EPA Responses to HD TRUCS Peer Review Comments

Introduction

EPA developed a flexible spreadsheet-based framework called the Heavy-Duty Technology Resource Use Case Scenario (HD TRUCS) tool. The tool in its original form is used to evaluate internal combustion engine (ICE) vehicles, battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) but could be adapted to evaluate other technologies. HD TRUCS is an analytic tool for assessing heavy-duty vehicle suitability, cost, and payback comparisons between BEV and FCEV technologies as compared to a comparable ICE vehicle, based on data and resources available to EPA at the time of the analysis. The tool was developed to support EPA's technical assessment to support the Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles: Phase 3 rulemaking. Details, including the methodologies, equations, and inputs used in HD TRUCS, are included in Chapter 2 of the Regulatory Impact Analysis (RIA) that supports the final rule.[1] In addition, EPA responded to public comments received regarding this original HD TRUCS version in Section 3 of the Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles: Phase 3 Response to Comments document.[2]

This document contains EPA's responses to the comments received from an External Peer Review of the HD TRUCS tool. The peer review was conducted by Eastern Research Group (ERG) under Work Assignment 4-22 under EPA Contract 68HE0C18C0001. The contractor was asked to identify a group of independent subject matter experts and then facilitate each member's review and comment of this report. The reviewers were asked for expert opinions on the methodologies, cost inputs of the tool, and whether they are likely to yield an accurate assessment of the true cost of ownership of vehicles and their subsystems. The specific charge questions and the reviewers' detailed responses are provided in the Peer Review Report. The sections below include the text of the peer reviewers' responses to each charge question in each of two categories—methodology/results and editorial content—followed by EPA's responses.

[1] U.S. EPA." Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles: Phase 3— Regulatory Impact Analysis." March 2024. EPA-420-R-24-006. Docket EPA-HQ-OAR-2022-0985. Referred to as "HD GHG Phase 3 RIA" in this document. More information can be found at https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-greenhouse-gas-emissions-commercial-trucks.

[2] U.S. EPA. "Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles: Phase 3 Response to Comments. . EPA-420-R-24-007. Docket EPA-HQ-OAR-2022-0985. March 2024.

Questions about Methodology/Results

1.a: Is the methodology documented in the report generally reasonable and likely to yield accurate results? Is any bias likely to be introduced to the results due to methodological issues? If so, please indicate the direction of this bias and potential remedies.

Reviewer 1: Dr. Baha Al-Alawi

Reviewer Comment: Taking the average in such an analysis is risky and will not yield accurate results in a dynamic and changing market. The structure of the model prevents simulating annual (year by year) operations and, therefore, the operating costs for each vehicle.

EPA Response:
We have revised HD TRUCS to evaluate operating costs on a year-by-year basis. This approach more accurately captures changes in annual miles traveled, maintenance and repair costs, and changes to fuel and charging costs that vary by either the age of the vehicle or the calendar year of analysis.

Reviewer Comment: The developed tool and analysis/simulation run nationally and is a very big assumption. If it is hard to simulate by state, it will be better to divide the U.S. into three regions. For example, divide states based on regulation (innovative (ACT), early majority (MOU), and laggers (non-MOU)). This will allow the opportunity to include any available incentives that will lower BEV/FCV retail prices and support infrastructure (availability and incentives).

EPA Response:
The purpose of this tool is to evaluate the vehicles on a nationwide level because it is being used to support a federal rulemaking. Vehicle manufacturers design vehicles that operate in all states. HD TRUCS includes consideration of the energy demand due to heating, ventilation, and air conditioning (HVAC) and battery thermal conditioning that vary with ambient temperature. We agree that there are additional state incentives available today to support HD vehicles, however, the impact of these incentives in the model year (MY) 2027 through 2032 is not clear and we have taken a conservative approach to not include any additional incentives beyond those offered at the federal level.

