current associated with regenerative braking. The equation for calculating powertrain E_{DCD} is given in Eq. 1036.545–12, however, it is expected that this calculation will typically be performed internally by the power analyzer specified in paragraph (a)(10)(i) of this section. Battery voltage measurements made by the powertrain's own on-board sensors (such as those available via a diagnostic port) may be used for calculating EDCD if these measurements are equivalent to those produced by the power analyzer.

$$E_{\text{DCD}} = \sum_{i=0}^{N} V_i \cdot I_i \cdot \Delta t$$

Eq. 1036.545-12

Where:

i = an indexing variable that represents one individual measurement.

N = total number of measurements.

V = battery DC bus voltage.

I = battery current.

$\Delta t = 1/f_{\text{record}}$

f_{record} = the data recording frequency.

Example:

N = 13360

$V_1 = 454.0$

$V_2 = 454.0$

$I_1 = 0$

$I_2 = 0$

$f_{\text{record}} = 20$ Hz

$\Delta t = 1/20 = 0.05$ s

$$E_{\text{DCD}} = \sum_{i=0}^{13360} (454.0 \cdot 0 + 454.0 \cdot 0 + \cdots + V_{13360} \cdot I_{13360}) \cdot 0.05$$

$E_{\text{DCD}} = 6540232.7$ W·s = 1816.7 W·hr

(2) Determine a declared UBE that is at or below the corresponding value determined in paragraph (p)(1) of this section, including those from redundant measurements. This declared UBE serves as the initial UBE determined under 40 CFR 1037.115(f).

■ 30. Amend § 1036.550 by revising paragraphs (b)(1)(i), (b)(2) introductory text, and (b)(2)(i) to read as follows:

§ 1036.550 Calculating greenhouse gas emission rates.

* * * * *

(b) * * *

(1) * * *

(i) For liquid fuels, determine $E_{\text{mfuelmeas}}$ according to ASTM D4809 (incorporated by reference, see § 1036.810). Have the sample analyzed by at least three different labs and determine the final value of your test fuel's $E_{\text{mfuelmeas}}$ as the median of all the lab test results you obtained as described in 40 CFR 1065.602(m). If you have results from three different labs, we recommend you screen them to determine if additional observations are needed. To perform this screening, determine the absolute value of the difference between each lab result and the average of the other two lab results. If the largest of these three resulting absolute value differences is greater than 0.297 MJ/kg, we recommend you obtain additional results prior to determining the final value of $E_{\mathrm{mfuelmeas}}$.

* * * * *

(2) Determine your test fuel's carbon mass fraction, w_{C}, as described in 40 CFR 1065.655(d), expressed to at least three decimal places; however, you must measure fuel properties for α and β rather than using the default values specified in 40 CFR 1065.655(e).

(i) For liquid fuels, have the sample analyzed by at least three different labs and determine the final value of your test fuel's w_{C} as the median of all of the lab results you obtained as described in 40 CFR 1065.602(m). If you have results from three different labs, we recommend you screen them to determine if additional observations are needed. To perform this screening, determine the absolute value of the difference between each lab result and the average of the other two lab results. If the largest of these three resulting absolute value differences is greater than 1.56 percent carbon, we recommend you obtain additional results prior to determining the final value of w_{C}.

* * * * *

■ 31. Amend § 1036.605 by revising paragraph (e) to read as follows:

§ 1036.605 Alternate emission standards for engines used in specialty vehicles.

* * * * *

(e) In a separate application for a certificate of conformity, identify the corresponding nonroad engine family, describe the label required under section, state that you meet applicable diagnostic requirements under 40 CFR part 1039 or part 1048, and identify your projected U.S.-directed production volume.

* * * * *

■ 32. Amend § 1036.615 by revising paragraph (a) to read as follows:

§ 1036.615 Engines with Rankine cycle waste heat recovery and hybrid powertrains.

* * * * *

(a) *Pre-transmission hybrid powertrains.* Test pre-transmission hybrid powertrains with the hybrid engine procedures of 40 CFR part 1065 or with the post-transmission procedures in § 1036.545. Pre-transmission hybrid powertrains are those engine systems that include features to recover and store energy during engine motoring operation but not from the vehicle's wheels. Engines certified with pre-transmission hybrid powertrains must be certified to meet the diagnostic requirements as specified in § 1036.110 with respect to powertrain components and systems; if different manufacturers produce the engine and the hybrid powertrain, the hybrid powertrain manufacturer may separately certify its powertrain relative to diagnostic requirements.

* * * * *

■ 33. Amend § 1036.630 by revising paragraph (b) to read as follows:

§ 1036.630 Certification of engine greenhouse gas emissions for powertrain testing.

* * * * *

(b) If you choose to certify only fuel map emissions for an engine family and to not certify emissions over powertrain cycles under § 1036.545, we will not presume you are responsible for emissions over the powertrain cycles. However, where we determine that you are responsible in whole or in part for the emission exceedance in such cases, we may require that you participate in any recall of the affected vehicles. Note that this provision to limit your responsibility does not apply if you also hold the certificate of conformity for the vehicle.

* * * * *

■ 34. Amend § 1036.705 by revising paragraph (c) introductory text, redesignating paragraph (c)(4) as paragraph (c)(5), and adding a new paragraph (c)(4) to read as follows:

§ 1036.705 Generating and calculating emission credits.

* * * * *

(c) Compliance with the requirements of this subpart is determined at the end of the model year by calculating emission credits based on actual production volumes, excluding the following engines:

* * * * *

(4) Engines certified to state emission standards that are different than the emission standards in this part.

* * * * *

■ 35. Amend § 1036.725 by revising paragraph (b)(2) to read as follows:

§ 1036.725 Required information for certification.

* * * * *

(b) * * *

(2) Calculations of projected emission credits (positive or negative) based on projected production volumes as described in § 1036.705(c). We may require you to include similar calculations from your other engine families to project your net credit balances for the model year. If you project negative emission credits for a family, state the source of positive emission credits you expect to use to offset the negative emission credits.

■ 36. Amend § 1036.730 by revising paragraphs (b)(4) and (f)(1) to read as follows:

§ 1036.730 ABT reports.

* * * * *

(b) * * *

(4) The projected and actual production volumes for calculating emission credits for the model year. If you changed an FEL/FCL during the model year, identify the actual production volume associated with each FEL/FCL.

* * * * *

(f) * * *

(1) If you notify us by the deadline for submitting the final report that errors mistakenly decreased your balance of emission credits, you may correct the errors and recalculate the balance of emission credits. If you notify us that errors mistakenly decreased your balance of emission credits after the deadline for submitting the final report, you may correct the errors and recalculate the balance of emission credits after applying a 10 percent discount to the credit correction, but only if you notify us within 24 months after the deadline for submitting the final report. If you report a negative balance of emission credits, we may disallow corrections under this paragraph (f)(1).

* * * * *

■ 37. Amend § 1036.735 by revising paragraph (d) to read as follows:

§ 1036.735 Recordkeeping.

* * * * *

(d) Keep appropriate records to document production volumes of engines that generate or use emission credits under the ABT program. For example, keep available records of the engine identification number (usually the serial number) for each engine you produce that generates or uses emission credits. You may identify these numbers as a range. If you change the FEL/FCL after the start of production, identify the date you started using each FEL/FCL and the range of engine identification numbers associated with each FEL/FCL. You must also identify the purchaser and destination for each engine you produce to the extent this information is available.

* * * * *

■ 38. Amend § 1036.801 by:

■ a. Adding a definition of ''Carbon-containing fuel'' in alphabetical order.
■ b. Removing the definitions of ''Criteria pollutants'' and ''Greenhouse gas''.
■ c. Revising the definition of ''Hybrid''.
■ d. Removing the definitions of ''Hybrid engine'' and ''Hybrid powertrain''.
■ e. Revising the definition of ''Mild hybrid''.
■ f. Adding a definition of ''Neat'' in alphabetical order.
■ g. Revising the definitions of ''Small manufacturer'' and ''U.S.-directed production volume''.

The additions and revisions read as follows:

§ 1036.801 Definitions.

* * * * *

Carbon-containing fuel has the meaning given in 40 CFR 1065.1001.

* * * * *

Hybrid means relating to an engine or powertrain that includes a Rechargeable Energy Storage System. Hybrid engines store and recover energy in a way that is integral to the engine or otherwise upstream of the vehicle's transmission. Examples of hybrid engines include engines with hybrid components connected to the front end of the engine (P0), at the crankshaft before the clutch (P1), or connected between the clutch and the transmission where the clutch upstream of the hybrid feature is in addition to the transmission clutch(s) (P2). Engine-based systems that recover kinetic energy to power an electric heater in the aftertreatment are themselves not sufficient to qualify as a hybrid engine. Provisions that apply for hybrid powertrains apply equally for hybrid engines, except as specified. Note that certain provisions in this part treat hybrid powertrains intended for vehicles that include regenerative braking different than those intended for vehicles that do not include regenerative braking. The definition of hybrid includes plug-in hybrid electric powertrains.

* * * * *

Mild hybrid means relating to a hybrid engine or hybrid powertrain with regenerative braking capability where the system recovers less than 20 percent of the total braking energy over the transient cycle defined in appendix A of 40 CFR part 1037.

* * * * *

Neat has the meaning given in § 1065.1001.

* * * * *

Small manufacturer means a manufacturer meeting the criteria specified in 13 CFR 121.201. The employee and revenue limits apply to the total number of employees and total revenue together for all affiliated companies (as defined in 40 CFR 1068.30). Note that manufacturers with low production volumes may or may not be ''small manufacturers''.

* * * * *

U.S.-directed production volume means the number of engines, subject to the requirements of this part, produced by a manufacturer for which the manufacturer has a reasonable assurance that sale was or will be made to ultimate purchasers in the United States. Note that this includes engines certified to state emission standards that are different than the emission standards in this part.

* * * * *

■ 39. Amend § 1036.805 by adding an entry for ''GCWR'' to Table 5 in alphabetical order to read as follows:

§ 1036.805 Symbols, abbreviations, and acronyms.

* * * * *

(e) * * *

TABLE 5 TO PARAGRAPH (e) OF § 1036.805—OTHER ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
* * *	* *
GCWR	gross combined weight rating.
* * *	* *

* * * * *

■ 40. Amend § 1036.810 by adding paragraph (e) to read as follows:

§ 1036.810 Incorporation by reference.

* * * * *

(e) U.S. EPA, Office of Air and Radiation, 2565 Plymouth Road, Ann Arbor, MI 48105; *www.epa.gov*; *complianceinfo@epa.gov*.

(1) Greenhouse gas Emissions Model (GEM) Phase 2, Version 4.0, April 2022 (''GEM Phase 2, Version 4.0''); IBR approved for § 1036.545(a).

(2) [Reserved]

■ 41. Amend § 1036.815 by revising paragraph (b) to read as follows:

§ 1036.815 Confidential information.

* * * * *

(b) Emission data or information that is publicly available cannot be treated as confidential business information as described in 40 CFR 1068.11. Data that vehicle manufacturers need for demonstrating compliance with greenhouse gas emission standards, including fuel-consumption data as described in §§ 1036.535 and 1036.545, also qualify as emission data for purposes of confidentiality determinations.

PART 1037—CONTROL OF EMISSIONS FROM NEW HEAVY-DUTY MOTOR VEHICLES

■ 42. The authority citation for part 1037 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

■ 43. Amend § 1037.1 by revising paragraph (a) to read as follows:

§ 1037.1 Applicability.

(a) The regulations in this part 1037 apply for all new heavy-duty vehicles, except as provided in § 1037.5. This includes battery electric vehicles, fuel cell electric vehicles, and vehicles fueled by conventional and alternative fuels.

* * * * *

■ 44. Amend § 1037.5 by:
■ a. Revising paragraph (e).
■ b. Removing paragraphs (g) and (h).
■ c. Redesignating paragraph (i) as paragraph (g).

The revision reads as follows:

§ 1037.5 Excluded vehicles.

* * * * *

(e) Vehicles subject to the heavy-duty emission standards of 40 CFR part 86. See 40 CFR part 86, subpart S, for emission standards that apply for these vehicles.

* * * * *

■ 45. Amend § 1037.101 by revising paragraphs (a)(2) and (b)(2) and (3) to read as follows:

§ 1037.101 Overview of emission standards.

* * * * *

(a) * * *

(2) *Exhaust emissions of greenhouse gases.* Emission standards apply as follows for greenhouse gas emissions:

(i) CO_2 emission standards apply as described in §§ 1037.105 and 1037.106. No CH_4 or N_2O standards apply under this part. See 40 CFR part 1036 for CH_4 or N_2O standards that apply to engines used in these vehicles.

(ii) Hydrofluorocarbon standards apply as described in § 1037.115(e). These pollutants are also ''greenhouse gas pollutants'' but are treated separately from exhaust greenhouse gas pollutants listed in paragraph (a)(2)(i) of this section.

* * * * *

(b) * * *

(2) For greenhouse gas pollutants, vehicles are regulated in the following groups:

(i) Tractors above 26,000 pounds GVWR.

(ii) Vocational vehicles.

(3) The greenhouse gas emission standards apply differently depending on the vehicle service class as described in § 1037.140. In addition, standards apply differently for vehicles with spark-ignition and compression-ignition engines. References in this part 1037 to ''spark-ignition'' or ''compression-ignition'' generally relate to the application of standards under 40 CFR 1036.140. For example, a vehicle with an engine certified to spark-ignition standards under 40 CFR part 1036 is generally subject to requirements under this part 1037 that apply for spark-ignition vehicles. However, note that emission standards for Heavy HDE are considered to be compression-ignition standards for purposes of applying vehicle emission standards under this part. Also, for spark-ignition engines voluntarily certified as compression-ignition engines under 40 CFR part 1036, you must choose at certification whether your vehicles are subject to spark-ignition standards or compression-ignition standards. Heavy-duty vehicles with no installed propulsion engine, such as battery electric vehicles, are subject to compression-ignition emission standards for the purpose of calculating emission credits.

* * * * *

■ 46. Amend § 1037.102 by revising the section heading and paragraph (b) introductory text to read as follows:

§ 1037.102 Criteria exhaust emission standards—NO_X, HC, PM, and CO.

* * * * *

(b) Heavy-duty vehicles with no installed propulsion engine, such as battery electric vehicles, are subject to criteria pollutant standards under this part. The emission standards that apply are the same as the standards that apply for compression-ignition engines under 40 CFR 86.007–11 and 1036.104 for a given model year.

* * * * *

■ 47. Amend § 1037.105 by:

■ a. Revising paragraphs (a)(1) and (2) and (b)(1) and (4)

■ b. Removing and reserving paragraph (c).

■ c. Revising paragraph (h)(1).

The revisions read as follows:

§ 1037.105 CO_2 emission standards for vocational vehicles.

(a) * * *

(1) Heavy-duty vehicles at or below 14,000 pounds GVWR that are not subject to the greenhouse gas standards in 40 CFR part 86, subpart S, or that use engines certified under § 1037.150(m).

(2) Vehicles above 14,000 pounds GVWR and at or below 26,000 pounds GVWR, but not certified to the vehicle greenhouse gas standards in 40 CFR part 86, subpart S.

* * * * *

(b) * * *

(1) Model year 2027 and later vehicles are subject to CO_2 standards corresponding to the selected subcategories as shown in the following table:

TABLE 1 OF PARAGRAPH (b)(1) OF § 1037.105—PHASE 3 CO_2 STANDARDS FOR MODEL YEAR 2027 AND LATER VOCATIONAL VEHICLES

[g/ton-mile]

Model year	Subcategory	Compression-ignition engine			Spark-ignition engine	
		Light HDV	Medium HDV	Heavy HDV	Light HDV	Medium HDV
2027	Urban	294	213	232	340	252
	Multi-Purpose	257	190	193	299	223
	Regional	218	173	152	246	202
2028	Urban	275	209	228	321	248
	Multi-Purpose	238	186	189	280	219
	Regional	199	169	148	227	198
2029	Urban	255	202	225	301	241
	Multi-Purpose	218	179	186	260	212
	Regional	179	162	145	207	191
2030	Urban	238	195	200	284	234
	Multi-Purpose	201	172	161	243	205
	Regional	162	155	120	190	184
2031	Urban	219	188	193	265	227
	Multi-Purpose	182	165	154	224	198
	Regional	143	148	113	171	177
2032 and later	Urban	179	176	177	225	215
	Multi-Purpose	142	153	138	184	186
	Regional	103	136	97	131	165

* * * * *

(4) Model year 2014 through 2020 vehicles are subject to Phase 1 CO_2 standards as shown in the following table:

TABLE 4 OF PARAGRAPH (b)(4) § 1037.105—PHASE 1 CO_2 STANDARDS FOR MODEL YEAR 2014 THROUGH 2020 VOCATIONAL VEHICLES

[g/ton-mile]

Vehicle size	CO_2 standard for model years 2014–2016	CO_2 standard for model year 2017–2020
Light HDV	388	373
Medium HDV	234	225
Heavy HDV	226	222

* * * * *

(h) * * *

(1) The following alternative emission standards apply by vehicle type and model year as follows:

TABLE 5 OF PARAGRAPH (h)(1) OF § 1037.105—OPTIONAL PHASE 3 CO_2 STANDARDS FOR MODEL YEAR 2027 AND LATER CUSTOM CHASSIS VOCATIONAL VEHICLES

[g/ton-mile]

Optional custom chassis vehicle type	Model year 2027	Model year 2028	Model year 2029	Model year 2030	Model year 2031	Model year 2032 and later
School Bus	190	182	176	168	163	149
Other Bus	286	269	255	237	220	189
Coach Bus	205	205	205	185	164	154
Refuse Hauler	253	241	232	221	212	191
Concrete Mixer	259	250	240	231	224	205
Motor home	226	226	226	226	226	226
Mixed-use vehicle	316	316	316	316	316	316
Emergency vehicle	319	319	319	319	319	319

TABLE 6 OF PARAGRAPH (h)(1) OF § 1037.105—PHASE 2 CUSTOM CHASSIS STANDARDS FOR MODEL YEARS 2021 THROUGH 2026

[g/ton-mile]

Vehicle type [a]	Assigned vehicle service class	Model year 2021–2026
School bus	Medium HDV	291
Motor home	Medium HDV	228
Coach bus	Heavy HDV	210
Other bus	Heavy HDV	300
Refuse hauler	Heavy HDV	313
Concrete mixer	Heavy HDV	319
Mixed-use vehicle	Heavy HDV	319
Emergency vehicle	Heavy HDV	324

[a] Vehicle types are generally defined in § 1037.801. "Other bus" includes any bus that is not a school bus or a coach bus. A "mixed-use vehicle" is one that meets at least one of the criteria specified in § 1037.631(a)(1) or (2).

* * * * *

■ 48. Amend § 1037.106 by revising the section heading and paragraph (b), removing and reserving paragraph (c), and revising paragraphs (f)(2) introductory text and (f)(2)(i) to read as follows:

§ 1037.106 CO_2 emission standards for tractors above 26,000 pounds GVWR.

* * * * *

(b) CO_2 standards in this paragraph (b) apply based on modeling and testing as described in subpart F of this part. The provisions of § 1037.241 specify how to comply with these standards.

(1) Model year 2027 and later tractors are subject to CO_2 standards corresponding to the selected subcategories as shown in the following tables:

TABLE 1 OF PARAGRAPH (b)(1) OF § 1037.106—CO_2 EMISSION STANDARDS FOR MODEL YEAR 2027 AND LATER TRACTORS

[g/ton-mile]

Model year	Roof height	Class 7 all cab styles	Class 8 day cab	Class 8 sleeper cab	Heavy-haul
2027	Low	86.6	66.1	64.1	48.3
	Mid	93.1	70.2	69.6	
	High	90.0	68.1	64.3	
2028	Low	84.7	64.6	64.1	48.3
	Mid	91.0	68.6	69.6	
	High	88.0	66.6	64.3	
2029	Low	81.8	62.4	64.1	48.3
	Mid	87.9	66.3	69.6	
	High	85.0	64.3	64.3	
2030	Low	77.0	58.7	57.7	43.0
	Mid	82.7	62.4	62.6	
	High	80.0	60.6	57.9	
2031	Low	67.3	51.4	51.3	42.5
	Mid	72.4	54.6	55.7	
	High	70.0	53.0	51.4	
2032 and later	Low	63.5	48.4	48.1	41.1
	Mid	68.2	51.5	52.2	

TABLE 1 OF PARAGRAPH (b)(1) OF § 1037.106—CO_2 EMISSION STANDARDS FOR MODEL YEAR 2027 AND LATER TRACTORS—Continued

[g/ton-mile]

Model year	Roof height	Class 7 all cab styles	Class 8 day cab	Class 8 sleeper cab	Heavy-haul
	High	66.0	50.0	48.2	

(2) Model year 2026 and earlier tractors are subject to CO_2 standards corresponding to the selected subcategory as shown in the following table:

TABLE 2 OF PARAGRAPH (b)(2) OF § 1037.106—CO_2 STANDARDS FOR MODEL YEAR 2026 AND EARLIER TRACTORS

[g/ton-mile]

Subcategory [a]	Phase 1 standards for model years 2014–2016	Phase 1 standards for model years 2017–2020	Phase 2 standards for model years 2021–2023	Phase 2 standards for model years 2024–2026
Class 7 Low-Roof (all cab styles)	107	104	105.5	99.8
Class 7 Mid-Roof (all cab styles)	119	115	113.2	107.1
Class 7 High-Roof (all cab styles)	124	120	113.5	106.6
Class 8 Low-Roof Day Cab	81	80	80.5	76.2
Class 8 Low-Roof Sleeper Cab	68	66	72.3	68.0
Class 8 Mid-Roof Day Cab	88	86	85.4	80.9
Class 8 Mid-Roof Sleeper Cab	76	73	78.0	73.5
Class 8 High-Roof Day Cab	92	89	85.6	80.4
Class 8 High-Roof Sleeper Cab	75	72	75.7	70.7
Heavy-Haul Tractors			52.4	50.2

* * * * *

(f) * * *

(2) You may optionally certify Class 7 tractors not covered by paragraph (f)(1) of this section to the standards and useful life for Class 8 tractors. This paragraph (f)(2) applies equally for hybrid vehicles, battery electric vehicles, and fuel cell electric vehicles. Credit provisions apply as follows:

(i) If you certify all your Class 7 tractors to Class 8 standards, you may use these Heavy HDV credits without restriction.

* * * * *

§ 1037.107 [Removed]

■ 49. Remove § 1037.107.

■ 50. Amend § 1037.115 by revising paragraphs (a) and (e)(1) and adding paragraph (f) to read as follows:

§ 1037.115 Other requirements.

* * * * *

(a) *Adjustable parameters.* Vehicles that have adjustable parameters must meet all the requirements of this part for any adjustment in the practically adjustable range. We may require that you set adjustable parameters to any specification within the practically adjustable range during any testing. See 40 CFR 1068.50 for general provisions related to adjustable parameters. You must ensure safe vehicle operation throughout the practically adjustable range of each adjustable parameter, including consideration of production tolerances. Note that adjustable roof fairings are deemed not to be adjustable parameters.

* * * * *

(e) * * *

(1) This paragraph (e) is intended to address air conditioning systems for which the primary purpose is to cool the driver compartment. This would generally include all cab-complete pickups and vans. Similarly, it does not apply for self-contained air conditioning used to cool passengers or refrigeration units used to cool cargo on vocational vehicles. For purposes of this paragraph (e), a self-contained system is an enclosed unit with its own evaporator and condenser even if it draws power from the engine.

* * * * *

(f) *Battery durability monitor.* Battery electric vehicles and plug-in hybrid electric vehicles must meet monitoring requirements related to batteries serving as a Rechargeable Energy Storage System from GTR No. 22 (incorporated by reference, see § 1037.810). The requirements of this section apply starting in model year 2030. The following clarifications and adjustments to GTR No. 22 apply for vehicles subject to this section:

(1) Install a customer-accessible display that monitors, estimates, and communicates the vehicle's State of Certified Energy (SOCE) include information in the application for certification as described in § 1037.205. Monitoring requirements related to State of Certified Range (SOCR) do not apply.

(2) Accuracy requirements for SOCE in GTR No. 22 do not apply. Minimum Performance Requirements for battery durability also do not apply.

(3) For battery electric vehicles, use good engineering judgment to develop a test procedure for determining useable battery energy (UBE).

(4) For plug-hybrid electric vehicles, determine UBE as described in 40 CFR 1036.545.

■ 51. Amend § 1037.120 by:

■ a. Revising paragraph (b)(1)(iii).

■ b. Removing paragraph (b)(1)(iv).

■ c. Revising paragraph (c).

The revisions read as follows:

§ 1037.120 Emission-related warranty requirements.

* * * * *

(b) * * *

(1) * * *

(iii) 2 years or 24,000 miles for tires.

* * * * *

(c) *Components covered.* The emission-related warranty covers tires, automatic tire inflation systems, tire pressure monitoring systems, vehicle speed limiters, idle-reduction systems, devices added to the vehicle to improve aerodynamic performance (not including standard components such as hoods or mirrors even if they have been optimized for aerodynamics), fuel cell stacks, and RESS and other components used with hybrid systems, battery electric vehicles, and fuel cell electric vehicles to the extent such emission-related components are included in your application for certification. The emission-related warranty also covers other added emission-related components to the extent they are included in your application for certification, and any other components whose failure would increase a vehicle's CO_2 emissions. The emission-related warranty covers all components whose failure would increase a vehicle's emissions of air conditioning refrigerants (for vehicles subject to air conditioning leakage standards), and it covers all components whose failure would increase a vehicle's evaporative and refueling emissions (for vehicles subject to evaporative and refueling emission standards). The emission-related warranty covers components that are part of your certified configuration even if another company produces the component.

* * * * *

■ 52. Amend § 1037.130 by revising paragraph (a) to read as follows:

§ 1037.130 Assembly instructions for secondary vehicle manufacturers.

(a) If you sell a certified incomplete vehicle to a secondary vehicle manufacturer, give the secondary vehicle manufacturer instructions for completing vehicle assembly consistent with the requirements of this part. Include all information necessary to ensure that the final vehicle assembly (including the engine) will be in its certified configuration.

* * * * *

■ 53. Amend § 1037.140 by revising paragraph (g)(5) introductory text to read as follows:

§ 1037.140 Classifying vehicles and determining vehicle parameters.

* * * * *

(g) * * *

(5) Heavy-duty vehicles with no installed propulsion engine, such as battery electric vehicles, are divided as follows:

* * * * *

■ 54. Amend § 1037.150 by:

■ a. Revising paragraphs (c), (f) and (p);

■ b. Removing paragraphs (u) through (x);

■ c. Redesignating paragraphs (y) through (bb) as paragraphs (u) through (x);

■ d. Revising newly redesignated paragraph (x); and

■ e. Adding a new paragraph (y).

The revisions and addition read as follows:

§ 1037.150 Interim provisions.

* * * * *

(c) *Small manufacturers.* The following provisions apply for small manufacturers:

(1) The following provisions apply through model year 2026:

(i) The greenhouse gas standards of §§ 1037.105 and 1037.106 are optional for small manufacturers producing vehicles with a date of manufacture before January 1, 2022. In addition, small manufacturers producing vehicles that run on any fuel other than gasoline, E85, or diesel fuel may delay complying with every later standard under this part by one model year.

(ii) Qualifying manufacturers must notify the Designated Compliance Officer each model year before introducing excluded vehicles into U.S. commerce. This notification must include a description of the manufacturer's qualification as a small business under 13 CFR 121.201. Manufacturers must label excluded vehicles with the following statement: ''THIS VEHICLE IS EXCLUDED UNDER 40 CFR 1037.150(c).''

(iii) Small manufacturers may meet Phase 1 standards instead of Phase 2 standards in the first year Phase 2 standards apply to them if they voluntarily comply with the Phase 1 standards for the full preceding year. Specifically, small manufacturers may certify their model year 2022 vehicles to the Phase 1 greenhouse gas standards of §§ 1037.105 and 1037.106 if they certify all the vehicles from their annual production volume included in emission credit calculations for the Phase 1 standards starting on or before January 1, 2021.

(2) The following provisions apply for model year 2027 and later for qualifying small manufacturers:

(i) The following standards apply for vocational vehicles instead of the standards specified in § 1037.105:

TABLE 1 OF PARAGRAPH (c)(2)(i) OF § 1037.150—SMALL MANUFACTURER CO_2 STANDARDS VOCATIONAL VEHICLES

[g/ton-mile]

Engine cycle	Vehicle size	Multi-purpose	Regional	Urban
Compression-ignition	Light HDV	330	291	367
Compression-ignition	Medium HDV	235	218	258
Compression-ignition	Heavy HDV	230	189	269
Spark-ignition	Light HDV	372	319	413
Spark-ignition	Medium HDV	268	247	297

TABLE 2 OF PARAGRAPH (c)(2)(i) OF § 1037.150—SMALL MANUFACTURER CO_2 STANDARDS FOR CUSTOM CHASSIS VOCATIONAL VEHICLES

[g/ton-mile]

Vehicle type [a]	Assigned vehicle service class	MY 2027 and later
School bus	Medium HDV	271
Motor home	Medium HDV	226
Coach bus	Heavy HDV	205
Other bus	Heavy HDV	286
Refuse hauler	Heavy HDV	298
Concrete mixer	Heavy HDV	316
Mixed-use vehicle	Heavy HDV	316

TABLE 2 OF PARAGRAPH (c)(2)(i) OF § 1037.150—SMALL MANUFACTURER CO_2 STANDARDS FOR CUSTOM CHASSIS VOCATIONAL VEHICLES—Continued

[g/ton-mile]

Vehicle type [a]	Assigned vehicle service class	MY 2027 and later
Emergency vehicle	Heavy HDV	319

[a] Vehicle types are generally defined in § 1037.801. ''Other bus'' includes any bus that is not a school bus or a coach bus. A ''mixed-use vehicle'' is one that meets at least one of the criteria specified in § 1037.631(a)(1) or (2).

(ii) The following standards apply for tractors instead of the standards specified in § 1037.106:

TABLE 3 OF PARAGRAPH (c)(2)(ii) OF § 1037.150—SMALL MANUFACTURER CO_2 STANDARDS FOR CLASS 7 AND CLASS 8 TRACTORS BY SUBCATEGORY

[g/ton-mile]

Subcategory[a]	Phase 2 standards for model year 2027 and later
Class 7 Low-Roof (all cab styles)	96.2
Class 7 Mid-Roof (all cab styles)	103.4
Class 7 High-Roof (all cab styles)	100.0
Class 8 Low-Roof Day Cab	73.4
Class 8 Low-Roof Sleeper Cab	64.1
Class 8 Mid-Roof Day Cab	78.0
Class 8 Mid-Roof Sleeper Cab	69.6
Class 8 High-Roof Day Cab	75.7
Class 8 High-Roof Sleeper Cab	64.3
Heavy-Haul Tractors	48.3

[a] Subcategory terms are defined in § 1037.801.

(iii) Small manufacturers producing vehicles that run on any fuel other than gasoline, E85, or diesel fuel may delay complying with the model year 2027 standards under this paragraph (c) by one model year.

(iv) Label qualifying vehicles with the following statement: ''THIS VEHICLE MEETS PHASE 2 STANDARDS AS ALLOWED UNDER 40 CFR 1037.150(c).''

(v) Small manufacturers may bank emission credits only by certifying all their vehicle families within a given averaging set to the Phase 3 standards that apply for the current model year.

(vi) The battery durability monitor requirements of § 1037.115(f) apply for vehicles subject to standards under this paragraph (c).

(3) See paragraphs (r), (t), (u), and (w) of this section for additional allowances for small manufacturers.

* * * * *

(f) *Testing exemption for qualifying vehicles.* Tailpipe CO_2 emissions from battery electric vehicles, fuel cell electric vehicles, and vehicles with engines fueled with neat hydrogen are deemed to be zero. No CO_2-related testing is required under this part for these vehicles.

* * * * *

(p) *Credit multiplier for advanced technology.* You may calculate credits you generate from vehicles certified with advanced technology as follows:

(1) For Phase 1 vehicles, multiply the credits by 1.50, except that you may not apply this multiplier in addition to the early-credit multiplier of paragraph (a) of this section.

(2) For model year 2026 and earlier, apply multipliers of 3.5 for plug-in hybrid electric vehicles, 4.5 for battery electric vehicles, and 5.5 for fuel cell electric vehicles; calculate credits relative to the Phase 2 standard. In model year 2027, the advanced technology multiplier applies only for fuel cell electric vehicles, with credits multiplied relative to the Phase 3 standard.

* * * * *

(x) *Transition to updated GEM.* (1) Vehicle manufacturers may demonstrate compliance with Phase 2 greenhouse gas standards in model years 2021 through 2023 using GEM Phase 2, Version 3.0, Version 3.5.1, or Version 4.0 (all incorporated by reference, see § 1037.810). Manufacturers may change to a different version of GEM for model years 2022 and 2023 for a given vehicle family after initially submitting an application for certification; such a change must be documented as an amendment under § 1037.225. Manufacturers may submit an end-of-year report for model year 2021 using any of the three regulatory versions of GEM, but only for demonstrating compliance with the custom-chassis standards in § 1037.105(h); such a change must be documented in the report submitted under § 1037.730. Once a manufacturer certifies a vehicle family based on GEM Version 4.0, it may not revert back to using GEM Phase 2, Version 3.0 or Version 3.5.1 for that vehicle family in any model year.

(2) Vehicle manufacturers may certify for model years 2021 through 2023 based on fuel maps from engines or powertrains that were created using GEM Phase 2, Version 3.0, Version 3.5.1, or Version 4.0 (all incorporated by reference, see § 1037.810). Vehicle manufacturers may alternatively certify in those years based on fuel maps from powertrains that were created using GEM Phase 2, Version 3.0, GEM HIL model 3.8, or GEM Phase 2, Version 4.0 (all incorporated by reference, see

§ 1037.810). Vehicle manufacturers may continue to certify vehicles in later model years using fuel maps generated with earlier versions of GEM for model year 2024 and later vehicle families that qualify for using carryover provisions in § 1037.235(d).

(y) *Correcting credit calculations.* If you notify us by October 1, 2024 that errors mistakenly decreased your balance of emission credits for 2020 or any earlier model years, you may correct the errors and recalculate the balance of emission credits after applying a 10 percent discount to the credit correction.

■ 55. Amend § 1037.205 by revising the introductory text, paragraphs (b) introductory text, (b)(6), (e), (o), and (q) to read as follows:

§ 1037.205 What must I include in my application?

This section specifies the information that must be in your application, unless we ask you to include less information under § 1037.201(c). We may require you to provide additional information to evaluate your application. References to testing and emission-data vehicles refer to testing vehicles or components to measure any quantity that serves as an input value for modeling emission rates under § 1037.520.

* * * * *

(b) Explain how the emission control system operates. As applicable, describe in detail all system components for controlling greenhouse gas emissions, including all auxiliary emission control devices (AECDs) and all fuel-system components you will install on any production vehicle. Identify the part number of each component you describe. For this paragraph (b), treat as separate AECDs any devices that modulate or activate differently from each other. Also describe your modeling inputs as described in § 1037.520, with the following additional information if it applies for your vehicles:

* * * * *

(6) If you perform powertrain testing under 40 1036.545, report both CO_2 and NO_X emission levels corresponding to each test run.

* * * * *

(e) Describe any test equipment and procedures that you used, including any special or alternate test procedures you used (see § 1037.501). Include information describing the procedures you used to determine C_dA values as specified in §§ 1037.525 and 1037.527. Describe which type of data you are using for engine fuel maps (see 40 CFR 1036.505).

* * * * *

(o) Report calculated and modeled emission results as for ten configurations. Include modeling inputs and detailed descriptions of how they were derived. Unless we specify otherwise, include the configuration with the highest modeling result, the lowest modeling result, and the configurations with the highest projected sales.

* * * * *

(q) For battery electric vehicles and plug-in hybrid electric vehicles, describe the recharging procedures and methods for determining battery performance, such as state of charge and charging capacity. Also include the certified usable battery energy for each battery durability subfamily.

* * * * *

§ 1037.230 [Amended]

■ 56. Amend § 1037.230 by removing paragraphs (a)(3) and (d)(3).

■ 57. Amend § 1037.231 by revising paragraph (a) to read as follows:

§ 1037.231 Powertrain families.

(a) If you choose to perform powertrain testing as specified in 40 CFR 1036.545, use good engineering judgment to divide your product line into powertrain families that are expected to have similar fuel consumptions and CO_2 emission characteristics throughout the useful life. Your powertrain family is limited to a single model year.

* * * * *

■ 58. Amend § 1037.235 by revising the introductory text, paragraphs (a) and (c)(3) and removing paragraph (g)(3) to read as follows:

§ 1037.235 Testing requirements for certification.

This section describes the emission testing you must perform to show compliance with respect to the greenhouse gas emission standards in subpart B of this part, and to determine any input values from § 1037.520 that involve measured quantities.

(a) Select emission-data vehicles that represent production vehicles and components for the vehicle family consistent with the specifications in §§ 1037.205(o) and 1037.520. Where the test results will represent multiple vehicles or components with different emission performance, use good engineering judgment to select worst-case emission data vehicles or components. In the case of powertrain testing under 40 CFR 1036.545, select a test engine, test hybrid components, test axle and test transmission as applicable, by considering the whole range of vehicle models covered by the powertrain family and the mix of duty cycles specified in § 1037.510. If the powertrain has more than one transmission calibration, for example economy vs. performance, you may weight the results from the powertrain testing in 40 CFR 1036.545 by the percentage of vehicles in the family by prior model year for each configuration. This can be done, for example, through the use of survey data or based on the previous model year's sales volume. Weight the results of $M_{\text{fuel[cycle]}}$

$$\frac{f_{\text{npowertrain}}}{v_{\text{powertrain}}}$$

and $W_{\text{[cycle]}}$ from Table 2 of 40 CFR 1036.545 according to the percentage of vehicles in the family that use each transmission calibration.

* * * * *

(c) * * *

(3) Before we test one of your vehicles or components, we may set its adjustable parameters to any point within the practically adjustable ranges, if applicable.

* * * * *

■ 59. Amend § 1037.241 to read as follows:

§ 1037.241 Demonstrating compliance with exhaust emission standards for greenhouse gas pollutants.

(a) Compliance determinations for purposes of certification depend on whether or not you participate in the ABT program in subpart H of this part.

(1) If none of your vehicle families generate or use emission credits in a given model year, each of your vehicle families is considered in compliance with the CO_2 emission standards in §§ 1037.105 and 1037.106 if all vehicle configurations in the family have calculated or modeled CO_2 emission rates from § 1037.520 that are at or below the applicable standards. A vehicle family is deemed not to comply if any vehicle configuration in the family has a calculated or modeled CO_2 emission rate that is above the applicable standard.

(2) If you generate or use emission credits with one or more vehicle families in a given model year, your vehicle families within an averaging set are considered in compliance with the CO_2 emission standards in §§ 1037.105 and 1037.106 if the sum of positive and negative credits for all vehicle configurations in those vehicle families lead to a zero balance or a positive balance of credits, except as allowed by§ 1037.745. Note that the FEL is considered to be the applicable emission standard for an individual configuration.

(b) We may require you to provide an engineering analysis showing that the performance of your emission controls will not deteriorate during the useful life with proper maintenance. If we determine that your emission controls are likely to deteriorate during the useful life, we may require you to develop and apply deterioration factors consistent with good engineering judgment. For example, you may need to apply a deterioration factor to address deterioration of battery performance for a hybrid vehicle. Where the highest useful life emissions occur between the end of useful life and at the low-hour test point, base deterioration factors for the vehicles on the difference between (or ratio of) the point at which the highest emissions occur and the low-hour test point.

§ 1037.310 [Removed]

■ 60. Remove § 1037.310.

■ 61. Amend § 1037.315 by revising paragraph (a) to read as follows:

§ 1037.315 Audit procedures related to powertrain testing.

(a) For vehicles certified based on powertrain testing as specified in 40 CFR 1036.545, we may apply the selective enforcement audit requirements to the powertrain. If engine manufacturers perform the powertrain testing and include those results in their certification under 40 CFR part 1036, they are responsible for selective enforcement audits related to those results. Otherwise, the certificate holder for the vehicle is responsible for the selective enforcement audit.

* * * * *

■ 62. Amend § 1037.401 by revising paragraph (b) to read as follows:

§ 1037.401 General provisions.

* * * * *

(b) We may measure the drag area of a vehicle you produced after it has been placed into service. We may use any of the procedures as specified in §§ 1037.525 and 1037.527 for measuring drag area. Your vehicle conforms to the regulations of this part with respect to aerodynamic performance if we measure its drag area to be at or below the maximum drag area allowed for the bin to which that configuration was certified.

■ 63. Amend § 1037.501 by revising paragraphs (a) and (h) and removing paragraph (i) to read as follows:

§ 1037.501 General testing and modeling provisions.

* * * * *

(a) Except as specified in subpart B of this part, you must demonstrate that you meet emission standards using emission modeling as described in § 1037.520. This modeling depends on several measured values as described in this subpart F. You may use fuel-mapping information from the engine manufacturer as described in 40 CFR 1036.535 and 1036.540, or you may use powertrain testing as described in 40 CFR 1036.545.

* * * * *

(h) Note that declared GEM inputs for fuel maps and aerodynamic drag area typically includes compliance margins to account for testing variability; for other measured GEM inputs, the declared values are typically the measured values without adjustment.

■ 64. Amend § 1037.510 by:

■ a. Revising paragraphs (a) introductory text, (a)(2) introductory text, and (a)(2)(iii) and (iv);

■ b. In paragraph (b) in Equation 1037.510–1, in the Where entries for $\bar{v}_{\text{moving}}$ and $w_{[\text{cycle}]}$, removing the text ‘‘table 1 to this section’’ and adding, in its place, the text ‘‘table 1 of this section’’; and

■ c. Revising paragraphs (c)(3) and (d).

The revisions read as follows:

§ 1037.510 Duty-cycle exhaust testing.

* * * * *

(a) Measure emissions by testing the powertrain on a powertrain dynamometer with the applicable duty cycles. Each duty cycle consists of a series of speed commands over time—variable speeds for the transient test and constant speeds for the highway cruise tests. None of these cycles include vehicle starting or warmup.

* * * * *

(2) Perform cycle-average engine fuel mapping as described in 40 CFR 1036.540. For powertrain testing under 40 CFR 1036.545 or § 1037.555, perform testing as described in this paragraph (a)(2) to generate GEM inputs for each simulated vehicle configuration, and test runs representing different idle conditions. Perform testing as follows:

* * * * *

(iii) *Drive idle*. Perform testing at a loaded idle condition for Phase 2 vocational vehicles. For engines with an adjustable warm idle speed setpoint, test at the minimum warm idle speed and the maximum warm idle speed; otherwise simply test at the engine’s warm idle speed. Warm up the powertrain as described in 40 CFR 1036.520(d). Within 60 seconds after concluding the warm-up, linearly ramp the powertrain down to zero vehicle speed over 20 seconds. Apply the brake and keep the transmission in drive (or clutch depressed for manual transmission). Stabilize the powertrain for (60±1) seconds and then sample emissions for (30±1) seconds.

(iv) *Parked idle*. Perform testing at a no-load idle condition for Phase 2 vocational vehicles. For engines with an adjustable warm idle speed setpoint, test at the minimum warm idle speed and the maximum warm idle speed; otherwise simply test at the engine’s warm idle speed. Warm up the powertrain as described in 40 CFR 1036.520(d). Within 60 seconds after concluding the warm-up, linearly ramp the powertrain down to zero vehicle speed in 20 seconds. Put the transmission in park (or neutral for manual transmissions and apply the parking brake if applicable). Stabilize the powertrain for (180±1) seconds and then sample emissions for (600±1) seconds.

* * * * *

(c) * * *

(3) Table 1 follows:

TABLE 1 OF PARAGRAPH (c)(3) OF § 1037.510—WEIGHTING FACTORS FOR DUTY CYCLES

	Distance-weighted			Time-weighted [a]			Average speed during non-idle cycles (mi/hr) [b]
	Transient (percent)	55 mi/hr cruise (percent)	65 mi/hr cruise (percent)	Drive idle (percent)	Parked idle (percent)	Non-idle (percent)	
Day Cabs	19	17	64				
Sleeper Cabs	5	9	86				
Heavy-haul Tractors	19	17	64				
Vocational—Regional	20	24	56	0	25	75	38.41
Vocational—Multi-Purpose (2b–7)	54	29	17	17	25	58	23.18
Vocational—Multi-Purpose (8)	54	23	23	17	25	58	23.27
Vocational—Urban (2b–7)	92	8	0	15	25	60	16.25
Vocational—Urban (8)	90	10	0	15	25	60	16.51
Vocational with conventional powertrain (Phase 1 only)	42	21	37				

TABLE 1 OF PARAGRAPH (c)(3) OF § 1037.510—WEIGHTING FACTORS FOR DUTY CYCLES—Continued

	Distance-weighted			Time-weighted [a]			Average speed during non-idle cycles (mi/hr) [b]
	Transient (percent)	55 mi/hr cruise (percent)	65 mi/hr cruise (percent)	Drive idle (percent)	Parked idle (percent)	Non-idle (percent)	
Vocational Hybrid Vehicles (Phase 1 only)	75	9	16				

[a] Note that these drive idle and non-idle weighting factors do not reflect additional drive idle that occurs during the transient cycle. The transient cycle does not include any parked idle.

[b] These values apply even for vehicles not following the specified speed traces.

* * * * *

(d) For highway cruise and transient testing, compare actual second-by-second vehicle speed with the speed specified in the test cycle and ensure any differences are consistent with the criteria as specified in 40 CFR 1036.545(g)(1). If the speeds do not conform to these criteria, the test is not valid and must be repeated.

* * * * *

§ 1037.515 [Removed]

■ 65. Remove § 1037.515.

■ 66. Amend § 1037.520 by revising the introductory text and paragraphs (a)(2) introductory text, (b)(3), (e)(1) and (3), (g)(4), and (j)(1) to read as follows:

§ 1037.520 Modeling CO_2 emissions to show compliance for vocational vehicles and tractors.

This section describes how to use the Greenhouse gas Emissions Model (GEM) to show compliance with the CO_2 standards of §§ 1037.105 and 1037.106 for vocational vehicles and tractors. Use GEM version 2.0.1 to demonstrate compliance with Phase 1 standards; use GEM Phase 2, Version 4.0 to demonstrate compliance with Phase 2 and Phase 3 standards (both incorporated by reference, see § 1037.810). Use good engineering judgment when demonstrating compliance using GEM.

(a) * * *

(2) For Phase 2 and Phase 3 vehicles, the GEM inputs described in paragraphs (a)(1)(i) through (v) of this section continue to apply. Note that the provisions in this part related to vehicle speed limiters and automatic engine shutdown systems are available for vocational vehicles in Phase 2 and Phase 3. The rest of this section describes additional GEM inputs for demonstrating compliance with Phase 2 and Phase 3 standards. Simplified versions of GEM apply for limited circumstances as follows:

(b) * * *

(3) For Phase 2 and Phase 3 tractors other than heavy-haul tractors, determine bin levels and C_dA inputs as follows:

(i) Determine bin levels for high-roof tractors based on aerodynamic test results as specified in § 1037.525 and summarized in the following table:

TABLE 3 TO PARAGRAPH (b)(3)(i) OF § 1037.520—BIN DETERMINATIONS FOR PHASE 2 AND PHASE 3 HIGH-ROOF TRACTORS BASED ON AERODYNAMIC TEST RESULTS

[C_dA in m^2]

Tractor type	Bin I	Bin II	Bin III	Bin IV	Bin V	Bin VI	Bin VII
Day Cabs	≥7.2	6.6–7.1	6.0–6.5	5.5–5.9	5.0–5.4	4.5–4.9	≤4.4
Sleeper Cabs	≥6.9	6.3–6.8	5.7–6.2	5.2–5.6	4.7–5.1	4.2–4.6	≤4.1

(ii) For low- and mid-roof tractors, you may either use the same bin level that applies for an equivalent high-roof tractor as shown in Table 3 of this section, or you may determine your bin level based on aerodynamic test results as described in Table 4 of this section.

TABLE 4 TO PARAGRAPH (b)(3)(ii) OF § 1037.520—BIN DETERMINATIONS FOR PHASE 2 AND PHASE 3 LOW-ROOF AND MID-ROOF TRACTORS BASED ON AERODYNAMIC TEST RESULTS

[C_dA in m^2]

Tractor type	Bin I	Bin II	Bin III	Bin IV	Bin V	Bin VI	Bin VII
Low-Roof Cabs	≥5.4	4.9–5.3	4.5–4.8	4.1–4.4	3.8–4.0	3.5–3.7	≤3.4
Mid-Roof Cabs	≥5.9	5.5–5.8	5.1–5.4	4.7–5.0	4.4–4.6	4.1–4.3	≤4.0

(iii) Determine the C_dA input according to the tractor's bin level as described in the following table:

TABLE 5 TO PARAGRAPH (b)(3)(iii) OF § 1037.520—PHASE 2 AND PHASE 3 C_dA TRACTOR INPUTS BASED ON BIN LEVEL

Tractor type	Bin I	Bin II	Bin III	Bin IV	Bin V	Bin VI	Bin VII
High-Roof Day Cabs	7.45	6.85	6.25	5.70	5.20	4.70	4.20
High-Roof Sleeper Cabs	7.15	6.55	5.95	5.40	4.90	4.40	3.90
Low-Roof Cabs	6.00	5.60	5.15	4.75	4.40	4.10	3.80
Mid-Roof Cabs	7.00	6.65	6.25	5.85	5.50	5.20	4.90

* * * * *

(e) * * *

(1) Vehicle weight reduction inputs for wheels are specified relative to dual-wide tires with conventional steel wheels. For purposes of this paragraph (e)(1), an aluminum alloy qualifies as light-weight if a dual-wide drive wheel made from this material weighs at least 21 pounds less than a comparable conventional steel wheel. The inputs are listed in Table 6 of this section. For example, a tractor or vocational vehicle with aluminum steer wheels and eight (4 × 2) dual-wide aluminum drive wheels would have an input of 210 pounds (2 × 21 + 8 × 21).