Reviewer Comment: VMT of each vehicle/vocation declines over time. New vehicles are driven more in the early years, so their fuel consumption is higher in addition to their operating costs (fuel consumption, and maintenance costs). This impacts their payback. Taking the average will treat new, used, and old vehicles the same.

EPA Response:
EPA has addressed this comment in the final version of HD TRUCS; we are no longer using a 10-year average of VMT or 10-year average of maintenance and

repair cost but are instead assessing year-by-year operational costs when determining the payback period.

Reviewer Comment: Taking the average of fuel/energy consumption per mile over the life of the vehicle is another issue as the vehicle's performance declines over time. Again, an annual estimation is needed, and simulating annual fuel consumption is the right path.

EPA Response:
EPA does not expect a vehicle's performance to degrade during the period assessed in HD TRUCS.

Reviewer Comment: The model uses fixed Diesel, electricity, and hydrogen prices. (The model uses only one diesel price, $3.15/gallon over the period and nationally. The model uses only one price of electricity, $0.11/kWh, over the period and nationally. The model uses only one price of hydrogen, $6.1/Kg over the period and nationally.) Fuel/energy prices change over time and vary by state.

EPA Response:
For the final version of HD TRUCS, fuel and charging costs are calculated on an annual year-by-year basis. These costs represent a national-average cost because we are evaluating the vehicles on a nationwide basis.

The diesel fuel prices for each year are those projected by the Energy Independence Administration's Annual Energy Outlook (AEO) 2023 Reference Case scenario, the latest information available. EIA is the recognized official source for such projections. We have used AEO Reference Case scenarios in each of our Heavy-Duty (HD) Greenhouse Gase (GHG) emission standards rulemakings to date and are continuing to do so for this work.

For the final version of HD TRUCS, we differentiate between depot charging and public charging when assigning charging costs. We also have updated the charging costs for the final version of HD TRUCS. As described in HD GHG Phase 3 RIA Chapter 2.4.4.2, we modeled future electricity prices, as charged by utilities, that account for the costs of BEV charging demand and the associated distribution system upgrade costs.[3] We do this in three steps: 1) we model future power generation using the Integrated Planning Model (IPM), 2) we estimate the cost of distribution system upgrades associated with charging demand through the DOE Transportation Electrification Impact Study (TEIS),[4] and 3) we use the Retail Price Model (RPM) to project electricity prices accounting for both (1) and (2). The resulting national average retail prices, which include distribution upgrade costs, were used as a basis for the charging costs in HD TRUCS. We also included EVSE maintenance costs based on the estimate from a recent ICCT

[3] U.S. EPA." Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles: Phase 3— Regulatory Impact Analysis." March 2024. EPA-420-R-24-006. Docket EPA-HQ-OAR-2022-0985.
[4] National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, Kevala Inc., and U.S. Department of Energy. "Multi-State Transportation Electrification Impact Study: Preparing the Grid for Light-, Medium-, and Heavy-Duty Electric Vehicles". DOE/EE-2818. U.S. Department of Energy. March 2024. ("TEIS").

paper[5] of $0.0052 per kWh. Our public charging price additionally includes the amortized cost of public charging equipment and land costs for the station; we project that third parties may install and operate these stations and pass costs onto BEV owners via charging costs. For public charging, we use a total charging cost of 19.6 cents per kWh, from an ICCT paper and as recommended by DTNA, for 2027.[6] We adjust it for future years according to the results of the IPM Retail Price Model.

EPA discusses the issue of hydrogen cost in detail in the HD GHG Phase 3 RIA Chapter 2.5.3.1, which includes a review of literature. We note here in summary that our original estimate of a retail hydrogen price of $4 per kg in 2030 was adjusted higher in this final version of HD TRUCS to $6 per kg in 2030 and dropping to $4 per kg in 2035. This is intended to reflect a price that fleet owners would pay at hydrogen refueling stations.