TABLE 6 TO § 1037.520—WHEEL-RELATED WEIGHT REDUCTIONS

Tire type	Material	Weight reduction—Phase 1 (pounds per wheel)	Weight reduction—Phase 2 and Phase 3 (pounds per wheel)
Wide-Base Single Drive Tire with . . .[a]	Steel Wheel	84	84
	Aluminum Wheel	139	147
	Light-Weight Aluminum Alloy Wheel	147	147
Steer Tire or Dual-wide Drive Tire with . . .	High-Strength Steel Wheel	8	8
	Aluminum Wheel	21	25
	Light-Weight Aluminum Alloy Wheel	30	25

[a] The weight reduction for wide-base tires accounts for reduced tire weight relative to dual-wide tires.

* * * * *

(3) Weight-reduction inputs for vocational-vehicle components other than wheels are specified in the following table:

TABLE 8 TO § 1037.520—NONWHEEL-RELATED WEIGHT REDUCTIONS FROM ALTERNATIVE MATERIALS FOR PHASE 2 AND PHASE 3 VOCATIONAL VEHICLES

[pounds][a]

<table>
<tr><th rowspan="2">Component</th><th rowspan="2">Material</th><th colspan="3">Vehicle type</th></tr>
<tr><th>Light HDV</th><th>Medium HDV[b]</th><th>Heavy HDV</th></tr>
<tr><td>Axle Hubs—Non-Drive</td><td>Aluminum</td><td colspan="2">40</td><td>40</td></tr>
<tr><td>Axle Hubs—Non-Drive</td><td>High Strength Steel</td><td colspan="2">5</td><td>5</td></tr>
<tr><td>Axle—Non-Drive</td><td>Aluminum</td><td colspan="2">60</td><td>60</td></tr>
<tr><td>Axle—Non-Drive</td><td>High Strength Steel</td><td colspan="2">15</td><td>15</td></tr>
<tr><td>Brake Drums—Non-Drive</td><td>Aluminum</td><td colspan="2">60</td><td>60</td></tr>
<tr><td>Brake Drums—Non-Drive</td><td>High Strength Steel</td><td colspan="2">42</td><td>42</td></tr>
<tr><td>Axle Hubs—Drive</td><td>Aluminum</td><td colspan="2">40</td><td>80</td></tr>
<tr><td>Axle Hubs—Drive</td><td>High Strength Steel</td><td colspan="2">10</td><td>20</td></tr>
<tr><td>Brake Drums—Drive</td><td>Aluminum</td><td colspan="2">70</td><td>140</td></tr>
<tr><td>Brake Drums—Drive</td><td>High Strength Steel</td><td colspan="2">37</td><td>74</td></tr>
<tr><td>Suspension Brackets, Hangers</td><td>Aluminum</td><td colspan="2">67</td><td>100</td></tr>
<tr><td>Suspension Brackets, Hangers</td><td>High Strength Steel</td><td colspan="2">20</td><td>30</td></tr>
<tr><td>Crossmember—Cab</td><td>Aluminum</td><td>10</td><td>15</td><td>15</td></tr>
<tr><td>Crossmember—Cab</td><td>High Strength Steel</td><td>2</td><td>5</td><td>5</td></tr>
<tr><td>Crossmember—Non-Suspension</td><td>Aluminum</td><td>15</td><td>15</td><td>15</td></tr>
<tr><td>Crossmember—Non-Suspension</td><td>High Strength Steel</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Crossmember—Suspension</td><td>Aluminum</td><td>15</td><td>25</td><td>25</td></tr>
<tr><td>Crossmember—Suspension</td><td>High Strength Steel</td><td>6</td><td>6</td><td>6</td></tr>
<tr><td>Driveshaft</td><td>Aluminum</td><td>12</td><td>40</td><td>50</td></tr>
<tr><td>Driveshaft</td><td>High Strength Steel</td><td>5</td><td>10</td><td>12</td></tr>
<tr><td>Frame Rails</td><td>Aluminum</td><td>120</td><td>300</td><td>440</td></tr>
<tr><td>Frame Rails</td><td>High Strength Steel</td><td>40</td><td>40</td><td>87</td></tr>
</table>

[a] Weight-reduction values apply per vehicle unless otherwise noted.

[b] For Medium HDV with 6 × 4 or 6 × 2 axle configurations, use the values for Heavy HDV.

* * * * *

* * * * *

(g) * * *

(4) GEM inputs associated with powertrain testing include powertrain family, transmission calibration identifier, test data from 40 CFR 1036.545, and the powertrain test configuration (dynamometer connected to transmission output or wheel hub). You do not need to identify or provide inputs for transmission gear ratios, fuel map data, or engine torque curves, which would otherwise be required under paragraph (f) of this section.

* * * * *

(j) * * *

(1) *Intelligent controls.* Enter 2 for tractors with predictive cruise control. This includes any cruise control system that incorporates satellite-based global-positioning data for controlling operator demand. For tractors without predictive cruise control and for all vocational vehicles, enter 1.5 if they have neutral coasting or full cylinder deactivation when coasting, unless good engineering judgment indicates that a lower percentage should apply.

* * * * *

■ 67. Amend § 1037.525 by revising paragraphs (a) introductory text, (b)(1), (4), and (5), (c)(1) introductory text, and (c)(2) introductory text to read as follows:

§ 1037.525 Aerodynamic measurements for tractors.

* * * * *

(a) *General provisions.* The GEM input for a tractor's aerodynamic performance is a C_d value for Phase 1 and a C_dA value for Phase 2 and Phase 3. The input value is measured or calculated for a tractor in a specific test configuration with a trailer, such as a high-roof tractor with a box van meeting the requirements for the standard trailer.

* * * * *

(b) * * *

(1) Determine the functional relationship between your alternate method and coastdown testing. Specify this functional relationship as $F_{\text{alt-aero}}$ for a given alternate drag measurement method. The effective yaw angle, ψ_{eff}, is assumed to be zero degrees for Phase 1. For Phase 2 and Phase 3, determine Ψ_{eff} from coastdown test results using the following equation:

$$F_{\text{alt-aero}} = \frac{C_d A_{\text{coastdown}}(\psi_{\text{eff}})}{C_d A_{\text{alt}}(\psi_{\text{eff}})}$$

Eq. 1037.525-1

Where:

$C_dA_{\text{coastdown}}(\psi_{\text{eff}})$ = the average drag area measured during coastdown at an effective yaw angle, ψ_{eff}.

$C_dA_{\text{alt}}(\psi_{\text{eff}})$ = the average drag area calculated from an alternate drag measurement method at an effective yaw angle, ψ_{eff}.

* * * * *

(4) Measure the drag area using your alternate method for a Phase 2 and Phase 3 tractor used to determine $F_{\text{alt-aero}}$ with testing at yaw angles of 0°, ±1°, ±3°, ±4.5°, ±6°, and ±9° (you may include additional angles), using direction conventions described in Figure 2 of SAE J1252 (incorporated by reference, see § 1037.810). Also, determine the drag area at the coastdown effective yaw angle, $C_dA_{\text{alt}}(\psi_{\text{eff}})$, by taking the average drag area at ψ_{eff} and $-\psi_{\text{eff}}$ for your vehicle using the same alternate method.

(5) For Phase 2 and Phase 3 testing, determine separate values of $F_{\text{alt-aero}}$ for at least one high-roof day cab and one high-roof sleeper cab for model year 2021, at least two high-roof day cabs and two high-roof sleeper cabs for model year 2024, and at least three high-roof day cabs and three high-roof sleeper cabs for model year 2027. These test requirements are cumulative; for example, you may meet these requirements by testing two vehicles to support model year 2021 certification and four additional vehicles to support model year 2023 certification. For any untested tractor models, apply the value of $F_{\text{alt-aero}}$ from the tested tractor model that best represents the aerodynamic characteristics of the untested tractor model, consistent with good engineering judgment. Testing under this paragraph (b)(5) continues to be valid for later model years until you change the tractor model in a way that causes the test results to no longer represent production vehicles. You must also determine unique values of $F_{\text{alt-aero}}$ for low-roof and mid-roof tractors if you determine C_dA values based on low or mid-roof tractor testing as shown in Table 4 of § 1037.520. For Phase 1 testing, if good engineering judgment allows it, you may calculate a single, constant value of $F_{\text{alt-aero}}$ for your whole product line by dividing the coastdown drag area, $C_dA_{\text{coastdown}}$, by drag area from your alternate method, C_dA_{alt}.

* * * * *

(c) * * *

(1) Apply the following method for all Phase 2 and Phase 3 testing with an alternate method:

* * * * *

(2) Apply the following method for Phase 2 and Phase 3 coastdown testing other than coastdown testing used to establish $F_{\text{alt-aero}}$:

* * * * *

§ 1037.526 [Removed]

■ 68. Remove § 1037.526.

■ 69. Revise § 1037.527 to read as follows:

§ 1037.527 Aerodynamic measurements for vocational vehicles.

This section describes a methodology for determining vocational vehicle aerodynamic input values for as described in § 1037.520. This measurement is optional. A vocational vehicle's aerodynamic performance is based on a ΔC_dA value relative to a baseline vehicle. Determine a ΔC_dA value by performing A to B testing as follows:

(a) Determine a baseline C_dA value for a vehicle representing a production configuration without the aerodynamic improvement. Repeat this testing and measure C_dA for a vehicle with the improved aerodynamic design.

(b) Use good engineering judgment to perform paired tests that accurately demonstrate the reduction in aerodynamic drag associated with the improved design.

(c) Measure C_dA in m^2 to two decimal places. Calculate ΔC_dA by subtracting the drag area for the test vehicle from the drag area for the baseline vehicle.

■ 70. Amend § 1037.528 by:

■ a. Revising the introductory text, paragraphs (b) introductory text and (h)(5)(iv);

■ b. Removing paragraph (h)(7);

■ c. Redesignating paragraphs (h)(8) through (12) as paragraphs (h)(7) through (11); and

■ d. Revising newly redesignated paragraph (h)(10).

The revisions read as follows:

§ 1037.528 Coastdown procedures for calculating drag area (C_dA).

The coastdown procedures in this section describe how to calculate drag area, C_dA, for Phase 2 and Phase 3 tractors and vocational vehicles, subject to the provisions of §§ 1037.525 and 1037.527. These procedures are considered the reference method for tractors. Follow the provisions of Sections 1 through 9 of SAE J2263 (incorporated by reference, see § 1037.810), with the clarifications and exceptions described in this section. Several of these exceptions are from SAE J1263 (incorporated by reference, see § 1037.810). The coastdown procedures in 40 CFR 1066.310 apply instead of the provisions of this section for Phase 1 tractors.

* * * * *

(b) To determine C_dA values for a tractor, perform coastdown testing with a tractor-trailer combination using the manufacturer's tractor and a standard trailer. Prepare the vehicles for testing as follows:

* * * * *

(h) * * *

(5) * * *

(iv) Calculate ΔF_{spin} using the following equation:

$$\Delta F_{\text{spin}} = F_{\text{spinhi}} - F_{\text{spinlo}}$$

Eq. 1037.528-10

Example:

$\Delta F_{\text{spin}} = 129.7 - 52.7$

$\Delta F_{\text{spin}} = 77.0$ N

* * * * *

(10) Calculate drag area, C_dA, in m^2 for each high-speed segment using the following equation, expressed to at least three decimal places:

$$C_dA = \frac{2 \cdot (F_{\text{hi}} - F_{\text{lo,pair}} - \Delta F_{\text{spin}} - \Delta F_{\text{TRR}})}{(\bar{v}^2_{\text{air,hi}} - \bar{v}^2_{\text{air,lo,pair}})} \cdot \frac{R \cdot \bar{T}}{\bar{p}_{\text{act}}}$$

Eq. 1037.528-16

Where:

F_{hi} = road load force at high speed determined from Eq. 1037.528–7.

$F_{\text{lo,pair}}$ = the average of F_{lo} values for a pair of opposite direction runs calculated as described in paragraph (h)(9) of this section.

ΔF_{spin} = the difference in drive-axle spin loss force between high-speed and low-speed coastdown segments. This is described in paragraph (h)(5) of this section for tractor testing.

ΔF_{TRR} = the difference in tire rolling resistance force between high-speed and low-speed coastdown segments as described in paragraph (h)(6) of this section.

$\bar{v}^2_{\text{air,lo,pair}}$ = the average of $\bar{v}^2_{\text{air,lo}}$ values for a pair of opposite direction runs calculated as described in paragraph (h)(9) of this section.

R = specific gas constant = 287.058 J/(kg·K).

$\bar{T}$ = mean air temperature expressed to at least one decimal Place.

$\bar{p}_{\text{act}}$ = mean absolute air pressure expressed to at least one decimal place.

Example:

F_{hi} = 4645.5 N

$F_{\text{lo,pair}}$ = 1005.0 N

ΔF_{spin} = 77.0 N

ΔF_{TRR} = 187.4 N

$\bar{v}^2_{\text{air,hi}} = 933.4 \text{ m}^2/\text{s}^2$

$\bar{v}^2_{\text{air,lo,pair}} = 43.12 \text{ m}^2/\text{s}^2$

R = 287.058 J/(kg·K)

$\bar{T}$ = 285.97 K

$\bar{p}_{\text{act}}$ = 101.727 kPa = 101727 Pa

$$C_dA = \frac{2 \cdot (4640.5 - 1005.0 - 77.0 - 187.4)}{(933.4 - 43.12)} \cdot \frac{287.058 \cdot 285.97}{101727}$$

$C_dA = 6.120 \text{ m}^2$

* * * * *

■ 71. Amend § 1037.530 by revising the introductory text, paragraphs (a) introductory text, (c), and (d) introductory text to read as follows:

§ 1037.530 Wind-tunnel procedures for calculating drag area (C_dA).

The wind-tunnel procedure specified in this section is an alternate procedure for tractors.

(a) You may measure drag areas consistent with published SAE procedures as described in this section using any wind tunnel recognized by the Subsonic Aerodynamic Testing Association, subject to the provisions of §§ 1037.525 and 1037.527. If your wind tunnel does not meet the specifications described in this section, you may ask us to approve it as an alternate method under § 1037.525(d). All wind tunnels and wind tunnel tests must meet the specifications described in SAE J1252 (incorporated by reference, see § 1037.810), with the following exceptions and additional provisions:

* * * * *

(c) To determine C_dA values for certifying tractors, perform wind-tunnel testing with a tractor-trailer combination using the manufacturer's tractor and a standard trailer. Use a moving/rolling floor if the facility has one. For Phase 1 tractors, conduct the wind tunnel tests at a zero yaw angle. For Phase 2 and Phase 3 vehicles, conduct the wind tunnel tests by measuring the drag area at yaw angles of +4.5° and −4.5° and calculating the average of those two values.

(d) In your request to use wind-tunnel testing for tractors, describe how you meet all the specifications that apply under this section, using terminology consistent with SAE J1594 (incorporated by reference, see § 1037.810). If you request our approval to use wind-tunnel testing even though you do not meet all the specifications of this section, describe how your method nevertheless qualifies as an alternate method under § 1037.525(d) and include all the following information:

* * * * *

■ 72. Amend § 1037.532 by revising the introductory text, paragraphs (a) introductory text, (b), and (c) introductory text to read as follows:

§ 1037.532 Using computational fluid dynamics to calculate drag area (CdA).

This section describes how to use commercially available computational fluid dynamics (CFD) software to determine C_dA values, subject to the provisions of §§ 1037.525 and 1037.527. This is considered to be an alternate method for tractors.

(a) For Phase 2 and Phase 3 vehicles, use SAE J2966 (incorporated by reference, see § 1037.810), with the following clarifications and exceptions:

* * * * *

(b) For Phase 1 tractors, apply the procedures as specified in paragraphs (c) through (f) of this section. Paragraphs (c) through (f) of section apply for Phase 2 and Phase 3 vehicles only as specified in paragraph (a) of this section.

(c) To determine C_dA values for certifying a tractor, perform CFD modeling based on a tractor-trailer combination using the manufacturer's tractor and a standard trailer. Perform all CFD modeling as follows:

* * * * *

■ 73. Amend § 1037.540 by:

■ a. Revising the introductory text and paragraphs (c)(2) and (5), (d)(4), and (f) introductory text; and

■ b. In paragraph (f)(3), by removing the text ''the approved utility factor curve'' and adding, in its place, the text ''the utility factor curve in appendix E of this part''.

The revisions read as follows:

§ 1037.540 Special procedures for testing vehicles with hybrid power take-off.

This section describes optional procedures for quantifying the reduction in greenhouse gas emissions for vehicles as a result of running power take-off (PTO) devices with a hybrid energy delivery system. See 40 CFR 1036.545 for powertrain testing requirements that apply for drivetrain hybrid systems. The procedures are written to test the PTO by ensuring that the engine produces all of the energy with no net change in stored energy (charge-sustaining), and for plug-in hybrid electric vehicles, also allowing for drawing down the stored energy (charge-depleting). The full charge-sustaining test for the hybrid vehicle is from a fully charged rechargeable energy storage system (RESS) to a depleted RESS and then back to a fully charged RESS. You must include all hardware for the PTO system. You may ask us to modify the provisions of this section to allow testing hybrid vehicles that use a technology other than batteries for storing energy, consistent with good engineering judgment. For plug-in hybrid electric vehicles, use a utility factor to properly weight charge-sustaining and charge-depleting operation as described in paragraph (f)(3) of this section.

* * * * *

(c) * * *

(2) Prepare the vehicle for testing by operating it as needed to stabilize the RESS at a full state of charge (or equivalent for vehicles that use a technology other than batteries for storing energy).

* * * * *

(5) Operate the vehicle over one or both of the denormalized PTO duty cycles without turning the vehicle off, until the engine starts and then shuts down. This may require running multiple repeats of the PTO duty cycles. For systems that are not plug-in hybrid systems, the test cycle is completed once the engine shuts down. For plug-in hybrid systems, continue running until the PTO hybrid is running in a charge-sustaining mode such that the ''End of Test'' requirements defined in 40 CFR 1066.501 are met. Measure emissions as described in paragraph (b)(7) of this section. Use good engineering judgment to minimize the variability in testing between the two types of vehicles.

* * * * *

(d) * * *

(4) Divide the total PTO operating time from paragraph (d)(3) of this section by a conversion factor of 0.0144 hr/mi for Phase 1 and 0.0217 hr/mi for Phase 2 and Phase 3 to determine the equivalent distance driven. The conversion factors are based on estimates of average vehicle speed and PTO operating time as a percentage of total engine operating time; the Phase 2 and Phase 3 conversion factor is calculated from an average speed of 27.1 mi/hr and PTO operation 37% of engine operating time, as follows:

$$Factor = \frac{37\%}{(100\% - 37\%) \cdot 27.1\text{mi/hr}} = 0.0217\text{hr/mi}$$

* * * * *

(f) For Phase 2 and Phase 3, calculate the delta PTO fuel results for input into GEM during vehicle certification as follows:

* * * * *

§ 1037.550—[Removed]

■ 74. Remove § 1037.550.

■ 75. Amend § 1037.551 by revising the introductory text and paragraphs (b) and (c) to read as follows:

§ 1037.551 Engine-based simulation of powertrain testing.

40 CFR 1036.545 describes how to measure fuel consumption over specific duty cycles with an engine coupled to a transmission; 40 CFR 1036.545(a)(5) describes how to create equivalent duty cycles for repeating those same measurements with just the engine. This § 1037.551 describes how to perform this engine testing to simulate the powertrain test. These engine-based measurements may be used for selective enforcement audits as described in § 1037.301, as long as the test engine's operation represents the engine operation observed in the powertrain test. If we use this approach for confirmatory testing, when making compliance determinations, we will consider the uncertainty associated with this approach relative to full powertrain testing. Use of this approach for engine SEAs is optional for engine manufacturers.

* * * * *

(b) Operate the engine over the applicable engine duty cycles corresponding to the vehicle cycles specified in § 1037.510(a)(2) for powertrain testing over the applicable vehicle simulations described in 40 CFR 1036.545(j). Warm up the engine to prepare for the transient test or one of the highway cruise cycles by operating it one time over one of the simulations of the corresponding duty cycle. Warm up the engine to prepare for the idle test by operating it over a simulation of the 65-mi/hr highway cruise cycle for 600 seconds. Within 60 seconds after concluding the warm up cycle, start emission sampling while the engine operates over the duty cycle. You may perform any number of test runs directly in succession once the engine is warmed up. Perform cycle validation as described in 40 CFR 1065.514 for engine speed, torque, and power.

(c) Calculate the mass of fuel consumed as described in 40 CFR 1036.545(n) and (o). Correct each measured value for the test fuel's mass-specific net energy content as described in 40 CFR 1036.550. Use these corrected values to determine whether the engine's emission levels conform to the declared fuel-consumption rates from the powertrain test.

■ 76. Amend § 1037.555 by revising the introductory text to read as follows:

§ 1037.555 Special procedures for testing Phase 1 hybrid systems.

This section describes a powertrain testing procedure for simulating a chassis test with a pre-transmission or post-transmission hybrid system to perform A to B testing of Phase 1 vehicles. These procedures may also be used to perform A to B testing with non-hybrid systems. See 40 CFR 1036.545 for Phase 2 and Phase 3 hybrid systems.

* * * * *

■ 77. Amend § 1037.560 by revising paragraph (e)(2) to read as follows:

§ 1037.560 Axle efficiency test.

* * * * *

(e) * * *

(2) Maintain gear oil temperature at (81 to 83) °C. You may alternatively specify a lower range by shifting both temperatures down by the same amount for all test points or on a test point by test point basis. We will test your axle assembly using the same temperature range you specify for your testing. You may use an external gear oil conditioning system, as long as it does not affect measured values.

* * * * *

■ 78. Amend § 1037.601 by revising paragraph (b) to read as follows:

§ 1037.601 General compliance provisions.

* * * * *

(b) Vehicles exempted from the applicable standards of 40 CFR part 86 or part 1036 other than glider vehicles are exempt from the standards of this part without request. Similarly, vehicles other than glider vehicles are exempt without request if the installed engine is exempted from the applicable standards in 40 CFR part 86 or part 1036.

* * * * *

■ 79. Amend § 1037.610 by revising paragraph (f)(2) to read as follows:

§ 1037.610 Vehicles with off-cycle technologies.

* * * * *

(f) * * *

(2) For model years 2021 and later, you may not rely on an approval for model years before 2021. You must separately request our approval before applying an improvement factor or credit under this section for Phase 2 and Phase 3 vehicles, even if we approved an improvement factor or credit for similar vehicle models before model year 2021. Note that Phase 2 and Phase 3 approval may carry over for multiple years.

* * * * *

■ 80. Amend § 1037.615 by revising paragraphs (a) and (d) through (g) to read as follows:

§ 1037.615 Advanced technologies.

(a) This section describes how to calculate emission credits for advanced technologies. You may calculate Phase 1 advanced technology credits through model year 2020 for hybrid vehicles with regenerative braking, vehicles equipped with Rankine-cycle engines, battery electric vehicles, and fuel cell vehicles. You may calculate Phase 2 advanced technology credits through model year 2026 for plug-in hybrid electric vehicles, battery electric vehicles, and fuel cell vehicles. You may calculate Phase 3 advanced technology credits for model year 2027 for fuel cell vehicles. You may not generate credits for Phase 1 engine technologies for which the engines generate credits under 40 CFR part 1036.

* * * * *

(d) For Phase 2 and Phase 3 plug-in hybrid electric vehicles and for fuel cells powered by any fuel other than hydrogen, calculate CO_2 credits using an FEL based on emission measurements from powertrain testing. Phase 2 and Phase 3 advanced technology credits do not apply for hybrid vehicles that have no plug-in capability.

(e) [Reserved]

(f) For battery electric vehicles and for fuel cell electric vehicles, calculate CO_2 credits using an FEL of 0 g/ton-mile. Note that these vehicles are subject to compression-ignition standards for CO_2.

(g) As specified in subpart H of this part, advanced-technology credits generated from Phase 1 vehicles under this section may be used under this part 1037 outside of the averaging set in which they were generated, or they may be used under 40 CFR part 86, subpart S, or 40 CFR part 1036. Advanced-technology credits generated from Phase 2 and Phase 3 vehicles are subject to all the averaging-set restrictions that apply to other emission credits.

* * * * *

§ 1037.620 [Amended]

■ 81. Amend § 1037.620 by removing paragraph (c) and redesignating paragraphs (d) through (f) as paragraphs (c) through (e).

■ 82. Amend § 1037.622 by revising the introductory text and paragraph (d)(5) to read as follows:

§ 1037.622 Shipment of partially complete vehicles to secondary vehicle manufacturers.

This section specifies how manufacturers may introduce partially complete vehicles into U.S. commerce (or in the case of certain custom vehicles, introduce complete vehicles into U.S. commerce for modification by a small manufacturer). The provisions of this section are intended to accommodate normal business practices without compromising the effectiveness of certified emission controls. You may not use the provisions of this section to circumvent the intent of this part. For vehicles subject to both exhaust greenhouse gas and evaporative standards, the provisions of this part apply separately for each certificate.

* * * * *

(d) * * *

(5) The provisions of this paragraph (d) may apply separately for vehicle greenhouse gas, evaporative, and refueling emission standards.

* * * * *

■ 83. Amend§ 1037.630 by revising paragraphs (a)(1)(iii) and (c) to read as follows:

§ 1037.630 Special purpose tractors.

(a) * * *

(1) * * *

(iii) Model year 2020 and earlier tractors with a gross combination weight rating (GCWR) at or above 120,000 pounds. Note that Phase 2 and Phase 3 tractors meeting the definition of ‘‘heavy-haul’’ in § 1037.801 must be certified to the heavy-haul standards in §§ 1037.106 or 1037.670.

* * * * *

(c) *Production limit.* No manufacturer may produce more than 21,000 Phase 1 vehicles under this section in any consecutive three model year period. This means you may not exceed 6,000 in a given model year if the combined total for the previous two years was 15,000. The production limit applies with respect to all Class 7 and Class 8 Phase 1 tractors certified or exempted as vocational tractors. No production limit applies for tractors subject to Phase 2 and Phase 3 standards.

* * * * *

■ 84. Amend § 1037.631 by revising paragraph (a) introductory text to read as follows:

§ 1037.631 Exemption for vocational vehicles intended for off-road use.

* * * * *

(a) *Qualifying criteria.* Vocational vehicles intended for off-road use are exempt without request, subject to the provisions of this section, if they are primarily designed to perform work off-road (such as in oil fields, mining, forests, or construction sites), and they meet at least one of the criteria of paragraph (a)(1) of this section and at least one of the criteria of paragraph (a)(2) of this section. See § 1037.105(h) for alternate Phase 2 and Phase 3 standards that apply for vehicles meeting only one of these sets of criteria.

* * * * *

■ 85. Amend § 1037.635 by revising paragraph (b)(1) to read as follows:

§ 1037.635 Glider kits and glider vehicles.

* * * * *

(b) * * *

(1) The engine must meet the greenhouse gas standards of 40 CFR part 1036 that apply for the engine model year corresponding to the vehicle's date of manufacture. For example, for a vehicle with a 2024 date of manufacture, the engine must meet the greenhouse gas standards that apply for model year 2024.

* * * * *

■ 86. Amend § 1037.640 by revising the introductory text to read as follows:

§ 1037.640 Variable vehicle speed limiters.

This section specifies provisions that apply for vehicle speed limiters (VSLs) that you model under § 1037.520. This does not apply for VSLs that you do not model under § 1037.520. (e) This section is written to apply for tractors; however, you may use good engineering judgment to apply equivalent adjustments for Phase 2 and Phase 3 vocational vehicles with vehicle speed limiters.

* * * * *

■ 87. Amend § 1037.660 by revising paragraphs (a)(1)(iv), (2), and (3) to read as follows:

§ 1037.660 Idle-reduction technologies.

* * * * *

(a) * * *

(1) * * *

(iv) For Phase 2 and Phase 3 tractors, you may identify AES systems as ''adjustable'' if, before delivering to the ultimate purchaser, you enable authorized dealers to modify the vehicle in a way that disables the AES system or makes the threshold inactivity period longer than 300 seconds. However, the vehicle may not be delivered to the ultimate purchaser with the AES system disabled or the threshold inactivity period set longer than 300 seconds. You may allow dealers or repair facilities to make such modifications; this might involve password protection for electronic controls, or special tools that only you provide. Any dealers making any modifications before delivery to the ultimate purchaser must notify you, and you must account for such modifications in your production and ABT reports after the end of the model year. Dealers failing to provide prompt notification are in violation of the tampering prohibition of 40 CFR 1068.101(b)(1). Dealer notifications are deemed to be submissions to EPA. Note that these adjustments may not be made if the AES system was not ''adjustable'' when first delivered to the ultimate purchaser.

* * * * *

(2) *Neutral idle.* Phase 2 and Phase 3 vehicles with hydrokinetic torque converters paired with automatic transmissions qualify for neutral-idle credit in GEM modeling if the transmission reduces torque equivalent to shifting into neutral throughout the interval during which the vehicle's brake pedal is depressed and the vehicle is at a zero-speed condition (beginning within five seconds of the vehicle reaching zero speed with the brake depressed). If a vehicle reduces torque partially but not enough to be equivalent to shifting to neutral, you may use the provisions of § 1037.610(g) to apply for an appropriate partial emission reduction; this may involve A to B testing with the powertrain test procedure in 40 CFR 1036.545 or the spin-loss portion of the transmission efficiency test in § 1037.565.

(3) *Stop-start.* Phase 2 and Phase 3 vocational vehicles qualify for stop-start reduction in GEM modeling if the engine shuts down no more than 5 seconds after the vehicle's brake pedal is depressed when the vehicle is at a zero-speed condition.

* * * * *

■ 88. Amend § 1037.665 by revising paragraphs (a)(1) and (d) to read as follows:

§ 1037.665 Production and in-use tractor testing.

* * * * *

(a) * * *

(1) Each calendar year, select for testing three sleeper cabs and two day cabs certified to Phase 1 or Phase 2 or Phase 3 standards. If we do not identify certain vehicle configurations for your testing, select models that you project to be among your 12 highest-selling vehicle configurations for the given year.

* * * * *

(d) Greenhouse gas standards do not apply with respect to testing under this section. Note however that NTE standards apply for any qualifying operation that occurs during the testing in the same way that it would during any other in-use testing.

■ 89. Amend § 1037.670 by revising paragraph (a) to read as follows:

§ 1037.670 Optional CO_2 emission standards for tractors at or above 120,000 pounds GCWR.

(a) You may certify tractors at or above 120,000 pounds GCWR to the following CO_2 standards instead of the Phase 2 CO_2 standards of § 1037.106:

TABLE 1 OF PARAGRAPH (a) OF § 1037.670—OPTIONAL CO_2 STANDARDS FOR MODEL YEAR 2026 AND EARLIER TRACTORS ABOVE 120,000 POUNDS GCWR

(g/ton-mile) [a]

Subcategory	Model years 2021–2023	Model years 2024–2026
Heavy Class 8 Low-Roof Day Cab	53.5	50.8
Heavy Class 8 Low-Roof Sleeper Cab	47.1	44.5
Heavy Class 8 Mid-Roof Day Cab	55.6	52.8
Heavy Class 8 Mid-Roof Sleeper Cab	49.6	46.9
Heavy Class 8 High-Roof Day Cab	54.5	51.4
Heavy Class 8 High-Roof Sleeper Cab	47.1	44.2

[a] Note that these standards are not directly comparable to the standards for Heavy-Haul Tractors in § 1037.106 because GEM handles aerodynamic performance differently for the two sets of standards.

* * * * *

■ 90. Amend § 1037.701 by revising paragraphs (a) and (h) to read as follows:

§ 1037.701 General provisions.

(a) You may average, bank, and trade emission credits for purposes of certification as described in this subpart and in subpart B of this part to show compliance with the standards of §§ 1037.105 and 1037.106. Note that § 1037.105(h) specifies standards involving limited or no use of emission credits under this subpart. Participation in this program is voluntary.

* * * * *

(h) See § 1037.740 for special credit provisions that apply for credits generated under 40 CFR 86.1819–14(k)(7), 40 CFR 1036.615, or § 1037.615.

* * * * *

■ 91. Revise § 1037.705 to read as follows:

§ 1037.705 Generating and calculating CO_2 emission credits.

(a) The provisions of this section apply separately for calculating CO_2 emission credits for each pollutant.

(b) For each participating family or subfamily, calculate positive or negative emission credits relative to the otherwise applicable emission standard. Calculate positive emission credits for a family or subfamily that has an FEL below the standard. Calculate negative emission credits for a family or subfamily that has an FEL above the standard. Sum your positive and negative credits for the model year before rounding. Round the sum of emission credits to the nearest megagram (Mg), using consistent units with the following equation:

$$\text{Emission credits (Mg)} = (\text{Std} - \text{FEL}) \cdot \text{PL} \cdot \text{Volume} \cdot \text{UL} \cdot 10^{-6}$$

Where:

Std = the emission standard associated with the specific regulatory subcategory (g/ton-mile). For credits generated on all model year 2027 and later vocational vehicles with tailpipe CO_2 emissions deemed to be zero under 40 CFR 1037.150(f), use the emission standard in § 1037.105 that applies for the compression-ignition multi-purpose subcategory for the corresponding vehicle weight class.

FEL = the family emission limit for the vehicle subfamily (g/ton-mile).

PL = standard payload, in tons.

Volume = U.S.-directed production volume of the vehicle subfamily, subject to the exclusions described in paragraph (c) of this section. For example, if you produce three configurations with the same FEL, the subfamily production volume would be the sum of the production volumes for these three configurations.

UL = useful life of the vehicle, in miles, as described in §§ 1037.105 and 1037.106.

(c) Compliance with the requirements of this subpart is determined at the end of the model year by calculating emission credits based on actual production volumes, excluding any of the following engines:

(1) Vehicles that you do not certify to the CO_2 standards of this part because they are permanently exempted under subpart G of this part or under 40 CFR part 1068.

(2) Exported vehicles even if they are certified under this part and labeled accordingly.

(3) Vehicles not subject to the requirements of this part, such as those excluded under § 1037.5.

(4) Any other vehicles, where we indicate elsewhere in this part 1037 that they are not to be included in the calculations of this subpart.

■ 92. Amend § 1037.710 by revising paragraph (c) to read as follows:

§ 1037.710 Averaging.

* * * * *

(c) If you certify a vehicle family to an FEL that exceeds the otherwise applicable standard, you must obtain enough emission credits to offset the vehicle family's deficit by the due date for the final report required in § 1037.730. The emission credits used to address the deficit may come from your other vehicle families that generate emission credits in the same model year (or from later model years as specified in § 1037.745), from emission credits you have banked from previous model years, or from emission credits generated in the same or previous model years that you obtained through trading.

■ 93. Amend § 1037.715 by revising paragraph (a) to read as follows:

§ 1037.715 Banking.

(a) Banking is the retention of surplus emission credits by the manufacturer generating the emission credits for use in future model years for averaging or trading.

* * * * *

■ 94. Amend § 1037.720 by revising paragraph (a) to read as follows:

§ 1037.720 Trading.

(a) Trading is the exchange of emission credits between manufacturers, or the transfer of credits to another party to retire them. You may use traded emission credits for averaging, banking, or further trading transactions. Traded emission credits remain subject to the averaging-set restrictions based on the averaging set in which they were generated.

* * * * *

■ 95. Amend § 1037.730 by revising paragraphs (b)(4) and (f) to read as follows:

§ 1037.730 ABT reports.

* * * * *

(b) * * *

(4) The projected and actual production volumes for the model year for calculating emission credits. If you changed an FEL during the model year, identify the actual production volume associated with each FEL.

* * * * *

(f) * * *

(1) If you notify us by the deadline for submitting the final report that errors mistakenly decreased your balance of emission credits, you may correct the errors and recalculate the balance of emission credits. If you notify us that errors mistakenly decreased your balance of emission credits after the deadline for submitting the final report, you may correct the errors and recalculate the balance of emission credits after applying a 10 percent discount to the credit correction, but only if you notify us within 24 months after the deadline for submitting the final report. If you report a negative balance of emission credits, we may disallow corrections under this paragraph (f)(1).

* * * * *

■ 96. Amend § 1037.740 by:

■ a. Removing paragraphs (a)(4) and (5);

■ b. Redesignating paragraph (a)(6) as paragraph (a)(4); and

■ c. Revising paragraphs (b)(1) introductory text and (b)(2).

The revisions read as follows:

§ 1037.740 Restrictions for using emission credits.

* * * * *

(a) * * *

(4) Note that other separate averaging sets also apply for emission credits not related to this part. For example, vehicles certified to the greenhouse gas standards of 40 CFR part 86, subpart S, comprise a single averaging set. Separate averaging sets also apply for engines under 40 CFR part 1036, including engines used in vehicles subject to this subpart.

(b) * * *

(1) Credits generated from Phase 1 vehicles may be used for any of the averaging sets identified in paragraph (a) of this section; you may also use those credits to demonstrate compliance with the CO_2 emission standards in 40 CFR part 86, subpart S, and 40 CFR part 1036. Similarly, you may use Phase 1 advanced-technology credits generated under 40 CFR 86.1819–14(k)(7) or 40 CFR 1036.615 to demonstrate compliance with the CO_2 standards in this part. The maximum amount of advanced-technology credits generated from Phase 1 vehicles that you may bring into each of the following service class groups is 60,000 Mg per model year:

* * * * *

(2) Credits generated from Phase 2 and Phase 3 vehicles are subject to all the averaging-set restrictions that apply to other emission credits.

* * * * *

■ 97. Amend § 1037.745 by revising paragraph (a) to read as follows:

§ 1037.745 End-of-year CO_2 credit deficits.

* * * * *

(a) Your certificate for a vehicle family for which you do not have sufficient CO_2 credits will not be void if you remedy the deficit with surplus credits within three model years (this applies equally for tractors and vocational vehicles). For example, if you have a credit deficit of 500 Mg for a vehicle family at the end of model year 2015, you must generate (or otherwise obtain) a surplus of at least 500 Mg in that same averaging set by the end of model year 2018.

* * * * *

■ 98. Amend § 1037.801 by:

■ a. Adding a definition of ''Battery electric vehicle'' in alphabetical order;

■ b. Removing the definition of ''Box van'';

■ c. Revising the definition of ''Class'';

■ d. Removing the definitions of ''Container chassis'', ''Electric vehicle'', and ''Flatbed trailer'';

■ e. Adding a definition of ''Fuel cell electric vehicle'' in alphabetical order;

■ f. Revising the definitions of ''Heavy-duty vehicle'' and ''Heavy-haul tractor'';

■ g. Adding a definition of ''Hybrid'' in alphabetical order;

■ h. Removing the definitions of ''Hybrid engine or hybrid powertrain'' and ''Hybrid vehicle'';

■ i. Revising the definitions of ''Low rolling resistance tire'', ''Manufacturer'', and ''Model year'';

■ j. Adding a definition of ''Neat'' in alphabetical order;

■ k. Revising the definitions of ''Phase 1'' and ''Phase 2'';

■ l. Adding definitions of ''Phase 3'' and ''Plug-in hybrid electric vehicle'' in alphabetical order;

■ m. Revising the definitions of ''Preliminary approval'', ''Small manufacturer'', and ''Standard payload'';

■ n. Removing the definitions of ''Standard tractor'' and ''Tank trailer''; and

■ o. Revising the definitions of ''Tire rolling resistance level (TRRL)'', ''Trailer'', ''U.S.-directed production volume'', and ''Vehicle''.

The additions and revision read as follows:

§ 1037.801 Definitions.

* * * * *

Battery electric vehicle means a motor vehicle powered solely by an electric motor where energy for the motor is supplied by one or more batteries that receive power from an external source of electricity. Note that this definition does not include hybrid vehicles or plug-in hybrid electric vehicles.

* * * * *

Class means relating to GVWR classes for vehicles, as follows:

(1) *Class 2b* means relating to heavy-duty motor vehicles at or below 10,000 pounds GVWR.

(2) *Class 3* means relating to heavy-duty motor vehicles above 10,000 pounds GVWR but at or below 14,000 pounds GVWR.

(3) *Class 4* means relating to heavy-duty motor vehicles above 14,000 pounds GVWR but at or below 16,000 pounds GVWR.

(4) *Class 5* means relating to heavy-duty motor vehicles above 16,000 pounds GVWR but at or below 19,500 pounds GVWR.

(5) *Class 6* means relating to heavy-duty motor vehicles above 19,500 pounds GVWR but at or below 26,000 pounds GVWR.

(6) *Class 7* means relating to heavy-duty motor vehicles above 26,000 pounds GVWR but at or below 33,000 pounds GVWR.

(7) *Class 8* means relating to heavy-duty motor vehicles above 33,000 pounds GVWR.

* * * * *

Fuel cell electric vehicle means a motor vehicle powered solely by an electric motor where energy for the motor is supplied by hydrogen fuel cells. Fuel cell electric vehicles may include energy storage from the fuel cells or from regenerative braking in a battery.

* * * * *

Heavy-duty vehicle means any motor vehicle that has a GVWR above 8,500 pounds. An incomplete vehicle is also a heavy-duty vehicle if it has a curb weight above 6,000 pounds or a basic vehicle frontal area greater than 45 square feet.

Heavy-haul tractor means a tractor with GCWR greater than or equal to 120,000 pounds. A heavy-haul tractor is not a vocational tractor in Phase 2 and Phase 3.

* * * * *

Hybrid has the meaning given in 40 CFR 1036.801. Note that a hybrid vehicle is a vehicle with a hybrid powertrain (including a hybrid engine). This includes plug-in hybrid electric vehicles.

* * * * *

Low rolling resistance tire means a tire on a vocational vehicle with a TRRL at or below of 7.7 N/kN, a steer tire on a tractor with a TRRL at or below 7.7 N/kN, a drive tire on a tractor with a TRRL at or below 8.1 N/kN.

* * * * *

Manufacturer has the meaning given in section 216(1) of the Act. In general, this term includes any person who manufactures or assembles a vehicle (including an incomplete vehicle) for sale in the United States or otherwise introduces a new motor vehicle into commerce in the United States. This includes importers who import vehicles for resale, entities that manufacture glider kits, and entities that assemble glider vehicles.

* * * * *

Model year means one of the following for compliance with this part. Note that manufacturers may have other model year designations for the same vehicle for compliance with other requirements or for other purposes:

(1) For tractors and vocational vehicles with a date of manufacture on or after January 1, 2021, *model year* means the manufacturer's annual new model production period based on the vehicle's date of manufacture, where the model year is the calendar year corresponding to the date of manufacture, except as follows:

(i) The vehicle's model year may be designated as the year before the calendar year corresponding to the date of manufacture if the engine's model year is also from an earlier year. You may ask us to extend your prior model year certificate to include such vehicles. Note that § 1037.601(a)(2) limits the extent to which vehicle manufacturers may install engines built in earlier calendar years.

(ii) The vehicle's model year may be designated as the year after the calendar year corresponding to the vehicle's date of manufacture. For example, a manufacturer may produce a new vehicle by installing the engine in December 2023 and designating it as a model year 2024 vehicle.

(2) For Phase 1 tractors and vocational vehicles with a date of manufacture before January 1, 2021, *model year* means the manufacturer's annual new model production period, except as restricted under this definition and 40 CFR part 85, subpart X. It must include January 1 of the calendar year for which the model year is named, may not begin before January 2 of the previous calendar year, and it must end by December 31 of the named calendar year. The model year may be set to match the calendar year corresponding to the date of manufacture.

(i) The manufacturer who holds the certificate of conformity for the vehicle must assign the model year based on the date when its manufacturing operations are completed relative to its annual model year period. In unusual circumstances where completion of your assembly is delayed, we may allow you to assign a model year one year earlier, provided it does not affect which regulatory requirements will apply.

(ii) Unless a vehicle is being shipped to a secondary vehicle manufacturer that will hold the certificate of conformity, the model year must be assigned prior to introduction of the vehicle into U.S. commerce. The certifying manufacturer must redesignate the model year if it does not complete its manufacturing operations within the originally identified model year. A vehicle introduced into U.S. commerce without a model year is deemed to have a model year equal to the calendar year of its introduction into U.S. commerce unless the certifying manufacturer assigns a later date.

* * * * *

Neat has the meaning given in 40 CFR 1065.1001.

* * * * *

Phase 1 means relating to the Phase 1 standards specified in §§ 1037.105 and 1037.106. For example, a vehicle subject to the Phase 1 standards is a Phase 1 vehicle.

Phase 2 means relating to the Phase 2 standards specified in §§ 1037.105 and 1037.106.

Phase 3 means relating to the Phase 3 standards specified in §§ 1037.105 and 1037.106.

* * * * *

Plug-in hybrid electric vehicle means a hybrid vehicle that has the capability to charge one or more batteries from an external source of electricity while the vehicle is parked.

* * * * *

Preliminary approval means approval granted by an authorized EPA representative prior to submission of an application for certification, consistent with the provisions of § 1037.210.

* * * * *

Small manufacturer means a manufacturer meeting the small business criteria specified in 13 CFR 121.201 for heavy-duty truck manufacturing (NAICS code 336120). The employee limit applies to the total number employees for all affiliated companies (as defined in 40 CFR 1068.30).

* * * * *

Standard payload means the payload assumed for each vehicle, in tons, for modeling and calculating emission credits, as follows:

(1) For vocational vehicles:

(i) 2.85 tons for Light HDV.

(ii) 5.6 tons for Medium HDV.

(iii) 7.5 tons for Heavy HDV.

(2) For tractors:

(i) 12.5 tons for Class 7.

(ii) 19 tons for Class 8, other than heavy-haul tractors.

(iii) 43 tons for heavy-haul tractors.

* * * * *

Tire rolling resistance level (TRRL) means a value with units of N/kN that represents the rolling resistance of a tire configuration. TRRLs are used as modeling inputs under § 1037.520. Note that a manufacturer may use the measured value for a tire configuration's coefficient of rolling resistance, or assign some higher value.

* * * * *

Trailer means a piece of equipment designed for carrying cargo and for being drawn by a tractor when coupled to the tractor's fifth wheel.

* * * * *

U.S.-directed production volume means the number of vehicle units, subject to the requirements of this part, produced by a manufacturer for which the manufacturer has a reasonable assurance that sale was or will be made to ultimate purchasers in the United States. Note that this includes vehicles certified to state emission standards that are different than the emission standards in this part.

* * * * *

Vehicle means equipment intended for use on highways that meets at least one of the criteria of paragraph (1) of this definition, as follows:

(1) The following equipment are vehicles:

(i) A piece of equipment that is intended for self-propelled use on highways becomes a vehicle when it includes at least an engine, a transmission, and a frame. (**Note:** For purposes of this definition, any electrical, mechanical, and/or hydraulic devices attached to engines for the purpose of powering wheels are considered to be transmissions.)

(ii) A piece of equipment that is intended for self-propelled use on highways becomes a vehicle when it includes a passenger compartment attached to a frame with one or more axles.

(2) Vehicles may be complete or incomplete vehicles as follows:

(i) A *complete vehicle* is a functioning vehicle that has the primary load carrying device or container (or equivalent equipment) attached when it is first sold as a vehicle. Examples of equivalent equipment would include fifth wheel trailer hitches, firefighting equipment, and utility booms.

(ii) An *incomplete vehicle* is a vehicle that is not a complete vehicle. Incomplete vehicles may also be cab-complete vehicles. This may include vehicles sold to secondary vehicle manufacturers.

(iii) You may ask us to allow you to certify a vehicle as incomplete if you manufacture the engines and sell the unassembled chassis components, as long as you do not produce and sell the body components necessary to complete the vehicle.

* * * * *

■ 99. In § 1037.805 amend Table 5 in paragraph (e) by adding an entry for "GHG" in alphabetical order and removing the entry for "PHEV" to read as follows:

§ 1037.805 Symbols, abbreviations, and acronyms.

* * * * *

(e) * * *

TABLE 5 TO PARAGRAPH (e) OF § 1037.805—OTHER ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
* * *	* *
GHG	Greenhouse gas.
* * *	* *

* * * * *

■ 100. Amend § 1037.810 by:

■ a. Removing paragraph (c)(9);

■ b. Redesignating paragraph (c)(10) as paragraph (c)(9);

■ c. Revising paragraph (d)(4);

■ d. Removing the text "bb" in paragraphs (d)(2), (3), and (5) and add, in their place, the text "x"; and

■ e. Adding paragraph (e).

The revision and addition read as follows:

§ 1037.810 Incorporation by reference.

* * * * *

(d) * * *

(4) Greenhouse gas Emissions Model (GEM) Phase 2, Version 4.0, April 2022 ("GEM Phase 2, Version 4.0"); IBR approved for §§ 1037.150(x); 1037.520.

* * * * *

(e) UN Economic Commission for Europe, Information Service, Palais des Nations, CH–1211 Geneva 10, Switzerland; *unece_info@un.org*; *www.unece.org*:

(1) Addendum 22: United Nations Global Technical Regulation, No. 22, United Nations Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles, Adopted April 14, 2022, ("GTR No. 22"); IBR approved for § 1037.115(f).

(2) [Reserved]

■ 101. Revise appendix C of part 1037 to read as follows:

Appendix C of Part 1037—Emission Control Identifiers

This appendix identifies abbreviations for emission control information labels, as required under § 1037.135.