Reviewer Comment: Scheduled maintenance and replacement vary over the life of the vehicle. The cost increases over the vehicle's life as more replacement is needed (Auxiliary battery, tires, brakes, ICE components). Since maintenance costs are a benefit of BEV/FCV over ICE, a maintenance model is needed. Since it is incorrect, I am against using fixed maintenance costs ($/miles) for each vehicle. The model has annual maintenance costs ($/miles_year1, … $/miles_year10), but increase over the vehicle's life. That is true, but the costs have peaks due to some scheduled maintenance and replacement costs that occur when the vehicle hits a certain mile or time (year).

EPA Response:

To establish a baseline cost for maintenance and repair of diesel-fueled ICE vehicles, we relied on the research compiled by Burnham et al. in Chapter 3.5.5 of "Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains"[7,8] and used equations found in the 2022 BEAN tool (see the "TCO" tab).[9] Burnham et al. used data from Utilimarc and American Transportation Research Institute (ATRI) to estimate maintenance and repair costs per mile for multiple heavy-duty vehicle categories over time. M&R cost per mile (2022$/mi) are shown in the figure below. As shown below, the M&R costs increase with both vehicle age and with miles travelled.

[5] Hussein Basma, Claire Buysee, Yuanrong Zhou, and Felipe Rodriguez. "Total Cost of Ownership of Alternative Powertrain Technologies for Class 8 Long-haul Trucks in the United States." April 2023. Available online: https://theicct.org/wp-content/uploads/2023/04/tco-alt-powertrain-long-haul-trucks-us-apr23.pdf.

[6] Hussein Basma, Claire Buysee, Yuanrong Zhou, and Felipe Rodriguez. "Total Cost of Ownership of Alternative Powertrain Technologies for Class 8 Long-haul Trucks in the United States." April 2023. Available online: https://theicct.org/wp-content/uploads/2023/04/tco-alt-powertrain-long-haul-trucks-us-apr23.pdf.

[7] Burnham, Andrew, David Gohlke, Luke Rush, Thomas Stephens, Yan Zhou, Mark A. Delucchi, Alicia Birky, Chad Hunter, Zhenhong Lin, Shiqi Ou, Fei Xie, Camron Proctor, Steven Wiryadinata, Nawei Liu, and Madhur Boloor. "Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains". April 2021. Accessible online: https://publications.anl.gov/anlpubs/2021/05/167399.pdf.

[8] Burnham, et al uses 2019$ in this report. See page 22 of https://publications.anl.gov/anlpubs/2021/05/167399.pdf.

[9] Argonne National Laboratory. VTO HFTO Analysis Reports – 2022. "ANL – ESD-2206 Report – BEAN Tool – MD HD Vehicle Techno-Economic Analysis.xlsm". Available online: https://anl.app.box.com/s/an4nx0v2xpudxtpsnkhd5peimzu4j1hk/folder/242640145714.

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EPA Response:

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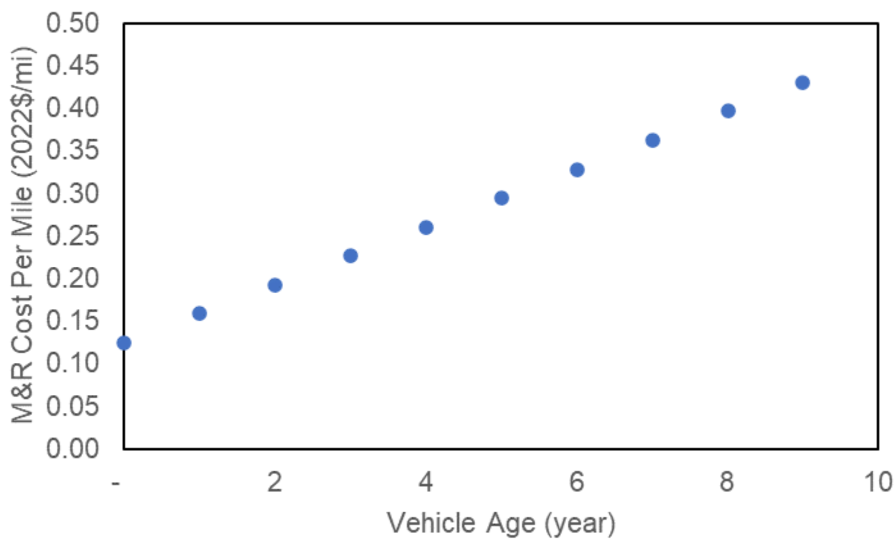