Vehicle Speed Limiters
- —VSL—Vehicle speed limiter
- —VSLS—''Soft-top'' vehicle speed limiter
- —VSLE—Expiring vehicle speed limiter
- —VSLD—Vehicle speed limiter with both ''soft-top'' and expiration

Idle Reduction Technology
- —IRT5—Engine shutoff after 5 minutes or less of idling
- —IRTE—Expiring engine shutoff

Tires
- —LRRA—Low rolling resistance tires (all)
- —LRRD—Low rolling resistance tires (drive)
- —LRRS—Low rolling resistance tires (steer)

Aerodynamic Components
- —ATS—Aerodynamic side skirt and/or fuel tank fairing
- —ARF—Aerodynamic roof fairing
- —ARFR—Adjustable height aerodynamic roof fairing
- —TGR—Gap reducing tractor fairing (tractor to trailer gap)

Other Components
- —ADVH—Vehicle includes advanced hybrid technology components
- —ADVO—Vehicle includes other advanced-technology components (*i.e.,* non-hybrid system)
- —INV—Vehicle includes innovative (off-cycle) technology components
- —ATI—Automatic tire inflation system
- —TPMS—Tire pressure monitoring system

■ 102. Amend appendix D of part 1037 by revising the appendix heading to read as follows:

Appendix D of Part 1037—Heavy-Duty Grade Profile for Phase 2 and Phase 3 Steady-State Test Cycles

* * * * *

PART 1054—CONTROL OF EMISSIONS FROM NEW, SMALL NONROAD SPARK-IGNITION ENGINES AND EQUIPMENT

■ 103. The authority citation for part 1054 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

■ 104. Amend § 1054.501 by revising paragraph (b)(7) to read as follows:

§ 1054.501 How do I run a valid emission test?

* * * * *

(b) * * *

(7) Determine your test fuel's carbon mass fraction, w_c, using a calculation based on fuel properties as described in 40 CFR 1065.655(d); however, you must measure fuel properties for α and β rather than using the default values specified in 40 CFR 1065.655(e).

* * * * *

PART 1065—ENGINE-TESTING PROCEDURES

■ 105. The authority citation for part 1065 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

■ 106. Amend § 1065.210 by revising paragraph (a) to read as follows:

§ 1065.210 Work input and output sensors.

(a) *Application.* Use instruments as specified in this section to measure work inputs and outputs during engine operation. We recommend that you use sensors, transducers, and meters that meet the specifications in Table 1 of § 1065.205. Note that your overall systems for measuring work inputs and outputs must meet the linearity verifications in § 1065.307. We recommend that you measure work inputs and outputs where they cross the system boundary as shown in Figure 1 of this section. The system boundary is different for air-cooled engines than for liquid-cooled engines. If you choose to measure work before or after a work conversion, relative to the system boundary, use good engineering judgment to estimate any work-conversion losses in a way that avoids overestimation of total work. For example, if it is impractical to instrument the shaft of an exhaust turbine generating electrical work, you may decide to measure its converted electrical work. As another example, your engine may include an engine exhaust electrical heater where the heater is powered by an external power source. In these cases, assume an electrical generator efficiency of 0.67 (η=0.67), which is a conservative estimate of the efficiency and could over-estimate brake-specific emissions. As another example, you may decide to measure the tractive (*i.e.,* electrical output) power of a locomotive, rather than the brake power of the locomotive engine. In these cases, divide the electrical work by accurate values of electrical generator efficiency (η<1), or assume an efficiency of 1 (η=1), which would over-estimate brake-specific emissions. For the example of using locomotive tractive power with a generator efficiency of 1 (η=1), this means using the tractive power as the brake power in emission calculations. Do not underestimate any work conversion efficiencies for any components outside the system boundary that do not return work into the system boundary. And do not overestimate any work conversion efficiencies for components outside the system boundary that do return work into the system boundary. In all cases, ensure that you are able to accurately demonstrate compliance with the applicable standards in this chapter. Figure 1 follows:

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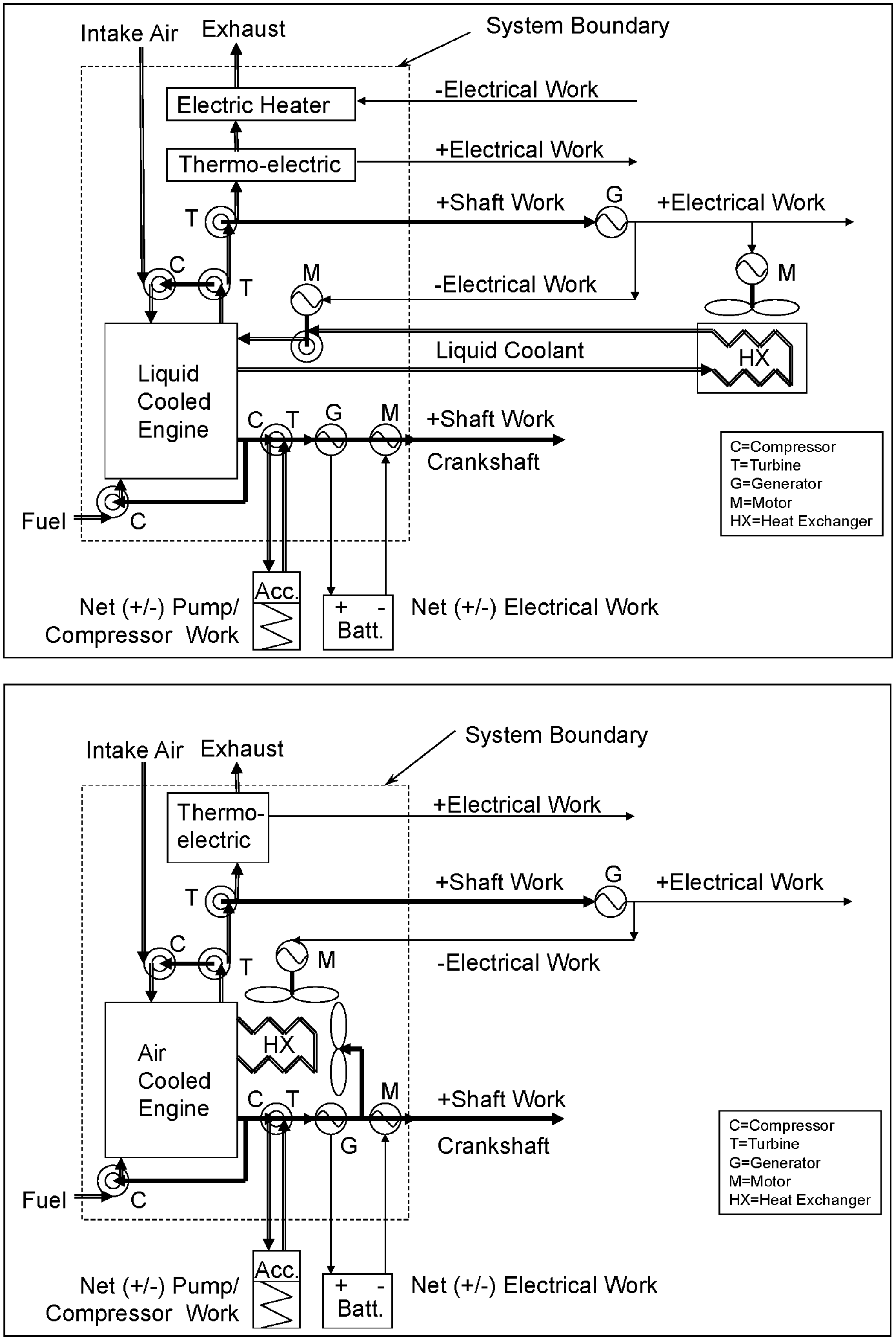
Figure 1 to paragraph (a) of § 1065.210: Work Inputs, Outputs, and System Boundaries



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* * * * *

■ 107. Amend subpart C by adding a new center header ''H_2 AND H_2O MEASUREMENTS'' after § 1065.250 and adding §§ 1065.255 and 1065.257 under the new center header to read as follows:

H_2 and H_2O MEASUREMENTS

§ 1065.255 H_2 measurement devices.

(a) *General component requirements.* We recommend that you use an analyzer that meets the specifications in Table 1 of § 1065.205. Note that your system must meet the linearity verification in § 1065.307.

(b) *Instrument types.* You may use any of the following analyzers to measure H2:

(1) Magnetic sector mass spectrometer.

(2) Raman spectrometer.

(c) *Interference verification.* Certain species can positively interfere with magnetic sector mass spectroscopy and raman spectroscopy by causing a response similar to H_2. When running the interference verification for these analyzers, use good engineering judgment to determine interference species. Note that for raman spectroscopy interference species are dependent on the H_2 infrared absorption band chosen by the instrument manufacturer. For each analyzer determine the H_2 infrared absorption band. For each H_2 infrared adsorption band, determine the interference species to use in the verification. Use the interference species specified by the instrument manufacturer or use good engineering judgment to determine the interference species.

§ 1065.257 Fourier transform infrared analyzer for H_2O measurement.

(a) *Component requirements.* We recommend that you use an FTIR analyzer that meets the specifications in Table 1 of § 1065.205. Note that your system must meet the linearity verification in § 1065.307 using a water generation system that meets the requirements of § 1065.750(a)(6). Use appropriate analytical procedures for interpretation of infrared spectra. For example, EPA Test Method 320 (see § 1065.266(b)) and ASTM D6348 (incorporated by reference, see § 1065.1010) are considered valid methods for spectral interpretation. You must use heated FTIR analyzers that maintain all surfaces that are exposed to emissions at a temperature of (110 to 202) °C.

(b) *Interference verification.* Certain species can interfere with FTIR analyzers by causing a response similar to the water.

(1) Perform CO_2 interference verification for FTIR analyzers using the procedures of § 1065.357 as CO_2 gas can positively interfere with FTIR analyzers by causing a response similar to H_2O.

(2) Use good engineering judgment to determine other interference species for FTIR analyzers. Possible interference species include, but are not limited to, CO, NO, C_2H_4, and C_7H_8. Perform interference verification using the procedures of § 1065.357, replacing occurances of CO_2 (except for § 1065.357(e)(1)) with the targeted interferent specie. Note that interference species, with the exception of CO_2, are dependent on the H_2O infrared absorption band chosen by the instrument manufacturer. For each analyzer determine the H_2O infrared absorption band. For each H_2O infrared absorption band, use good engineering judgment to determine interference species to use in the verification.

■ 108. Amend § 1065.266 by revising paragraph (e) as follows:

§ 1065.266 Fourier transform infrared analyzer.

* * * * *

(e) *Interference verification.* Perform interference verification for FTIR analyzers using the procedures of § 1065.366. Certain species can interfere with FTIR analyzers by causing a response similar to the hydrocarbon species of interest. When running the interference verification for these analyzers, use interference species as follows:

(1) The interference species for CH_4 are CO_2, H_2O, and C_2H_6.

(2) The interference species for C_2H_6 are CO_2, H_2O, and CH_4.

(3) The interference species for other measured hydrocarbon species are CO_2, H_2O, CH_4, and C_2H_6.

■ 109. Revise the undesignated center heading preceding § 1065.270 to read as follows:

NO_X, N_2O, and NH_3 MEASUREMENTS

■ 110. Add § 1065.277 under the undesignated and newly revised center header ''NO_X, N_2O, and NH_3 Measurements'' to read as follows:

§ 1065.277 NH_3 measurement devices.

(a) *General component requirements.* We recommend that you use an analyzer that meets the specifications in Table 1 of § 1065.205. Note that your system must meet the linearity verification in § 1065.307.

(b) *Instrument types.* You may use any of the following analyzers to measure NH_3:

(1) Nondispersive ultravoilet (NDUV) analyzer.

(2) Fourier transform infrared (FTIR) analyzer. Use appropriate analytical procedures for interpretation of infrared spectra. For example, EPA Test Method 320 (see § 1065.266(b)) and ASTM D6348 (incorporated by reference, see § 1065.1010) are considered valid methods for spectral interpretation.

(3) Laser infrared analyzer. Examples of laser infrared analyzers are pulsed-mode high-resolution narrow band mid-infrared analyzers, modulated continuous wave high-resolution narrow band mid-infrared analyzers, and modulated continuous wave high-resolution near-infrared analyzers. A quantum cascade laser, for example, can emit coherent light in the mid-infrared region where nitrogen compounds including NH_3 have strong absorption.

(c) *Sampling system.* NH_3 has a tendency to adsorb to surfaces that it encounters. Minimize NH_3 losses and sampling artifacts by using sampling system components (sample lines, prefilters and valves) made of stainless steel or PTFE heated to (110 to 202) °C. If you heat these components to temperatures ≥130 °C, use good engineering judgement to minimize NH_3 formation due to thermal decomposition and hydrolysis of any DEF present in the sample gas. Use a sample line that is as short as practically possible.

(d) *Interference verification.* Certain species can positively interfere with NDUV, FTIR, and laser infrared analyzers by causing a response similar to NH_3. Perform interference verification for NDUV analyzers using the procedures of § 1065.372, replacing occurances of NO_X with NH_3 and interference species with those listed in paragraph (d)(1) of this section. NDUV analyzers must have combined interference that is within (0.0±2.0) µmol/mol. Perform interference verification for FTIR and laser infrared analyzers using the procedures of § 1065.377. When running the interference verification for these analyzers, use interference species as follows:

(1) For NDUV analyzers, use SO_2 and H_2O as the interference species.

(2) Use good engineering judgment to determine interference species for FTIR and laser infrared analyzers. Note that interference species, with the exception of H_2O, are dependent on the NH_3 infrared absorption band chosen by the instrument manufacturer. For each analyzer determine the NH_3 infrared absorption band. For each NH_3 infrared absorption band, use the interference gases specified by the instrument manufacturer or use good engineering judgment to determine the interference gases to use in the verification.

■ 111. Amend § 1065.315 by revising paragraphs (a)(2) and (3) to read as follows:

§ 1065.315 Pressure, temperature, and dewpoint calibration.

(a) * * *

(2) *Temperature.* We recommend digital dry-block or stirred-liquid temperature calibrators, with data logging capabilities to minimize transcription errors. We recommend using calibration reference quantities that are NIST-traceable within ±0.5% uncertainty of absolute temperature. You may perform linearity verification for temperature measurement systems with thermocouples, RTDs, and thermistors by removing the sensor from the system and using a simulator in its place. Use a NIST-traceable simulator that is independently calibrated and, as appropriate, cold-junction compensated. The simulator uncertainty scaled to absolute temperature must be less than 0.5% of T_{max}. If you use this option, you must use sensors that the supplier states are accurate to better than 0.5% of T_{max} compared with their standard calibration curve.

(3) *Dewpoint.* We recommend a minimum of three different temperature-equilibrated and temperature-monitored calibration salt solutions in containers that seal completely around the dewpoint sensor. We recommend using calibration reference quantities that are NIST-traceable within ±0.5% uncertainty of absolute dewpoint temperature.

* * * * *

■ 112. Amend subpart D by adding a new center header ‘‘H_2O MEASUREMENTS’’ after § 1065.355 and adding §§ 1065.357 under the new center header to read as follows:

H_2O MEASUREMENTS

§ 1065.357 CO_2 interference verification for H_2O FTIR analyzers.

(a) *Scope and frequency.* If you measure H_2O using an FTIR analyzer, verify the amount of CO_2 interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles.* CO_2 can interfere with an FTIR analyzer’s response to H_2O. If the FTIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) *System requirements.* An H_2O FTIR analyzer must have a CO_2 interference that is within (0.0±0.4) mmol/mol, though we strongly recommend a lower interference that is within (0.0±0.2) mmol/mol.

(d) *Procedure.* Perform the interference verification as follows:

(1) Start, operate, zero, and span the H_2O FTIR analyzer as you would before an emission test.

(2) Use a CO_2 span gas that meets the specifications of § 1065.750 and a concentration that is approximately the maximum CO_2 concentration expected during emission testing.

(3) Introduce the CO_2 test gas into the sample system.

(4) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(5) While the analyzer measures the sample’s concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of this data. The analyzer meets the interference verification if this value is within (0.0 ± 0.4) mmol/mol.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification for CO_2 for engines operating on fuels other than carbon-containing fuels.

(2) You may omit this verification if you can show by engineering analysis that for your H_2O sampling system and your emission-calculation procedures, the CO_2 interference for your H_2O FTIR analyzer always affects your brake-specific emission results within ±0.5% of each of the applicable standards in this chapter. This specification also applies for vehicle testing, except that it relates to emission results in g/mile or g/kilometer.

(3) You may use an H_2O FTIR analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

■ 113. Amend § 1065.360 by revising paragraphs (a)(4), (b), (d) introductory text, and (d)(12) to read as follows:

§ 1065.360 FID optimization and verification.

(a) * * *

(4) You may determine the methane (CH_4) and ethane (C_2H_6) response factors as a function of the molar water concentration in the raw or diluted exhaust. If you choose the option in this paragraph (a)(4), generate and verify the humidity level (or fraction) as described in § 1065.365(g).

(b) *Calibration.* Use good engineering judgment to develop a calibration procedure, such as one based on the FID-analyzer manufacturer’s instructions and recommended frequency for calibrating the FID. Alternately, you may remove system components for off-site calibration. For a FID that measures THC, calibrate using C_3H_8 calibration gases that meet the specifications of § 1065.750. For a FID that measures CH_4, calibrate using CH_4 calibration gases that meet the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O_2 expected during testing. If you use a FID to measure CH_4 downstream of a nonmethane cutter (NMC), you may calibrate that FID using CH_4 calibration gases with the NMC. Regardless of the calibration gas composition, calibrate on a carbon number basis of one (C_1). For example, if you use a C_3H_8 span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol. As another example, if you use a CH_4 span gas with a concentration of 200 µmol/mol, span the FID to respond with a value of 200 µmol/mol.

* * * * *

(d) *THC FID CH_4 response factor determination.* This procedure is only for FID analyzers that measure THC. Since FID analyzers generally have a different response to CH_4 versus C_3H_8, determine the THC–FID analyzer’s CH_4 response factor, $RF_{\mathrm{CH4[THC-FID]}}$, after FID optimization. Use the most recent $RF_{\mathrm{CH4[THC-FID]}}$ measured according to this section in the calculations for HC determination described in § 1065.660 to compensate for CH_4 response. Determine $RF_{\mathrm{CH4[THC-FID]}}$ as follows, noting that you do not determine $RF_{\mathrm{CH4[THC-FID]}}$ for FIDs that are calibrated and spanned using CH_4 with an NMC:

* * * * *

(12) You may determine the response factor as a function of molar water concentration and use this response factor to account for the CH_4 response for NMHC determination described in § 1065.660(b)(2)(iii). If you use this option, humidify the CH_4 span gas as described in § 1065.365(g) and repeat the steps in paragraphs (d)(7) through (9) of this section until measurements are complete for each setpoint in the selected range. Divide each mean measured CH_4 concentration by the recorded span concentration of the CH_4 calibration gas, adjusted for water content, to determine the FID analyzer’s CH_4 response factor, $RF_{\mathrm{CH4[THC-FID]}}$. Use the CH_4 response factors at the different setpoints to create a functional relationship between response factor and molar water concentration,

downstream of the last sample dryer if any sample dryers are present. Use this functional relationship to determine the response factor during an emission test.

* * * * *

■ 114. Revise § 1065.365 to read as follows:

§ 1065.365 Nonmethane cutter penetration fractions and NMC FID response factors.

(a) *Scope and frequency.* If you use a FID analyzer and a nonmethane cutter (NMC) to measure methane (CH_4), determine the NMC's penetration fractions of CH_4, PF_{CH4}, and ethane (C_2H_6), PF_{C2H6}. As detailed in this section, these penetration fractions may be determined as a combination of NMC penetration fractions and FID analyzer response factors, depending on your particular NMC and FID analyzer configuration. Perform this verification after installing the NMC. Repeat this verification within 185 days of testing to verify that the catalytic activity of the NMC has not deteriorated. Note that because NMCs can deteriorate rapidly and without warning if they are operated outside of certain ranges of gas concentrations and outside of certain temperature ranges, good engineering judgment may dictate that you determine an NMC's penetration fractions more frequently.

(b) *Measurement principles.* A NMC is a heated catalyst that removes nonmethane hydrocarbons from an exhaust sample stream before the FID analyzer measures the remaining hydrocarbon concentration. An ideal NMC would have a CH_4 penetration fraction, PF_{CH4}, of 1.000, and the penetration fraction for all other nonmethane hydrocarbons would be 0.000, as represented by PF_{C2H6}. The emission calculations in § 1065.660 use the measured values from this verification to account for less than ideal NMC performance.

(c) *System requirements.* We do not limit NMC penetration fractions to a certain range. However, we recommend that you optimize an NMC by adjusting its temperature to achieve a PF_{C2H6} <0.02, as determined by paragraphs (d), (e), or (f) of this section, as applicable, using dry gases. If we use an NMC for testing, it will meet this recommendation. If adjusting NMC temperature does not result in achieving this recommendation, we recommend that you replace the catalyst material. Use the most recently determined penetration values from this section to calculate HC emissions according to § 1065.660 and § 1065.665 as applicable.

(d) *Procedure for a FID calibrated with the NMC.* The method described in this paragraph (d) is recommended over the procedures specified in paragraphs (e) and (f) of this section and required for any gaseous-fueled engine, including dual-fuel and flexible-fuel engines. For any gaseous-fueled engine, including dual-fuel and flexible-fuel engines, you must determine the combined CH_4 response factor and penetration fraction, $RFPF_{CH4[NMC-FID]}$, and combined C_2H_6 response factor and penetration fraction, $RFPF_{C2H6[NMC-FID]}$, as a function of the molar water concentration in the raw or diluted exhaust as described in paragraphs (d)(9) and (g) of this section. Note that $RFPF_{CH4[NMC-FID]}$ is set equal to 1.0 only for zero molar water concentration. For any other engine you may use the same procedure, or you may set $RFPF_{CH4[NMC-FID]}$ equal to 1.0 and determine $RFPF_{C2H6[NMC-FID]}$ at zero molar water concentration. Generate and verify the humidity generation as described in paragraph (g) of this section.

(1) Select CH_4 and C_2H_6 analytical gas mixtures and ensure that both mixtures meet the specifications of § 1065.750. Select a CH_4 concentration that you would use for spanning the FID during emission testing and select a C_2H_6 concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to the THC analyzer's span value. For CH_4 analyzers with multiple ranges, perform this procedure on the highest range used for emission testing.

(2) Start, operate, and optimize the NMC according to the manufacturer's instructions, including any temperature optimization.

(3) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(4) Start and operate the FID analyzer according to the manufacturer's instructions.

(5) Zero and span the FID with the NMC as you would during emission testing. Span the FID through the NMC by using CH_4 span gas.

(6) Introduce the C_2H_6 analytical gas mixture upstream of the NMC. Use good engineering judgment to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.

(7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the NMC and to account for the analyzer's response.

(8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.

(9) Divide the mean C_2H_6 concentration by the reference concentration of C_2H_6, converted to a C_1 basis and adjusted for water content, if necessary. The result is the combined C_2H_6 response factor and penetration fraction, $RFPF_{C2H6[NMC-FID]}$. Use this combined C_2H_6 response factor and C_2H_6 penetration fraction and the product of the CH_4 response factor and CH_4 penetration fraction, $RFPF_{CH4[NMC-FID]}$, set to 1.0 in emission calculations according to § 1065.660(b)(2)(i) or (d)(1)(i) or § 1065.665, as applicable. If you are generating mixtures as a function of molar water concentration, follow the guidance in paragraph (g) of this section and repeat the steps in paragraphs (d)(6) to (9) of this section until all setpoints have been completed. Use $RFPF_{C2H6[NMC-FID]}$ at the different setpoints to create a functional relationship between $RFPF_{C2H6[NMC-FID]}$ and molar water concentration, downstream of the last sample dryer if any sample dryers are present. Use this functional relationship to determine the combined response factor and penetration fraction during the emission test.

(10) If required by this paragraph (d), repeat the steps in paragraphs (d)(6) through (9) of this section, but with the CH_4 analytical gas mixture instead of C_2H_6 and determine $RFPF_{CH4[NMC-FID]}$ instead.

(11) Use this combined C_2H_6 response factor and penetration fraction, $RFPF_{C2H6[NMC-FID]}$, and this combined CH_4 response factor and penetration fraction, $RFPF_{CH4[NMC-FID]}$, in emission calculations according to §§ 1065.660(b)(2)(i) and 1065.660(d)(1)(i).

(e) *Procedure for a FID calibrated with propane, bypassing the NMC.* If you use a single FID for THC and CH_4 determination with an NMC that is calibrated with propane, C_3H_8, by bypassing the NMC, determine its penetration fractions, $PF_{C2H6[NMC-FID]}$ and $PF_{CH4[NMC-FID]}$, as follows:

(1) Select CH_4 and C_2H_6 analytical gas mixtures and ensure that both mixtures meet the specifications of § 1065.750. Select a CH_4 concentration that you would use for spanning the FID during emission testing and select a C_2H_6 concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard and the C_2H_6 concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or equal to the THC analyzer's span value. For CH_4 analyzers with multiple ranges, perform this procedure on the highest range used for emission testing.

(2) Start and operate the NMC according to the manufacturer's

instructions, including any temperature optimization.

(3) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(4) Start and operate the FID analyzer according to the manufacturer's instructions.

(5) Zero and span the FID as you would during emission testing. Span the FID by bypassing the NMC and by using C_3H_8 span gas. Note that you must span the FID on a C_1 basis. For example, if your span gas has a propane reference value of 100 µmol/mol, the correct FID response to that span gas is 300 µmol/mol because there are three carbon atoms per C_3H_8 molecule.

(6) Introduce the C_2H_6 analytical gas mixture upstream of the NMC. Use good engineering judgment to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.

(7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the NMC and to account for the analyzer's response.

(8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.

(9) Reroute the flow path to bypass the NMC, introduce the C_2H_6 analytical gas mixture, and repeat the steps in paragraphs (e)(7) through (8) of this section.

(10) Divide the mean C_2H_6 concentration measured through the NMC by the mean C_2H_6 concentration measured after bypassing the NMC. The result is the C_2H_6 penetration fraction, $PF_{\mathrm{C2H6[NMC-FID]}}$. Use this penetration fraction according to § 1065.660(b)(2)(ii), § 1065.660(d)(1)(ii), or § 1065.665, as applicable.

(11) Repeat the steps in paragraphs (e)(6) through (10) of this section, but with the CH_4 analytical gas mixture instead of C_2H_6. The result will be the CH_4 penetration fraction, $PF_{\mathrm{CH4[NMC-FID]}}$. Use this penetration fraction according to § 1065.660(b)(2)(ii) or § 1065.665, as applicable.

(f) *Procedure for a FID calibrated with CH_4, bypassing the NMC.* If you use a FID with an NMC that is calibrated with CH_4, by bypassing the NMC, determine its combined C_2H_6 response factor and penetration fraction, $RFPF_{\mathrm{C2H6[NMC-FID]}}$, as well as its CH_4 penetration fraction, $PF_{\mathrm{CH4[NMC-FID]}}$, as follows:

(1) Select CH_4 and C_2H_6 analytical gas mixtures and ensure that both mixtures meet the specifications of § 1065.750. Select a CH_4 concentration that you would use for spanning the FID during emission testing and select a C_2H_6 concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to the THC analyzer's span value. For CH_4 analyzers with multiple ranges, perform this procedure on the highest range used for emission testing.

(2) Start and operate the NMC according to the manufacturer's instructions, including any temperature optimization.

(3) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(4) Start and operate the FID analyzer according to the manufacturer's instructions.

(5) Zero and span the FID as you would during emission testing. Span the FID by bypassing the NMC and by using CH_4 span gas.

(6) Introduce the C_2H_6 analytical gas mixture upstream of the NMC. Use good engineering judgment to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.

(7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the NMC and to account for the analyzer's response.

(8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.

(9) Divide the mean C_2H_6 concentration by the reference concentration of C_2H_6, converted to a C_1 basis. The result is the combined C_2H_6 response factor and C_2H_6 penetration fraction, $RFPF_{\mathrm{C2H6[NMC-FID]}}$. Use this combined C_2H_6 response factor and penetration fraction according to § 1065.660(b)(2)(iii) or (d)(1)(iii) or § 1065.665, as applicable.

(10) Introduce the CH_4 analytical gas mixture upstream of the NMC. Use good engineering judgment to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.

(11) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the NMC and to account for the analyzer's response.

(12) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.

(13) Reroute the flow path to bypass the NMC, introduce the CH_4 analytical gas mixture, and repeat the steps in paragraphs (e)(11) and (12) of this section.

(14) Divide the mean CH_4 concentration measured through the NMC by the mean CH_4 concentration measured after bypassing the NMC. The result is the CH_4 penetration fraction, $PF_{\mathrm{CH4[NMC-FID]}}$. Use this CH_4 penetration fraction according to § 1065.660(b)(2)(iii) or (d)(1)(iii) or § 1065.665, as applicable.

(g) *Test gas humidification.* If you are generating gas mixtures as a function of the molar water concentration in the raw or diluted exhaust according to paragraph (d) of this section, then create a humidified test gas by bubbling the analytical gas mixture that meets the specifications in § 1065.750 through distilled H_2O in a sealed vessel or use a device that introduces distilled H_2O as vapor into a controlled gas flow. Determine H_2O concentration as an average value over intervals of at least 30 seconds. We recommend that you design your system so the wall temperatures in the transfer lines, fittings, and valves from the point where the mole fraction of H_2O in the humidified calibration gas, x_{H2Oref}, is measured to the analyzer are at least 5 °C above the local calibration gas dewpoint. Verify the humidity generator's uncertainty upon initial installation, within 370 days before verifying response factors and penetration fractions, and after major maintenance. Use the uncertainties from the calibration of the humidity generator's measurements and follow NIST Technical Note 1297 (incorporated by reference, see § 1065.1010) to verify that the amount of H_2O in x_{H2Oref} is determined within ±3% uncertainty, $U_{x\mathrm{H2O}}$, for one of the options described in § 1065.750(a)(6)(i) or (ii). If the humidity generator requires assembly before use, after assembly follow the instrument manufacturer's instructions to check for leaks.

(1) If the sample does not pass through a dryer during emission testing, generate at least five different H_2O concentrations that cover the range from less than the minimum expected to greater than the maximum expected water concentration during testing. Use good engineering judgment to determine the target concentrations.

(2) If the sample passes through a dryer during emission testing, humidify your test gas to an H_2O level at or above the level determined in § 1065.145(e)(2) for that dryer and determine a single wet analyzer response to the dehumidified sample.

■ 115. Amend § 1065.366 by revising paragraph (b) to read as follows:

§ 1065.366 Interference verification for FTIR analyzers.

* * * * *

(b) *Measurement principles.* Certain species can interfere with analyzers by causing a response similar to the target analyte. If the analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.

* * * * *

■ 116. Amend § 1065.375 by revising paragraphs (b) and (d)(9) to read as follows:

§ 1065.375 Interference verification for N_2O analyzers.

* * * * *

(b) *Measurement principles.* Certain species can positively interfere with analyzers by causing a response similar to N_2O. If the analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.

* * * * *

(d) * * *

(9) You may also run interference procedures separately for individual interference species. If the concentration of the interference species used are higher than the maximum levels expected during testing, you may scale down each observed interference value (the arithmetic mean of 30 second data described in paragraph (d)(7) of this section) by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. You may run separate interference concentrations of H_2O (down to 0.025 mol/mol H_2O content) that are lower than the maximum levels expected during testing, but you must scale up the observed H_2O interference by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the scaled interference values must meet the tolerance for combined interference as specified in paragraph (c) of this section.

■ 117. Add § 1065.377 to read as follows:

§ 1065.377 Interference verification for NH_3 analyzers.

(a) *Scope and frequency.* See § 1065.277 to determine whether you need to verify the amount of interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles.* Certain species can positively interfere with analyzers by causing a response similar to NH_3. If the analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) *System requirements.* Analyzers must have combined interference that is within (0.0±2.0) µmol/mol.

(d) *Procedure.* Perform the interference verification as follows:

(1) Start, operate, zero, and span the NH_3 analyzer as you would before an emission test. If the sample is passed through a dryer during emission testing, you may run this verification test with the dryer if it meets the requirements of § 1065.342. Operate the dryer at the same conditions as you will for an emission test. You may also run this verification test without the sample dryer.

(2) Create a humidified test gas using a multi component span gas that incorporates the target interference species and meets the specifications in § 1065.750 and a humidity generator device that introduces distilled H_2O as vapor into a controlled gas flow. If the sample does not pass through a dryer during emission testing, humidify your test gas to an H_2O level at or above the maximum expected during emission testing. If the sample passes through a dryer during emission testing, you must humidify your test gas to an H_2O level at or above the level determined in § 1065.145(e)(2) for that dryer. Use interference span gas concentrations that are at least as high as the maximum expected during testing.

(3) Introduce the humidified interference test gas into the sample system. You may introduce it downstream of any sample dryer, if one is used during testing.

(4) If the sample is not passed through a dryer during this verification test, measure the H_2O mole fraction, x_{H2O}, of the humidified interference test gas as close as possible to the inlet of the analyzer. For example, measure dewpoint, T_{dew}, and absolute pressure, p_{total}, to calculate x_{H2O}. Verify that the H_2O content meets the requirement in paragraph (d)(2) of this section. If the sample is passed through a dryer during this verification test, you must verify that the H_2O content of the humidified test gas downstream of the vessel meets the requirement in paragraph (d)(2) of this section based on either direct measurement of the H_2O content (*e.g.,* dewpoint and pressure) or an estimate based on the vessel pressure and temperature. Use good engineering judgment to estimate the H_2O content. For example, you may use previous direct measurements of H_2O content to verify the vessel's level of saturation.

(5) If a sample dryer is not used in this verification test, use good engineering judgment to prevent condensation in the transfer lines, fittings, or valves from the point where x_{H2O} is measured to the analyzer. We recommend that you design your system so that the wall temperatures in the transfer lines, fittings, and valves from the point where x_{H2O} is measured to the analyzer are at least 5 °C above the local sample gas dewpoint.

(6) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(7) While the analyzer measures the sample's concentration, record its output for 30 seconds. Calculate the arithmetic mean of this data. When performed with all the gases simultaneously, this is the combined interference.

(8) The analyzer meets the interference verification if the result of paragraph (d)(7) of this section meets the tolerance in paragraph (c) of this section.

(9) You may also run interference procedures separately for individual interference species. If the concentration of the interference species used are higher than the maximum levels expected during testing, you may scale down each observed interference value (the arithmetic mean of 30 second data described in paragraph (d)(7) of this section) by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. You may run separate interference concentrations of H_2O (down to 0.025 mol/mol H_2O content) that are lower than the maximum levels expected during testing, but you must scale up the observed H_2O interference by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the scaled interference values must meet the tolerance for combined interference as specified in paragraph (c) of this section.

■ 118. Amend § 1065.512 by revising paragraphs (b)(1) and (2) to read as follows:

§ 1065.512 Duty cycle generation.

* * * * *

(b) * * *

(1) *Engine speed for variable-speed engines*. For variable-speed engines, normalized speed may be expressed as a percentage between warm idle speed, f_{nidle}, and maximum test speed, f_{ntest}, or speed may be expressed by referring to a defined speed by name, such as ''warm idle,'' ''intermediate speed,'' or ''A,'' ''B,'' or ''C'' speed. Section 1065.610 describes how to transform these normalized values into a sequence of reference speeds, f_{nref}. Running duty cycles with negative or small normalized speed values near warm idle speed may cause low-speed idle governors to activate and the engine torque to exceed the reference torque even though the operator demand is at a minimum. In such cases, we recommend controlling the dynamometer so it gives priority to follow the reference torque instead of the reference speed and let the engine govern the speed. Note that the cycle-validation criteria in § 1065.514 allow an engine to govern itself. This allowance permits you to test engines with enhanced-idle devices, to simulate the effects of transmissions such as automatic transmissions, and for engines with speed derate intended to limit exhaust mass flowrate.

(i) For example, an enhanced-idle device might be an idle speed value that is normally commanded only under cold-start conditions to quickly warm up the engine and aftertreatment devices. In this case, negative and very low normalized speeds will generate reference speeds below this higher enhanced-idle speed. Control the dynamometer so it gives priority to follow the reference torque, controlling the operator demand so it gives priority to follow reference speed and let the engine govern the speed when the operator demand is at minimum.

You may do either of the following when using enhanced-idle devices:

(A) While running an engine where the ECM broadcasts an enhanced-idle speed that is above the denormalized speed, use the broadcast speed as the reference speed. Use these new reference points for duty-cycle validation. This does not affect how you determine denormalized reference torque in paragraph (b)(2) of this section.

(B) If an ECM broadcast signal is not available, perform one or more practice cycles to determine the enhanced-idle speed as a function of cycle time. Generate the reference cycle as you normally would but replace any reference speed that is lower than the enhanced-idle speed with the enhanced-idle speed. This does not affect how you determine denormalized reference torque in paragraph (b)(2) of this section.

(ii) For example, an engine with power derate intended to limit exhaust mass flowrate might include controls that reduce engine speed under cold-start conditions, resulting in reduced exhaust flow that assists other aftertreatment thermal management technologies (*e.g.,* electric heater). In this case, normalized speeds will generate reference speeds above this engine speed derate. Control the dynamometer so it gives priority to follow the reference speed, controlling the operator demand so it gives priority to follow reference torque. You may do one of the following, as specified, when using engine derate devices:

(A) While running an engine where the ECM broadcasts engine derate speed that is below the denormalized speed, use the broadcast speed as the reference speed. Use these new reference points for duty-cycle validation. This does not affect how you determine denormalized reference torque in paragraph (b)(2) of this section.

(B) If an ECM broadcast signal is not available, perform one or more practice cycles to determine the engine derate speed as a function of cycle time. Generate the reference cycle as you normally would but replace any reference speed that is greater than the engine derate speed with the engine derate speed. This does not affect how you determine denormalized reference torque in paragraph (b)(2) of this section.

(2) *Engine torque for variable-speed engines*. For variable-speed engines, normalized torque is expressed as a percentage of the mapped torque at the corresponding reference speed. Section 1065.610 describes how to transform normalized torques into a sequence of reference torques, T_{ref}. Section 1065.610 also describes special requirements for modifying transient duty cycles for variable-speed engines intended primarily for propulsion of a vehicle with an automatic or manual transmission. Section 1065.610 also describes under what conditions you may command T_{ref} greater than the reference torque you calculated from a normalized duty cycle, which permits you to command T_{ref} values that are limited by a declared minimum torque. For any negative torque commands, command minimum operator demand and use the dynamometer to control engine speed to the reference speed, but if reference speed is so low that the idle governor activates, we recommend using the dynamometer to control torque to zero, CITT, or a declared minimum torque as appropriate. Note that you may omit power and torque points during motoring from the cycle-validation criteria in § 1065.514. Also, use the maximum mapped torque at the minimum mapped speed as the maximum torque for any reference speed at or below the minimum mapped speed.

* * * * *

■ 119. Amend § 1065.530 by revising paragraphs (b)(4), (9), and (11) to read as follows:

§ 1065.530 Emission test sequence.

* * * * *

(b) * * *

(4) Pre-heat or pre-cool heat exchangers in the sampling system to within their operating temperature tolerances for a test interval.

* * * * *

(9) Select gas analyzer ranges. You may automatically or manually switch gas analyzer ranges during a test interval only if switching is performed by changing the span over which the digital resolution of the instrument is applied. During a test interval you may not switch the gains of an analyzer's analog operational amplifier(s).

* * * * *

(11) We recommend that you verify gas analyzer responses after zeroing and spanning by sampling a calibration gas that has a concentration near one-half of the span gas concentration. Based on the results and good engineering judgment, you may decide whether or not to re-zero, re-span, or re-calibrate a gas analyzer before starting a test interval.

* * * * *

■ 120. Amend § 1065.601 by revising paragraph (c)(1)(i) and removing and reserving paragraph (c)(1)(ii) to read as follows:

§ 1065.601 Overview.

* * * * *

(c) * * *

(1) * * *

(i) ISO 8178–4 Section 9.1.6, NO_X Correction for Humidity and Temperature. See § 1065.670 for approved methods for humidity corrections.

(ii) [Reserved].

* * * * *

■ 121. Amend § 1065.602 by adding paragraph (m) to read as follows:

§ 1065.602 Statistics.

* * * * *

(m) *Median*. Determine median, *M*, as described in this paragraph (m). Arrange the data points in the data set in increasing order where the smallest value is ranked 1, the second-smallest value is ranked 2, etc.

(1) For even numbers of data points:

(i) Determine the rank of the data point whose value is used to determine the median as follows:

$$i = \frac{N}{2}$$

Where:

i = an indexing variable that represents the rank of the data point whose value is used to determine the median.

N = the number of data points in the set.

Example:

$$N = 4$$
$$y_1 = 41.515$$
$$y_2 = 41.780$$
$$y_3 = 41.861$$
$$y_4 = 41.902$$
$$i = \frac{4}{2}$$
$$i = 2$$

(ii) Determine the median as the average of the data point *i* and the data point *i* + 1 as follows:

$$M = \frac{y_i + y_{i+1}}{2}$$

Example:

$$y_2 = 41.780$$
$$y_3 = 41.861$$
$$M = \frac{41.780 + 41.861}{2}$$
$$M = 41.821$$

(2) For odd numbers of data points, determine the rank of the data point whose value is the median and the corresponding median value as follows:

$$i = \frac{N + 1}{2}$$

Where:

i = an indexing variable that represents the rank of the data point whose value is the median.

N = the number of data points in the set.

Example:

$$N = 3$$
$$y_1 = 41.515$$
$$y_2 = 41.780$$
$$y_3 = 41.861$$
$$i = \frac{3 + 1}{2}$$
$$i = 2$$
$$M = 41.780$$

■ 122. Amend § 1065.655 by revising the section heading and paragraphs (a), (b)(4), and (e)(4) introductory text to read as follows:

§ 1065.655 Chemical balances of carbon-containing fuel, DEF, intake air, and exhaust.

(a) *General.* Chemical balances of fuel, intake air, and exhaust may be used to calculate flows, the amount of water in their flows, and the wet concentration of constituents in their flows. Use the chemical balance calculations in this section for carbon-containing fuels. For fuels other than carbon-containing fuels use the chemical balance calculations of section § 1065.656. With one flow rate of either fuel, intake air, or exhaust, you may use chemical balances to determine the flows of the other two. For example, you may use chemical balances along with either intake air or fuel flow to determine raw exhaust flow. Note that chemical balance calculations allow measured values for the flow rate of diesel exhaust fluid for engines with urea-based selective catalytic reduction.

(b) * * *

(4) The amount of water in a raw or diluted exhaust flow, χ_{H2Oexh}, when you do not measure the amount of water to correct for the amount of water removed by a sampling system. Note that you may not use the FTIR based water measurement method in § 1065.257 to determine χ_{H2Oexh}. Correct for removed water according to § 1065.659.

* * * * *

(e) * * *

(4) Calculate α, β, γ, and δ as described in this paragraph (e)(4). If your fuel mixture contains fuels other than carbon-containing fuel, calculate those fuels' mass fractions w_H, w_C, w_O, and w_N as described in § 1065.656(d) and set the fuels' mass fraction w_S to zero. Calculate α, β, γ, and δ using the following equations:

* * * * *

■ 123. Add § 1065.656 to read as follows:

§ 1065.656 Chemical balances of fuels other than carbon-containing fuel, DEF, intake air, and exhaust.

(a) *General.* Chemical balances of fuel, DEF, intake air, and exhaust may be used to calculate flows, the amount of water in their flows, and the wet concentration of constituents in their flows. Use the chemical balance calculations in this section for fuels other than carbon-containing fuels. For carbon-containing fuels, use the chemical balance calculations in section § 1065.655, including any dual-fuels or flexible-fuels where one of the fuels contains carbon. With one flow rate of either fuel, intake air, or exhaust, you may use chemical balances to determine the flows of the other two. For example, you may use chemical balances along with either intake air or fuel flow to determine raw exhaust flow. Note that chemical balance calculations allow measured values for the flow rate of diesel exhaust fluid for engines with urea-based selective catalytic reduction.

(b) *Procedures that require chemical balances.* We require chemical balances when you determine the following:

(1) A value proportional to total work, $\tilde{W}$ when you choose to determine brake-specific emissions as described in § 1065.650(f).

(2) Raw exhaust molar flow rate either from measured intake air molar flow rate or from fuel mass flow rate as described in paragraph (f) of this section.

(3) Raw exhaust molar flow rate from measured intake air molar flow rate and dilute exhaust molar flow rate as described in paragraph (g) of this section.

(4) The amount of water in a raw or diluted exhaust flow, χ_{H2Oexh}, when you do not measure the amount of water to correct for the amount of water removed by a sampling system. Correct for removed water according to § 1065.659.

(5) The calculated total dilution air flow when you do not measure dilution air flow to correct for background emissions as described in § 1065.667(c) and (d).

(c) *Chemical balance procedure.* The calculations for a chemical balance involve a system of equations that require iteration. We recommend using a computer to solve this system of equations. You must guess the initial values of two of the following quantities: the amount of water in the measured flow, $\chi_{H2Oexhdry}$, the amount of hydrogen in the measured flow, $\chi_{H2exhdry}$, the fraction of dilution air in diluted exhaust, $\chi_{dil/exhdry}$, and the amount of intake air required to produce actual combustion products per mole of dry exhaust, $\chi_{int/exhdry}$. You may use time-weighted mean values of intake air humidity and dilution air humidity in the chemical balance; as long as your intake air and dilution air humidities remain within tolerances of ±0.0025 mol/mol of their respective mean values over the test interval. For each emission concentration, χ, and amount of water, χ_{H2Oexh}, you must determine their completely dry concentrations, χ_{dry} and $\chi_{H2Oexhdry}$. You must also use your fuel mixture's atomic carbon-to-hydrogen ratio, τ, oxygen-to-hydrogen ratio, ϕ, and nitrogen-to-hydrogen ratio, ω; you may optionally account for diesel exhaust fluid (or other fluids injected into the exhaust), if applicable. You may calculate τ, ϕ, and ω based on measured fuel composition or based on measured fuel and diesel exhaust fluid (or other fluids injected into the exhaust) composition together, as described in paragraph (e) of this section. You may alternatively use any combination of default values and measured values as described in paragraph (e) of this section. Use the following steps to complete a chemical balance:

(1) Convert your measured concentrations such as, $\chi_{H2Omeas}$, χ_{O2meas}, χ_{H2meas}, χ_{NOmeas}, $\chi_{NO2meas}$, $\chi_{NH3meas}$, and χ_{H2Oint}, to dry concentrations by dividing them by one minus the amount of water present during their respective measurements; for example: $\chi_{H2Omeas}$, $\chi_{H2OxO2meas}$, $\chi_{H2OxNOmeas}$, and χ_{H2Oint}. If the amount of water present during a ''wet'' measurement is the same as an unknown amount of water in the exhaust flow, χ_{H2Oexh}, iteratively solve for that value in the system of equations. If you measure only total NO_X and not NO and NO_2 separately, use good engineering judgment to estimate a split in your total NO_X concentration between NO and NO_2 for the chemical balances. For example, if you measure emissions from a stoichiometric combustion engine, you may assume all NO_X is NO. For a lean-burn combustion engine, you may assume that your molar concentration of NO_X, χ_{NOx}, is 75% NO and 25% NO_2. For NO_2 storage aftertreatment systems, you may assume χ_{NOx} is 25% NO and 75% NO_2. Note that for calculating the mass of NO_X emissions, you must use the molar mass of NO_2 for the effective molar mass of all NO_X species, regardless of the actual NO_2 fraction of NO_X.

(2) Enter the equations in paragraph (c)(4) of this section into a computer program to iteratively solve for $\chi_{H2Oexhdry}$, $\chi_{H2exhdry}$, $\chi_{dil/exhdry}$, and $\chi_{int/exhdry}$. Use good engineering judgment to guess initial values for $\chi_{H2Oexhdry}$, $\chi_{H2exhdry}$, $\chi_{dil/exhdry}$, and $\chi_{int/exhdry}$. We recommend guessing an initial amount of water that is about twice the amount of water in your intake or dilution air. We recommend guessing an initial amount of hydrogen of 0 mol/mol. We recommend guessing an initial $\chi_{int/exhdry}$ of 1 mol/mol. We also recommend guessing an initial, $\chi_{dil/exhdry}$ of 0.8 mol/mol. Iterate values in the system of equations until the most recently updated guesses are all within ±1% or ±1 µmol/mol, whichever is larger, of their respective most recently calculated values.

(3) Use the following symbols and subscripts in the equations for performing the chemical balance calculations in this paragraph (c):

TABLE 1 OF § 1065.656—SYMBOLS AND SUBSCRIPTS FOR CHEMICAL BALANCE EQUATIONS

$\chi_{[emission]meas}$	Amount of measured emission in the sample at the respective gas analyzer.
$\chi_{[emission]exh}$	Amount of emission per dry mole of exhaust.
$\chi_{[emission]exhdry}$	Amount of emission per dry mole of dry exhaust.
$\chi_{H2O[emission]meas}$	Amount of H_2O in sample at emission-detection location; measure or estimate these values according to § 1065.145(e)(2).
$\chi_{dil/exh}$	Amount of dilution gas or excess air per mole of exhaust.
$\chi_{dil/exhdry}$	amount of dilution gas and/or excess air per mole of dry exhaust.
$\chi_{Hcombdry}$	Amount of hydrogen from fuel and any injected fluids in the exhaust per mole of dry exhaust.
$\chi_{int/exhdry}$	Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust.
$\chi_{raw/exhdry}$	Amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust.
χ_{CO2int}	Amount of intake air CO_2 per mole of intake air.
$\chi_{CO2intdry}$	amount of intake air CO_2 per mole of dry intake air; you may use xCO2intdry = 375 µmol/mol, but we recommend measuring the actual concentration in the intake air.
χ_{H2Oint}	Amount of H_2O in the intake air, based on a humidity measurement of intake air.
$\chi_{H2Ointdry}$	Amount of intake air H_2O per mole of dry intake air.
χ_{O2int}	Amount of intake air O2 per mole of intake air.
χ_{CO2dil}	Amount of dilution gas CO_2 per mole of dilution gas.
$\chi_{CO2dildry}$	Amount of dilution gas CO_2 per mole of dry dilution gas; if you use air as diluent, you may use xCO2dildry = 375 µmol/mol, but we recommend measuring the actual concentration in the dilution gas.
χ_{H2Odil}	Amount of dilution gas H_2O per mole of dilution gas.
$\chi_{H2Odildry}$	Amount of dilution gas H_2O per mole of dry dilution gas.
τ	Atomic carbon-to-hydrogen ratio of the fuel (or mixture of test fuels) and any injected fluids.
ϕ	Atomic oxygen-to-hydrogen ratio of the fuel (or mixture of test fuels) and any injected fluids.
ω	Atomic nitrogen-to-hydrogen ratio of the fuel (or mixture of test fuels) and any injected fluids.