Figure 1 M&R Cost Per Mile (2022$/mi)

Reviewer Comment: The work needs to include other parameters that simulate the purchasers' decision-making process. Vehicle technology availability and affordability do not mean it is going to be purchased. Do fleets have the capital to make a purchase? Does the vehicle technology fit their business needs? Can OEMs have the capacity to produce and meet the US annual sales of each vehicle segment? The payback period is the 1st step in estimating the penetration rate of technology adoption. It represents the quantitative calculation. Our Drive to Zero work excludes the TCO (that calculates the payback period) and the associated S curve (fleet purchaser decision). The director of D2Z's decision was not to use it and only include the other qualitative parameters. It was driven by policy more than the market. The comprehensive model I developed in Saudi Aramco and expanded at CALSTART includes many parameters (TCO(Payback), access to capital, technology/vocation suitability(demand), OEM type (supply), logistics, infrastructure availability, Roger's Market (dividing the market into 5 or three types (innovators, early majority and late majority))).

EPA Response:

As detailed in HD GHG Phase 3 RIA Chapter 2.7, EPA is using an adapted version of the NREL's TEMPO model that considers many of the factors the reviewer mentions.

Reviewer Comment: It is risky to follow policy works. I did two modeling for CARB. The 1st one was to estimate California ZEV penetration based on available incentives, incentive levels per vehicle, and projected sales. The other one depends on the 1st, but it was to validate that we can meet certain penetration rates over MHDV classes (let's say some ACT numbers). We disaggregated the numbers over vehicle segments and used available purchased (IHS DMV) sales numbers with our estimated penetration (1st modeling) for each vehicle category. Our work proved that we could meet and exceed the ZEV penetration numbers. Let me say that California has the largest incentive program in ACT state, and the state (9-10% of the U.S. MHDV sales) is an example of an innovative state. Other states are MOU and non-MOU. I am working on my Harvard capstone project, where I developed three scenarios: Scenario 1 (simulating 5 federal incentives policies, TCO/payback, and other qualitative parameters), Scenario 2 (No TCO/payback but with the other qualitative parameters, following the D2Z U.S. national curves), and Scenario 3(TCO/payback and other qualitative parameters, market without incentives but with ZEV technology retail price decline). My finding was, TCO/payback is significant at the early stage, 1-7 years, then the market will follow the S curves consented by the other qualitative parameters (supply/demand, logistics, and infrastructure).

EPA Response:

This comment is similar to the methodology EPA utilized in crafting the final version, which accounts for various incentives provided by the IRA, and likewise accounts for payback and TCO in a manner similar to that suggested by the reviewer.

Reviewer 2: Dr. Thomas Bradley

Reviewer Comment: It is difficult for me to see whether this is a bug or a bigger conceptual problem, but I think that you all should look pretty carefully at why the adoption rate for BEV Transit buses is modeled at ~0%, while the reality is that ZEV buses will be 100% of many state's transit bus portfolio by 2030. For example, Class 8 transit bus (Payback sheet, Column I, Row 91) has a <5Y payback period, but has <0.2% adoption (Adoption Sheet, Column M, Row 91) in 2032?

First, it seems that the adoption rate interpolation is not working correctly (Summary Sheet, B45, and associated code), but the algorithm there uses some combination of Sheets 4, 4a, and 4b, and I cannot really debug that code.