(4) Use the equations specified in this section to iteratively solve for $\chi_{int/exhdry}$, $\chi_{dil/exhdry}$, $\chi_{H2exhdry}$, and $\chi_{H2Oexhdry}$. For some quantities multiple equations are provided. The calculation of xO2exhdry is only required when xO2meas is measured. The calculation of $\chi_{NH3exhdry}$ is only required for engines that use ammonia as fuel, for all other fuels $\chi_{NH3exhdry}$ may be set to zero.

$$x_{\text{dil/exh}} = 1 - \frac{x_{\text{raw/exhdry}}}{1 + x_{\text{H2Oexhdry}}}$$

Eq. 1065.656-1

$$x_{\text{dil/exhdry}} = \frac{x_{\text{dil/exh}}}{1 - x_{\text{H2Oexh}}}$$

Eq. 1065.656-2

$$x_{\text{H2exhdry}} = \frac{x_{\text{H2meas}}}{1 - x_{\text{H2OH2meas}}}$$

Eq. 1065.656-3 (see Table 2 of § 1065.656)

$$x_{\text{H2exhdry}} = 2 \cdot \left(x_{\text{raw/exhdry}} - x_{\text{int/exhdry}}\right) - \left(\frac{1}{2} + \varphi + \omega\right) \cdot x_{\text{Hcombdry}} + \frac{1}{2} \cdot x_{\text{NH3exhdry}} + x_{\text{NO2exhdry}}$$

Eq. 1065.656-4 (see Table 2 of § 1065.656)

$$x_{\text{H2Oexh}} = \frac{x_{\text{H2Oexhdry}}}{1 + x_{\text{H2Oexhdry}}}$$

Eq. 1065.656-5

$$x_{\text{H2Oexhdry}} = \frac{x_{\text{H2Omeas}}}{1 - x_{\text{H2Omeas}}}$$

Eq. 1065.656-6 (see Table 2 of § 1065.656)

$$x_{\text{H2Oexhdry}} = \frac{1}{2} \cdot x_{\text{Hcombdry}} - x_{\text{H2exhdry}} - \frac{3}{2} \cdot x_{\text{NH3exhdry}} + x_{\text{H2Odil}} \cdot x_{\text{dil/exhdry}} + x_{\text{H2Oint}} \cdot x_{\text{int/exhdry}}$$

Eq. 1065.656-7 (see Table 2 of § 1065.656)

$$x_{\text{Hcombdry}} = 2 \cdot x_{\text{H2Oexhdry}} + 2 \cdot x_{\text{H2exhdry}} + 3 \cdot x_{\text{NH3exhdry}} - 2 \cdot x_{\text{H2Odil}} \cdot x_{\text{dil/exhdry}} - 2 \cdot x_{\text{H2Oint}} \cdot x_{\text{int/exhdry}}$$

Eq. 1065.656-8 (see Table 2 of § 1065.656)

$$x_{\text{Hcombdry}} = \frac{2 \cdot \left(x_{\text{raw/exhdry}} - x_{\text{int/exhdry}}\right) - x_{\text{H2exhdry}} + \frac{1}{2} \cdot x_{\text{NH3exhdry}} + x_{\text{NO2exhdry}}}{\frac{1}{2} + \varphi + \omega}$$

Eq. 1065.656-9 (see Table 2 of § 1065.656)

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot x_{\text{O2int}}} \cdot \left(\left(2 \cdot \tau + \frac{1}{2} - \varphi\right) \cdot x_{\text{Hcombdry}} - x_{\text{H2exhdry}} - \frac{3}{2} \cdot x_{\text{NH3exhdry}} + x_{\text{NOexhdry}} + 2 \cdot x_{\text{NO2exhdry}}\right)$$

Eq. 1065.656-10

$$x_{\mathrm{NH3exhdry}} = \frac{x_{\mathrm{NH3meas}}}{1 - x_{\mathrm{H2ONH3meas}}}$$

Eq. 1065.656-11

$$x_{\mathrm{NOexhdry}} = \frac{x_{\mathrm{NOmeas}}}{1 - x_{\mathrm{H2ONOmeas}}}$$

Eq. 1065.656-12

$$x_{\mathrm{NO2exhdry}} = \frac{x_{\mathrm{NO2meas}}}{1 - x_{\mathrm{H2ONO2meas}}}$$

Eq. 1065.656-13

$$x_{\mathrm{O2exhdry}} = \frac{x_{\mathrm{O2meas}}}{1 - x_{\mathrm{H2OO2meas}}}$$

Eq. 1065.656-14 (see Table 2 of § 1065.656)

$$x_{\mathrm{raw/exhdry}} = 1 + x_{\mathrm{H2Oexhdry}} - \frac{1 + x_{\mathrm{H2Odildry}}}{0.209820 - x_{\mathrm{CO2dildry}}} \cdot x_{\mathrm{O2exhdry}}$$

Eq. 1065.656-15 (see Table 2 of § 1065.656)

$$x_{\mathrm{raw/exhdry}} = \left(\frac{1}{4} + \frac{\varphi}{2} + \frac{\omega}{2}\right) \cdot x_{\mathrm{Hcombdry}} + \frac{1}{2} \cdot x_{\mathrm{H2exhdry}} - \frac{1}{4} \cdot x_{\mathrm{NH3exhdry}} - \frac{1}{2} x_{\mathrm{NO2exhdry}} + x_{\mathrm{int/exhdry}}$$

Eq. 1065.656-16 (see Table 2 of § 1065.656)

$$x_{\mathrm{CO2intdry}} = \frac{x_{\mathrm{CO2int}}}{1 - x_{\mathrm{H2Oint}}}$$

Eq. 1065.656-17

$$x_{\mathrm{H2Ointdry}} = \frac{x_{\mathrm{H2Oint}}}{1 - x_{\mathrm{H2Oint}}}$$

Eq. 1065.656-18

$$x_{\mathrm{O2int}} = \frac{0.209820 - x_{\mathrm{CO2intdry}}}{1 + x_{\mathrm{H2Ointdry}}}$$

Eq. 1065.656-19

$$x_{\mathrm{CO2dildry}} = \frac{\mathrm{x}_{\mathrm{CO2dil}}}{1 - x_{\mathrm{H2Odil}}}$$

Eq. 1065.656-20

$$x_{\mathrm{H2Odildry}} = \frac{x_{\mathrm{H2Odil}}}{1 - x_{\mathrm{H2Odil}}}$$

Eq. 1065.656-21

(5) Depending on your measurements, use the equations and guess the quantities specified in Table 2 of this section:

TABLE 2 OF § 1065.656—CHEMICAL BALANCE EQUATIONS FOR DIFFERENT MEASUREMENTS

When measuring	Guess	Calculate
(i) χ_{O2meas} and $\chi_{H2Omeas}$	$\chi_{int/exhdry}$ and $\chi_{H2exhdry}$	(A) $\chi_{H2exhdry}$ using Eq. 1065.656–4 (B) $\chi_{H2Oexhdry}$ using Eq. 1065.656–6 (C) $\chi_{Hcombdry}$ using Eq. 1065.656–8 (D) $\chi_{O2exhdry}$ using Eq. 1065.656–14 (E) $\chi_{raw/exhdry}$ using Eq. 1065.656–15
(ii) χ_{O2meas} and χ_{H2meas}	$\chi_{int/exhdry}$ and $\chi_{H2Oexhdry}$	(A) $\chi_{H2exhdry}$ using Eq. 1065.656–3 (B) $\chi_{H2Oexhdry}$ using Eq. 1065.656–7 (C) $\chi_{Hcombdry}$ using Eq. 1065.656–9 (D) $\chi_{O2exhdry}$ using Eq. 1065.656–14 (E) $\chi_{raw/exhdry}$ using Eq. 1065.656–15
(iii) $\chi_{H2Omeas}$ and χ_{H2meas}	$\chi_{int/exhdry}$ and $\chi_{dil/exhdry}$	(A) $\chi_{H2exhdry}$ using Eq. 1065.656–3 (B) $\chi_{H2Oexhdry}$ using Eq. 1065.656–6 (C) $\chi_{Hcombdry}$ using Eq. 1065.656–8 (D) $\chi_{raw/exhdry}$ using Eq. 1065.656–16

(d) *Mass fractions of fuel.* Determine the mass fractions of fuel, w_H, w_C, w_O, and w_N, based on the fuel properties as determined in paragraph (e) of this section, optionally accounting for diesel exhaust fluid's contribution to τ, ϕ, and ω, or other fluids injected into the exhaust, if applicable (for example, the engine is equipped with an emission control system that utilizes DEF). Calculate w_H, w_C, w_O, and $_N$ using the following equations:

$$w_{\mathrm{H}} = \frac{1 \cdot M_{\mathrm{H}}}{1 \cdot M_{\mathrm{H}} + \tau \cdot M_{\mathrm{C}} + \varphi \cdot M_{\mathrm{O}} + \omega \cdot M_{\mathrm{N}}}$$

Eq. 1065.656-22

$$w_{\mathrm{C}} = \frac{\tau \cdot M_{\mathrm{C}}}{1 \cdot M_{\mathrm{H}} + \tau \cdot M_{\mathrm{C}} + \varphi \cdot M_{\mathrm{O}} + \omega \cdot M_{\mathrm{N}}}$$

Eq. 1065.656-23

$$w_{\mathrm{O}} = \frac{\varphi \cdot M_{\mathrm{O}}}{1 \cdot M_{\mathrm{H}} + \tau \cdot M_{\mathrm{C}} + \varphi \cdot M_{\mathrm{O}} + \omega \cdot M_{\mathrm{N}}}$$

Eq. 1065.656-24

$$w_{\mathrm{N}} = \frac{\omega \cdot M_{\mathrm{N}}}{1 \cdot M_{\mathrm{H}} + \tau \cdot M_{\mathrm{C}} + \varphi \cdot M_{\mathrm{O}} + \omega \cdot M_{\mathrm{N}}}$$

Eq. 1065.656-25

Where:

w_H = hydrogen mass fraction of the fuel (or mixture of test fuels) and any injected fluids.
w_C = carbon mass fraction of the fuel (or mixture of test fuels) and any injected fluids.
w_O = oxygen mass fraction of the fuel (or mixture of test fuels) and any injected fluids.
w_N = nitrogen mass fraction of the fuel (or mixture of test fuels) and any injected fluids.
M_H = molar mass of hydrogen.
τ = atomic carbon-to- hydrogen ratio of the fuel (or mixture of test fuels) and any injected fluids.
M_C = molar mass of carbon.
ϕ = atomic oxygen-to-hydrogen ratio of the fuel (or mixture of test fuels) and any injected fluids.
M_O = molar mass of oxygen.
ω = atomic sulfur-to-hydrogen ratio of the fuel (or mixture of test fuels) and any injected fluids.
M_N = molar mass of nitrogen.

(e) *Fuel and diesel exhaust fluid composition.* Determine fuel and diesel exhaust fluid composition represented by τ, ϕ, and ω, as described in this paragraph (e). When using measured fuel or diesel exhaust fluid properties, you must determine values for τ, ϕ, and ω in all cases. If you determine compositions based on measured values and the default value listed in Table 3 of this section is zero, you may set τ, ϕ, and ω to zero; otherwise determine τ, ϕ, and ω based on measured values. Determine elemental mass fractions and values for τ, ϕ, and ω as follows:

(1) For fuel and diesel exhaust fluid, use the default values for τ, ϕ, and ω in Table 3 of this section, or use good engineering judgment to determine those values based on measurement.

(2) For nonconstant fuel mixtures, you must account for the varying proportions of the different fuels. This paragraph (e)(2) generally applies for dual-fuel and flexible-fuel engines, but it also applies if diesel exhaust fluid is injected in a way that is not strictly proportional to fuel flow. Account for these varying concentrations either with a batch measurement that provides averaged values to represent the test interval, or by analyzing data from continuous mass rate measurements. Application of average values from a batch measurement generally applies to

situations where one fluid is a minor component of the total fuel mixture; consistent with good engineering judgment.

(4) Calculate τ, φ and ω using the following equations;

$$\tau = \frac{M_{\mathrm{H}}}{M_{\mathrm{C}}} \cdot \frac{\sum_{j=1}^{N} \dot{m}_j \cdot \mathrm{w}_{\mathrm{C}j}}{\sum_{j=1}^{N} \dot{m}_j \cdot \mathrm{w}_{\mathrm{H}j}}$$

Eq. 1065.656-26

$$\varphi = \frac{M_{\mathrm{H}}}{M_{\mathrm{O}}} \cdot \frac{\sum_{j=1}^{N} \dot{m}_j \cdot \mathrm{w}_{\mathrm{O}j}}{\sum_{j=1}^{N} \dot{m}_j \cdot \mathrm{w}_{\mathrm{H}j}}$$

Eq. 1065.656-27

$$\omega = \frac{M_{\mathrm{H}}}{M_{\mathrm{N}}} \cdot \frac{\sum_{j=1}^{N} \dot{m}_j \cdot \mathrm{w}_{\mathrm{N}j}}{\sum_{j=1}^{N} \dot{m}_j \cdot \mathrm{w}_{\mathrm{H}j}}$$

Eq. 1065.656-28

Where:

N = total number of fuels and injected fluids over the duty cycle.

j = an indexing variable that represents one fuel or injected fluid, starting with j = 1.

$\dot{m}_j$ = the mass flow rate of the fuel or any injected fluid j. For applications using a single fuel and no DEF fluid, set this value to 1. For batch measurements, divide the total mass of fuel over the test interval duration to determine a mass rate.

$w_{\mathrm{H}j}$ = hydrogen mass fraction of fuel or any injected fluid j.

$w_{\mathrm{C}j}$ = carbon mass fraction of fuel or any injected fluid j.

$w_{\mathrm{O}j}$ = oxygen mass fraction of fuel or any injected fluid j.

$w_{\mathrm{N}j}$ = nitrogen mass fraction of fuel or any injected fluid j.

(4) Table 3 follows:

TABLE 3 OF § 1065.656–DEFAULT VALUES OF τ, ϕ, AND ω

Fuel or injected fluid	Atomic carbon, oxygen, and nitrogen-to-hydrogen ratios $HC_{\tau}O_{\phi}N_{\omega}$
Hydrogen	$HC_0O_0N_0$
Ammonia	$HC_0O_0N_{0.333}$
Diesel exhaust fluid	$HC_{0.056}O_{0.444}N_{0.112}$

(f) *Calculated raw exhaust molar flow rate from measured intake air molar flow rate or fuel mass flow rate.* You may calculate the raw exhaust molar flow rate from which you sampled emissions, $\dot{n}_{\mathrm{exh}}$, based on the measured intake air molar flow rate, $\dot{n}_{\mathrm{int}}$, or the measured fuel mass flow rate, $\dot{m}_{\mathrm{fuel}}$, and the values calculated using the chemical balance in paragraph (c) of this section. The chemical balance must be based on raw exhaust gas concentrations. Solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record $\dot{n}_{\mathrm{int}}$ or $\dot{m}_{\mathrm{fuel}}$. For laboratory tests, calculating raw exhaust molar flow rate using measured fuel mass flow rate is valid only for steady-state testing. See § 1065.915(d)(5)(iv) for application to field testing.

(1) *Crankcase flow rate.* If engines are not subject to crankcase controls under the standard-setting part, you may calculate raw exhaust flow based on $\dot{n}_{\mathrm{int}}$ or $\dot{m}_{\mathrm{fuel}}$ using one of the following:

(i) You may measure flow rate through the crankcase vent and subtract it from the calculated exhaust flow.

(ii) You may estimate flow rate through the crankcase vent by engineering analysis as long as the uncertainty in your calculation does not adversely affect your ability to show that your engines comply with applicable emission standards.

(iii) You may assume your crankcase vent flow rate is zero.

(2) *Intake air molar flow rate calculation.* Calculate $\dot{n}_{\mathrm{exh}}$ based on $\dot{n}_{\mathrm{int}}$ using the following equation:

$$\dot{n}_{\mathrm{exh}} = \frac{\dot{n}_{\mathrm{int}}}{\left(1 + \frac{\left(x_{\mathrm{int/exhdry}} - x_{\mathrm{raw/exhdry}}\right)}{\left(1 + x_{\mathrm{H2Oexhdry}}\right)}\right)}$$

Eq. 1065.656-29

Where:

$\dot{n}_{\mathrm{exh}}$ = raw exhaust molar flow rate from which you measured emissions.

$\dot{n}_{\mathrm{int}}$ = intake air molar flow rate including humidity in intake air.

Example:

$$\dot{n}_{\mathrm{int}} = 3.780 \text{ mol/s}$$
$$x_{\mathrm{int/exhdry}} = 0.69021 \text{ mol/mol}$$
$$x_{\mathrm{raw/exhdry}} = 1.10764 \text{ mol/mol}$$
$$x_{\mathrm{H20exhdry}} = 107.64 \text{ mmol/mol} = 0.10764 \text{ mol/mol}$$
$$\dot{n}_{\mathrm{exh}} = \frac{3.780}{\left(1 + \frac{(0.69021 - 1.10764)}{(1 + 0.10764)}\right)}$$
$$\dot{n}_{\mathrm{exh}} = 6.066 \text{ mol/s}$$

(3) *Fluid mass flow rate calculation.* This calculation may be used only for steady-state laboratory testing. See § 1065.915(d)(5)(iv) for application to field testing. Calculate $\dot{n}_{\mathrm{exh}}$ based on $\dot{m}_j$ using the following equation:

$$\dot{n}_{\mathrm{exh}} = \frac{1 + x_{\mathrm{H2Oexhdry}}}{M_{\mathrm{H}} \cdot x_{\mathrm{Hcombdry}}} \cdot \sum_{j=1}^{N} \dot{m}_{\mathrm{j}} \cdot w_{\mathrm{H}_j}$$

Eq. 1065.656-30

Where:

$\dot{n}_{\mathrm{exh}}$ = raw exhaust molar flow rate from which you measured emissions.

j = an indexing variable that represents one fuel or injected fluid, starting with j = 1.

N = total number of fuels and injected fluids over the duty cycle.

$\dot{m}_j$ = the mass flow rate of the fuel or any injected fluid j.

$w_{\mathrm{H}f}$ = hydrogen mass fraction of the fuel and any injected fluid j.

Example:

$x_{\mathrm{H20exhdry1}}$ = 107.64 mmol/mol = 0.10764 mol/mol

M_{H} = 1.00794 g/mol

$x_{\mathrm{Ccombdry1}}$ = 99.87 mmol/mol = 0.09987 mol/mol

$\dot{m}_1$ = 7.559 g/s

w_{H1} = 0.07293 g/g

N = 1

j = 1

$$\dot{n}_{\mathrm{exh}} = \frac{1 + 0.10764}{1.00794 \cdot 0.09987} \cdot 7.559 \cdot 0.07293$$

$\dot{n}_{\mathrm{exh}}$ = 6.066 mol/s

(g) *Calculated raw exhaust molar flow rate from measured intake air molar flow rate, dilute exhaust molar flow rate, and dilute chemical balance.* You may calculate the raw exhaust molar flow rate, $\dot{n}_{\mathrm{exh}}$, based on the measured intake air molar flow rate, $\dot{n}_{\mathrm{int}}$, the measured dilute exhaust molar flow rate, $\dot{n}_{\mathrm{dexh}}$, and the values calculated using the chemical balance in paragraph (c) of this section. Note that the chemical balance must be based on dilute exhaust gas concentrations. For continuous-flow calculations, solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record $\dot{n}_{\mathrm{int}}$ and $\dot{n}_{\mathrm{dexh}}$. This calculated $\dot{n}_{\mathrm{dexh}}$ may be used for the PM dilution ratio verification in § 1065.546; the calculation of dilution air molar flow rate in the background correction in § 1065.667; and the calculation of mass of emissions in § 1065.650(c) for species that are measured in the raw exhaust.

(1) *Crankcase flow rate.* If engines are not subject to crankcase controls under the standard-setting part, calculate raw exhaust flow as described in paragraph (f)(1) of this section.

(2) *Dilute exhaust and intake air molar flow rate calculation.* Calculate $\dot{n}_{\mathrm{exh}}$ as follows:

$$\dot{n}_{\mathrm{exh}} = \left(x_{\mathrm{raw/exhdry}} - x_{\mathrm{int/exhdry}}\right) \cdot \left(1 - x_{\mathrm{H2Oexh}}\right) \cdot \dot{n}_{\mathrm{dexh}} + \dot{n}_{\mathrm{int}}$$

Eq. 1065.656-31

Example:

$\dot{n}_{\mathrm{int}}$ = 7.930 mol/s

$\chi_{\mathrm{raw/exhdry}}$ = 0.1544 mol/mol

$\chi_{\mathrm{int/exhdry}}$ = 0.1451 mol/mol

χ_{H2Oexh} = 32.46 mmol/mol = 0.03246 mol/mol

$\dot{n}_{\mathrm{dexh}}$ = 49.02 mol/s

$\dot{n}_{\mathrm{exh}}$ = (0.1544 − 0.1451) · (1 − 0.03246) · 49.02 + 7.930 = 0.4411 + 7.930 = 8.371 mol/s

■ 124. Amend § 1065.660 by revising paragraphs (b)(2) and (3) introductory text, (c)(1)(ii) and (2) introductory text, (d), and (e) to read as follows:

§ 1065.660 THC, NMHC, NMNEHC, CH_4, and C_2H_6 determination.

* * * * *

(b) * * *

(2) For a nonmethane cutter (NMC), calculate χ_{NMHC} using the NMC's penetration fractions, response factors, and/or combined penetration fractions and response factors as described in § 1065.365, the THC FID's CH_4 response factor, $RF_{\mathrm{CH4[THC\text{-}FID]}}$, from § 1065.360, the initial THC contamination and dry-to-wet corrected THC concentration, $\chi_{\mathrm{THC[THC\text{-}FID]cor}}$, as determined in paragraph (a) of this section, and the dry-to-wet corrected CH_4 concentration, $\chi_{\mathrm{THC[NMC\text{-}FID]cor}}$, optionally corrected for initial THC contamination as determined in paragraph (a) of this section.

(i) Use the following equation for an NMC configured as described in § 1065.365(d):

$$x_{\mathrm{NMHC}} = \frac{x_{\mathrm{THC[THC\text{-}FID]cor}} \cdot RFPF_{\mathrm{CH4[NMC-FID]}} - x_{\mathrm{THC[NMC\text{-}FID]cor}} \cdot RF_{\mathrm{CH4[THC\text{-}FID]}}}{RFPF_{\mathrm{CH4[NMC-FID]}} - RFPF_{\mathrm{C2H6[NMC\text{-}FID]}} \cdot RF_{\mathrm{CH4[THC\text{-}FID]}}}$$

Eq. 1065.660-2

Where:

χ_{NMHC} = concentration of NMHC.

$\chi_{\text{THC[THC–FID]cor}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$\chi_{\text{THC[NMC–FID]cor}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$RF_{\text{CH4[THC–FID]}}$ = response factor of THC FID to CH_4, according to § 1065.360(d).

$RFPF_{\text{C2H6[NMC–FID]}}$ = NMC combined C_2H_6 response factor and penetration fraction, according to § 1065.365(d).

$RFPF_{\text{CH4[NMC–FID]}}$ = NMC combined CH_4 response factor and penetration fraction, according to § 1065.365(d).

Example:

$$x_{\text{THC[THC-FID]cor}} = 150.3\ \mu\text{mol/mol}$$

$$x_{\text{THC[NMC-FID]cor}} = 20.5\ \mu\text{mol/mol}$$

$$RFPF_{\text{C2H6[NMC-FID]}} = 0.019$$

$$RFPF_{\text{CH4[NMC-FID]}} = 1.000$$

$$RF_{\text{CH4[THC-FID]}} = 1.05$$

$$x_{\text{NMHC}} = \frac{150.3 - 20.5 \cdot 1.05}{1 - 0.019 \cdot 1.05}$$

$$x_{\text{NMHC}} = 131.4\ \mu\text{mol/mol}$$

(ii) Use the following equation for penetration fractions determined using an NMC configuration as outlined in § 1065.365(e):

$$x_{\text{NMHC}} = \frac{x_{\text{THC[THC-FID]cor}} \cdot PF_{\text{CH4[NMC-FID]}} - x_{\text{THC[NMC-FID]cor}}}{PF_{\text{CH4[NMC-FID]}} - PF_{\text{C2H6[NMC-FID]}}}$$

Eq. 1065.660-3

Where:

χ_{NMHC} = concentration of NMHC.

$\chi_{\text{THC[THC–FID]cor}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{\text{CH4[NMC–FID]}}$ = NMC CH_4 penetration fraction, according to § 1065.365(e).

$\chi_{\text{THC[NMC–FID]cor}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the THC FID during sampling through the NMC.

$PF_{\text{C2H6[NMC–FID]}}$ = NMC C_2H_6 penetration fraction, according to § 1065.365(e).

Example:

$$x_{\text{THC[THC-FID]cor}} = 150.3\ \mu\text{mol/mol}$$

$$PF_{\text{CH4[NMC-FID]}} = 0.990$$

$$x_{\text{THC[NMC-FID]cor}} = 20.5\ \mu\text{mol/mol}$$

$$PF_{\text{C2H6[NMC-FID]}} = 0.020$$

$$x_{\text{NMHC}} = \frac{150.3 \cdot 0.990 - 20.5}{0.990 - 0.020}$$

$$x_{\text{NMHC}} = 132.3\ \mu\text{mol/mol}$$

(iii) Use the following equation for an NMC configured as described in § 1065.365(f)§ :

$$x_{\text{NMHC}} = \frac{x_{\text{THC[THC-FID]cor}} \cdot PF_{\text{CH4[NMC-FID]}} - x_{\text{THC[NMC-FID]cor}} \cdot RF_{\text{CH4[THC-FID]}}}{PF_{\text{CH4[NMC-FID]}} - RFPF_{\text{C2H6[NMC-FID]}} \cdot RF_{\text{CH4[THC-FID]}}}$$

Eq. 1065.660-4

Where:

χ_{NMHC} = concentration of NMHC.

$\chi_{\text{THC[THC–FID]cor}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{\text{CH4[NMC–FID]}}$ = NMC CH_4 penetration fraction, according to § 1065.365(f).

$\chi_{\text{THC[NMC–FID]cor}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the THC FID during sampling through the NMC.

$RFPF_{C2H6[NMC-FID]}$ = NMC combined C_2H_6 response factor and penetration fraction, according to § 1065.365(f).

$RF_{CH4[THC-FID]}$ = response factor of THC FID to CH_4, according to § 1065.360(d).

Example:

$$x_{THC[THC\text{-}FID]cor} = 150.3\ \mu mol/mol$$
$$PF_{CH4[NMC\text{-}FID]} = 0.990$$
$$x_{THC[NMC\text{-}FID]cor} = 20.5\ \mu mol/mol$$
$$RFPF_{C2H6[NMC\text{-}FID]} = 0.019$$
$$RF_{CH4[THC\text{-}FID]} = 0.980$$
$$x_{NMHC} = \frac{150.3 \cdot 0.990 - 20.5 \cdot 0.980}{0.990 - 0.019 \cdot 0.980}$$
$$x_{NMHC} = 132.5\ \mu mol/mol$$

(3) For a GC–FID or FTIR, calculate xNMHC using the THC analyzer's CH_4 response factor, $RF_{CH4[THC-FID]}$, from § 1065.360, and the initial THC contamination and dry-to-wet corrected THC concentration, $\chi_{THC[THC-FID]cor}$, as determined in paragraph (a) of this section as follows:

* * * * *

(c) * * *

(1) * * *

(ii) If the content of your fuel test contains at least 0.010 mol/mol of C_2H_6, you may omit the calculation of NMNEHC concentration and calculate the mass of NMNEHC as described in § 1065.650(c)(6)(ii).

(2) For a GC–FID, NMC FID, or FTIR, calculate χ_{NMNEHC} using the THC analyzer's CH_4 response factor, $RF_{CH4[THC-FID]}$, and C_2H_6 response factor, $RF_{C2H6[THC-FID]}$, from § 1065.360, the initial contamination and dry-to-wet corrected THC concentration, $\chi_{THC[THC-FID]cor}$, as determined in paragraph (a) of this section, the dry-to-wet corrected CH_4 concentration, χ_{CH4}, as determined in paragraph (d) of this section, and the dry-to-wet corrected C_2H_6 concentration, χ_{C2H6}, as determined in paragraph (e) of this section as follows:

* * * * *

(d) *CH_4 determination.* Use one of the following methods to determine methane (CH_4) concentration, χ_{CH4}:

(1) For a nonmethane cutter (NMC), calculate χ_{CH4} using the NMC's penetration fractions, response factors, and/or combined penetration fractions and response factors as described in § 1065.365, the THC FID's CH_4 response factor, $RF_{CH4[THC-FID]}$, from § 1065.360, the initial THC contamination and dry-to-wet corrected THC concentration, $\chi_{THC[THC-FID]cor}$, as determined in paragraph (a) of this section, and the dry-to-wet corrected CH_4 concentration, $\chi_{THC[NMC-FID]cor}$, optionally corrected for initial THC contamination as determined in paragraph (a) of this section.

(i) Use the following equation for an NMC configured as described in § 1065.365(d):

$$x_{CH4} = \frac{x_{THC[NMC\text{-}FID]cor} - x_{THC[THC\text{-}FID]cor} \cdot RFPF_{C2H6[NMC\text{-}FID]}}{RFPF_{CH4[NMC\text{-}FID]} - RFPF_{C2H6[NMC\text{-}FID]} \cdot RF_{CH4[THC\text{-}FID]}}$$

Eq. 1065.660-9

Where:

χ_{CH4} = concentration of CH_4.

$\chi_{THC[NMC-FID]cor}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$\chi_{THC[THC-FID]cor}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$RFPF_{C2H6[NMC-FID]}$ = NMC combined C_2H_6 response factor and penetration fraction, according to § 1065.365(d).

$RF_{CH4[THC-FID]}$ = response factor of THC FID to CH_4, according to § 1065.360(d).

$RFPF_{CH4[NMC-FID]}$ = NMC combined CH_4 response factor and penetration fraction, according to § 1065.365(d).

Example:

$$x_{THC[NMC\text{-}FID]cor} = 10.4\ \mu mol/mol$$
$$x_{THC[THC\text{-}FID]cor} = 150.3\ \mu mol/mol$$
$$RFPF_{C2H6[NMC\text{-}FID]} = 0.019$$
$$RFPF_{CH4[NMC\text{-}FID]} = 1.000$$
$$RF_{CH4[THC\text{-}FID]} = 1.05$$
$$x_{CH4} = \frac{10.4 - 150.3 \cdot 0.019}{1 - 0.019 \cdot 1.05}$$
$$x_{CH4} = 7.69\ \mu mol/mol$$

(ii) Use the following equation for an NMC configured as described in § 1065.365(e):

$$x_{\mathrm{CH4}} = \frac{x_{\mathrm{THC[NMC\text{-}FID]cor}} - x_{\mathrm{THC[THC\text{-}FID]cor}} \cdot PF_{\mathrm{C2H6[NMC\text{-}FID]}}}{RF_{\mathrm{CH4[THC\text{-}FID]}} \cdot \left(PF_{\mathrm{CH4[NMC\text{-}FID]}} - PF_{\mathrm{C2H6[NMC\text{-}FID]}}\right)}$$

Eq. 1065.660-10

Where:

χ_{CH4} = concentration of CH_4.

$\chi_{\mathrm{THC[NMC–FID]cor}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$\chi_{\mathrm{THC[THC–FID]cor}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{\mathrm{C2H6[NMC–FID]}}$ = NMC C_2H_6 penetration fraction, according to § 1065.365(e).

$RF_{\mathrm{CH4[THC–FID]}}$ = response factor of THC FID to CH_4, according to § 1065.360(d).

$PF_{\mathrm{CH4[NMC–FID]}}$ = NMC CH_4 penetration fraction, according to § 1065.365(e).

Example:

$x_{\mathrm{THC[NMC\text{-}FID]cor}} = 10.4\ \mu\mathrm{mol/mol}$

$x_{\mathrm{THC[THC\text{-}FID]cor}} = 150.3\ \mu\mathrm{mol/mol}$

$PF_{\mathrm{C2H6[NMC\text{-}FID]}} = 0.020$

$RF_{\mathrm{CH4[THC\text{-}FID]}} = 1.05$

$PF_{\mathrm{CH4[NMC\text{-}FID]}} = 0.990$

$$x_{\mathrm{CH4}} = \frac{10.4 - 150.3 \cdot 0.020}{1.05 \cdot (0.990 - 0.020)}$$

$x_{\mathrm{CH4}} = 7.25\ \mu\mathrm{mol/mol}$

(iii) Use the following equation for an NMC configured as described in § 1065.365(f):

$$x_{\mathrm{CH4}} = \frac{x_{\mathrm{THC[NMC\text{-}FID]cor}} - x_{\mathrm{THC[THC\text{-}FID]cor}} \cdot RFPF_{\mathrm{C2H6[NMC\text{-}FID]}}}{PF_{\mathrm{CH4[NMC\text{-}FID]}} - RFPF_{\mathrm{C2H6[NMC\text{-}FID]}} \cdot RF_{\mathrm{CH4[THC\text{-}FID]}}}$$

Eq. 1065.660-11

Where:

χ_{CH4} = concentration of CH_4.

$\chi_{\mathrm{THC[NMC–FID]cor}}$ = concentration of THC, initial THC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$\chi_{\mathrm{THC[THC–FID]cor}}$ = concentration of THC, initial THC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$RFPF_{\mathrm{C2H6[NMC–FID]}}$ = the combined C_2H_6 response factor and penetration fraction of the NMC, according to § 1065.365(f).

$PF_{\mathrm{CH4[NMC–FID]}}$ = NMC CH_4 penetration fraction, according to § 1065.365(f).

$RF_{\mathrm{CH4[THC–FID]}}$ = response factor of THC FID to CH_4, according to § 1065.360(d).

Example:

$x_{\mathrm{THC[NMC\text{-}FID]cor}} = 10.4\ \mu\mathrm{mol/mol}$

$x_{\mathrm{THC[THC\text{-}FID]cor}} = 150.3\ \mu\mathrm{mol/mol}$

$RFPF_{\mathrm{C2H6[NMC\text{-}FID]}} = 0.019$

$PF_{\mathrm{CH4[NMC\text{-}FID]}} = 0.990$

$RF_{\mathrm{CH4[THC\text{-}FID]}} = 1.05$

$$x_{\mathrm{CH4}} = \frac{10.4 - 150.3 \cdot 0.019}{0.990 - 0.019 \cdot 1.05}$$

$x_{\mathrm{CH4}} = 7.78\ \mu\mathrm{mol/mol}$

(2) For a GC–FID or FTIR, χ_{CH4} is the actual dry-to-wet corrected CH_4 concentration as measured by the analyzer.

(e) *C_2H_6 determination.* For a GC–FID or FTIR, χ_{C2H6} is the C_1-equivalent, dry-to-wet corrected C_2H_6 concentration as measured by the analyzer.

■ 125. Amend § 1065.670 by revising paragraphs (a) introductory text and (b) introductory text to read as follows:

§ 1065.670 NO_X intake-air humidity and temperature corrections.

* * * * *

(a) For compression-ignition engines operating on carbon-containing fuels and lean-burn combustion engines operating on fuels other than carbon-containing fuels, correct for intake-air humidity using the following equation:

* * * * *

(b) For spark-ignition engines operating on carbon-containing fuels and stoichiometric combustion engines operating on fuels other than carbon-containing fuels, correct for intake-air humidity using the following equation:

* * * * *

■ 126. Amend § 1065.750 by revising paragraph (a)(1)(ii) and adding paragraph (a)(6) to read as follows:

§ 1065.750 Analytical gases.

* * * * *

(a) * * *

(1) * * *

(ii) Contamination as specified in the following table:

TABLE 1 OF § 1065.750—GENERAL SPECIFICATIONS FOR PURIFIED GASES[a]

Constituent	Purified air	Purified N_2
THC (C_1-equivalent)	≤0.05 µmol/mol	≤0.05 µmol/mol
CO	≤1 µmol/mol	≤1 µmol/mol
CO_2	≤10 µmol/mol	≤10 µmol/mol
O_2	0.205 to 0.215 mol/mol	≤2 µmol/mol
NO_X	≤0.02 µmol/mol	≤0.02 µmol/mol
N_2O[b]	≤0.02 µmol/mol	≤0.02 µmol/mol
H_2[c]	≤1 µmol/mol	≤1 µmol/mol
NH_3[d]	≤1 µmol/mol	≤1 µmol/mol
H_2O[e]	≤5 µmol/mol	≤5 µmol/mol

[a] We do not require these levels of purity to be NIST-traceable.

[b] The N_2O limit applies only if the standard-setting part requires you to report N_2O or certify to an N_2O standard.

[c] The H_2 limit only applies for testing with H_2 fuel.

[d] The NH_3 limit only applies for testing with NH_3 fuel.

[e] The H_2O limit only applies for water measurement according to § 1065.257.

* * * * *

(6) If you measure H_2O using an FTIR analyzer, generate H_2O calibration gases with a humidity generator using one of the options in this paragraph (a)(6). Use good engineering judgment to prevent condensation in the transfer lines, fittings, or valves from the humidity generator to the FTIR analyzer. Design your system so the wall temperatures in the transfer lines, fittings, and valves from the point where the mole fraction of H_2O in the humidified calibration gas, χ_{H2Oref}, is measured to the analyzer are at a temperature of (110 to 202) °C. Calibrate the humidity generator upon initial installation, within 370 days before verifying the H_2O measurement of the FTIR, and after major maintenance. Use the uncertainties from the calibration of the humidity generator's measurements and follow NIST Technical Note 1297 (incorporated by reference, see § 1065.1010) to verify that the amount of H_2O in the calibration gas, χ_{H2Oref}, is determined within ±3% uncertainty, U_{xH2O}. If the humidity generator requires assembly before use, after assembly follow the instrument manufacturer's instructions to check for leaks. You may generate the H_2O calibration gas using one of the following options:

(i) Bubble gas that meets the requirements of paragraph (a)(1) of this section through distilled H_2O in a sealed vessel. Adjust the amount of H_2O in the calibration gas by changing the temperature of the H_2O in the sealed vessel. Determine absolute pressure, p_{abs}, and dewpoint, T_{dew}, of the humidified gas leaving the sealed vessel. Calculate the amount of H_2O in the calibration gas as described in § 1065.645(a) and (b). Calculate the uncertainty of the amount of H_2O in the calibration gas, U_{xH2O}, using the following equations:

$$\frac{\partial x_{\mathrm{H2O}}}{\partial T_{\mathrm{dew}}} = x_{\mathrm{H2O}} \cdot \left(\frac{6790.241 + 2.961487 \cdot 10^{4.76955 \cdot \left(1 - \frac{273.16}{T_{dew}}\right)}}{T_{\mathrm{dew}}^2} - \frac{5.028}{T_{\mathrm{dew}}} + 2.423229 \cdot 10^{-5} \cdot 10^{-8.2969 \cdot \left(\frac{T_{\mathrm{dew}}}{273.16} - 1\right)} \right)$$

Eq. 1065.750-1

$$\frac{\partial x_{\mathrm{H2O}}}{\partial p_{\mathrm{abs}}} = -1 \cdot \frac{x_{\mathrm{H2O}}}{p_{\mathrm{abs}}}$$

Eq. 1065.750-2

$$U_{x_{\mathrm{H2O}}} = \sqrt{\left(\frac{\partial x_{\mathrm{H2O}}}{\partial p_{\mathrm{abs}}} \cdot U_{\mathrm{p_{abs}}}\right)^2 + \left(\frac{\partial x_{\mathrm{H2O}}}{\partial T_{\mathrm{dew}}} \cdot U_{\mathrm{T_{dew}}}\right)^2}$$

Eq. 1065.750-3

Where:

T_{dew} = saturation temperature of water at measured conditions.
$U_{T_{\text{dew}}}$ = expanded uncertainty (k = 2) of the measured saturation temperature of water at measured conditions.
p_{abs} = wet static absolute pressure at the location of the dewpoint measurement.
$U_{p_{\text{abs}}}$ = expanded uncertainty (k = 2) of the wet static absolute pressure at the location of the dewpoint measurement.
$\frac{\partial x_{\text{H2O}}}{\partial T_{\text{dew}}}$ = partial derivative of x_{H2O} with respect to T_{dew}.
$\frac{\partial x_{\text{H2O}}}{\partial p_{\text{abs}}}$ = partial derivative of x_{H2O} with respect to p_{abs}.
x_{H2O} = amount of water in the calibration gas.
$U_{x_{\text{H2O}}}$ = expanded uncertainty (k = 2) of the amount of H_2O in the calibration gas.

Example:

T_{dew} = 39.5 °C = 312.65 K
$U_{T_{\text{dew}}}$ = 0.390292 K
p_{abs} = 99.980 kPa
$U_{p_{\text{abs}}}$ = 1.15340 kPa

Using Eq. 1065.645-1,
x_{H2O} = 0.0718436 mol/mol

$$\frac{\partial x_{\text{H2O}}}{\partial T_{\text{dew}}} = 0.0718436 \cdot \left(\frac{6790.241 + 2.961487 \cdot 10^{4.76955 \cdot \left(1 - \frac{273.16}{312.65}\right)}}{312.65^2} - \frac{5.028}{312.65} + 2.423229 \cdot 10^{-5} \cdot 10^{-8.2969 \cdot \left(\frac{312.65}{273.16} - 1\right)} \right)$$

$$\frac{\partial x_{\text{H2O}}}{\partial T_{\text{dew}}} = 0.00384409\ (mol/mol)/K$$

$$\frac{\partial x_{\text{H2O}}}{\partial p_{\text{abs}}} = -1 \cdot \frac{0.0718436}{99.980}$$

$$\frac{\partial x_{\text{H2O}}}{\partial p_{\text{abs}}} = -0.000718580\ (mol/mol)/kPa$$

$$U_{x_{\text{H2O}}} = \sqrt{(-0.000718580 \cdot 1.15340)^2 + (0.00384409 \cdot 0.390292)^2}$$

$$U_{x_{\text{H2O}}} = 0.00171402 \text{ mol/mol}$$

(ii) Use a device that introduces a measured flow of distilled H_2O as vapor into a measured flow of gas that meets the requirements of paragraph (a)(1) of this section. Determine the molar flows of gas and H_2O that are mixed to generate the calibration gas.

(A) Calculate the amount of H_2O in the calibration gas as follows:

$$x_{\mathrm{H2O}} = \frac{\dot{n}_{\mathrm{H2O}}}{\dot{n}_{\mathrm{gas}} + \dot{n}_{\mathrm{H2O}}}$$

Eq. 1065.750-4

(B) Calculate the uncertainty of the amount of H_2O in the generated calibration gas, $U_{x\mathrm{H2O}}$, using the following equations:

$$\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{gas}}} = -1 \cdot \frac{\dot{n}_{\mathrm{H2O}}}{\left(\dot{n}_{\mathrm{gas}} + \dot{n}_{\mathrm{H2O}}\right)^2}$$

Eq. 1065.750-5

$$\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{H2O}}} = \frac{\dot{n}_{\mathrm{gas}}}{\left(\dot{n}_{\mathrm{gas}} + \dot{n}_{\mathrm{H2O}}\right)^2}$$

Eq. 1065.750-6

$$U_{x_{\mathrm{H2O}}} = \sqrt{\left(\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{gas}}} \cdot U_{\dot{\mathrm{n}}_{\mathrm{gas}}}\right)^2 + \left(\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{H2O}}} \cdot U_{\dot{\mathrm{n}}_{\mathrm{H2O}}}\right)^2}$$

Eq. 1065.750-7

Where:

$\dot{n}_{\mathrm{gas}}$ = molar flow of gas entering the humidity generator.
$U_{\dot{\mathrm{n}}_{\mathrm{gas}}}$ = expanded uncertainty (k=2) of the molar flow of gas entering the humidity generator.
$\dot{n}_{\mathrm{H2O}}$ = molar flow of H_2O entering the humidity generator, mol/s.
$U_{\dot{\mathrm{n}}_{\mathrm{H2O}}}$ = expanded uncertainty (k=2) of the molar flow of H2O entering the humidity generator.
$\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{gas}}}$ = partial derivative of x_{H2O} with respect to $\dot{n}_{\mathrm{gas}}$.
$\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{H2O}}}$ = partial derivative of x_{H2O} with respect to $\dot{n}_{\mathrm{H2O}}$.
x_{H2O} = amount of H_2O in the calibration gas.
$U_{x_{\mathrm{H2O}}}$ = expanded uncertainty (k=2) of the amount of H_2O in the generated calibration gas.

(C) The following example is a solution for $U_{x\mathrm{H2O}}$ using the equations in paragraph (c)(6)(B) of this section:

$$\dot{n}_{\mathrm{H2O}} = 0.00138771\ \mathrm{mol/s}$$
$$U_{\dot{\mathrm{n}}_{\mathrm{gas}}} = 0.000226137\ \mathrm{mol/s}$$
$$\dot{n}_{\mathrm{gas}} = 0.0148680\ \mathrm{mol/s}$$
$$U_{\dot{\mathrm{n}}_{\mathrm{H2O}}} = 0.0000207436\ \mathrm{mol/s}$$
$$x_{\mathrm{H2O}} = \frac{0.00138771}{0.0148680 + 0.00138771}$$
$$x_{\mathrm{H2O}} = 0.0853676\ \mathrm{mol/mol}$$
$$\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{gas}}} = -1 \cdot \frac{0.00138771}{(0.0148680 + 0.00138771\,)^2}$$

$$\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{gas}}} = -5.25155\ (mol/mol)/(mol/s)$$
$$\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{H2O}}} = \frac{0.0148680}{(0.0148680 + 0.00138771\,)^2}$$
$$\frac{\partial x_{\mathrm{H2O}}}{\partial \dot{n}_{\mathrm{H2O}}} = 56.2653\ (mol/mol)/(mol/s)$$
$$U_{\mathrm{x}_{\mathrm{H2O}}} = \sqrt{(-5.25155\ \cdot 0.000226137)^2 + (56.2653 \cdot 0.0000207436)^2}$$
$$U_{\mathrm{x}_{\mathrm{H2O}}} = 0.00166510\ \mathrm{mol/mol}$$

* * * * *

■ 127. Amend § 1065.1001 by:

■ a. Adding definitions of "Carbon-containing fuel", "Lean-burn engine", and "Neat" in alphabetical order; and

■ b. Revising the definition for "Rechargeable Energy Storage System (RESS)".

The additions and revisions read as follows:

§ 1065.1001 Definitions.

* * * * *

Carbon-containing fuel means an engine fuel that is characterized by compounds containing carbon. For example, gasoline, diesel, alcohol, liquefied petroleum gas, and natural gas are carbon-containing fuels.

* * * * *

Lean-burn engine means an engine with a nominal air fuel ratio substantially leaner than stoichiometric. For example, diesel-fueled engines are typically lean-burn engines, and gasoline-fueled engines are lean-burn engines if they have an air-to-fuel mass ratio above 14.7:1.

* * * * *

Neat means fuel that is free from mixture or dilution with other fuels. For example, hydrogen or natural gas fuel used without diesel pilot fuel are neat.

* * * * *

Rechargeable Energy Storage System (RESS) means engine or equipment components that store recovered energy for later use to propel the vehicle or accomplish a different primary function. Examples of RESS include the battery system or a hydraulic accumulator in a hybrid vehicle.

* * * * *

■ 128. Amend § 1065.1005 by revising the entry for M_{NMNEHC} in Table 7 of paragraph (f)(2) to read as follows:

§ 1065.1005 Symbols, abbreviations, acronyms, and units of measure.

* * * * *

(f) * * *

(2) * * *

TABLE 7 OF § 1065.1005—MOLAR MASSES

Symbol	Quantity	g/mol (10^{-3}·kg·mol^{-1})
* *	* * *	* *
M_{NMNEHC}	effective C_1 molar mass of nonmethane nonethane hydrocarbon[b]	13.875389
* *	* * *	* *

* * * * *

■ 129. Amend § 1065.1010 by revising paragraphs (a)(40) and (e)(2) to read as follows:

§ 1065.1010 Incorporation by reference.

* * * * *

(a) * * *

(40) ASTM D6348–12ε¹, Standard Test Method for Determination of Gaseous Compounds by Extractive Direct Interface Fourier Transform Infrared (FTIR) Spectroscopy, approved February 1, 2012 ("ASTM D6348"), IBR approved for §§ 1065.257(a), 1065.266(b), 1065.275(b), and 1065.277(b).

* * * * *

(e) * * *

(2) NIST Technical Note 1297, 1994 Edition, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, IBR approved for

§§ 1065.365(g), 1065.750(a), and 1065.1001.

PART 1074—PREEMPTION OF STATE STANDARDS AND PROCEDURES FOR WAIVER OF FEDERAL PREEMPTION FOR NONROAD ENGINES AND NONROAD VEHICLES

■ 130. The authority citation for part 1074 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

■ 131. Amend § 1074.10 by revising paragraph (b) and adding paragraph (c) to read as follows:

§ 1074.10 Scope of preemption.

* * * * *

(b) States and localities are preempted from adopting or enforcing standards or other requirements relating to the control of emissions from new locomotives and new engines used in locomotives.

(c) For nonroad engines or vehicles other than those described in paragraph (a) and (b) of this section, States and localities are preempted from enforcing any standards or other requirements relating to control of emissions from nonroad engines or vehicles except as provided in subpart B of this part.

§ 1074.12 [Removed]

■ 132. Remove § 1074.12.

■ 133. Amend § 1074.101 by revising paragraph (a) to read as follows:

§ 1074.101 Procedures for California nonroad authorization requests.

(a) California must request authorization from the Administrator to enforce its adopted standards and other requirements relating to control of emissions from nonroad engines or vehicles that are not preempted by § 1074.10(a) or (b). The request must include the record on which the state rulemaking was based.

* * * * *

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