Second, municipal bus fleet operators operate in a more complicated world of grants and payback than is acknowledged here. They will adopt at a higher rate if payback period is <5y, they have access to state and other federal funding, but also <50% of bus sales in the US are diesel so fleets are not always making a comparison to diesel as a baseline, but to biodiesel, or CNG.

I recommend that you adjust the relationship between payback periods and adoption by vehicle type to avoid such a glaring misprediction. Similar mispredictions could be present in other near-term BEV-ready vehicle types such as school buses, box trucks, etc.

EPA Response:
We note that the transit bus adoption rates highlighted by the commenter represent the HD fleet sales-weighted average adoption rate, not the adoption rate for just that vehicle type. The vehicle noted by the commenter had a 35% adoption rate in the original version of HD TRUCS.

We have made several updates to the final version of HD TRUCS that impact the adoption rates, as detailed in HD GHG Phase 3 RIA Chapter 2. Specifically for transit buses, we project adoption rates up to 39% in MY 2032 with the final version of HD TRUCS. We acknowledge that there may be additional grants available for municipal bus fleets, but we have taken a conservative approach to our cost estimates and only reflect the IRA battery, vehicle, and EVSE tax credits. The IRA,[10] contains several provisions relevant to vehicle electrification and the associated infrastructure via tax credits, grants, rebates, and loans through CY 2032, including three key provisions that provide tax credits to reduce the cost of producing qualified batteries (battery tax credit), purchasing qualified ZEVs (vehicle tax credit), and installing qualified refueling infrastructure (EVSE tax credit). The battery tax credit in "Advanced Manufacturing Production Credit" in IRA section 13502, the "Qualified Commercial Clean Vehicles" vehicle tax credit in IRA section 13403, and the "Alternative Fuel Vehicle Refueling Property Credit" in IRA section 13404 are included quantitatively in our analysis.

Reviewer Comment: I think that you all have a real problem in sizing the FCEV batteries.

On one end of the sizing spectrum, the small FCEV vehicles are very unconventional in that they have very large batteries and very small fuel cells (see FCEV Tech cell X8). For example, the Class 2b Ambulance FCEV has a 44kWh battery, while the Class 2b Ambulance BEV has a 100kWh battery. The FCEV fuel cell is only sized to generate 93kW of the 259kW required to drive the vehicle, and only stores 67kWh of DC energy as hydrogen (67kWh=65%*3.13kg*33kWh/kg). This ratio of battery power and energy to fuel cell power and energy would be characterized as some kind of a battery dominant

[10] Inflation Reduction Act of 2022, Pub. L. No. 117-169, 136 Stat. 1818 (2022) ("Inflation Reduction Act" or "IRA"), available at https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf.

fuel cell hybrid. A pretty unconventional vehicle; is it a Fuel Cell PHEV? Does it need a charger to maintain a battery that is 2x bigger than the battery for a Nissan Leaf (Gen 1)?

On the other end, the batteries that are in the Class 8 Tractors are too small. '82_TractorDCCl8_R' has only 72kWh of battery (less than 2x the ambulance above). This is not large enough to allow for climbing, or for downhill speed control through regen braking in over the road "rural" class 8 trucks. The class 8 vehicles under production now have PTC dissipation resistors to enable regen braking at high states of charge, or else they have electrical or hydraulic "retarders". Either way these costs should be included in the component costs for the vehicle (see comment under Inputs)

So overall, the fuel cell vehicles seem to be optimized to reduce their costs, instead of optimized for realistic performance and comparability to conventional ICEVs.

EPA Response:

Vehicle power in a fuel cell electric vehicle (FCEV) comes from a combination of the fuel cell stack and the battery pack. The fuel cell converts chemical energy stored in the hydrogen fuel into electrical energy. The battery is charged by power derived from regenerative braking, as well as excess power from the fuel cell. Some FCEVs are designed to rely on the fuel cell stack to produce the necessary power, with the battery primarily used to capture energy from regenerative braking. This is the type of HD FCEV that we modeled in HD TRUCS for the MY 2030 to 2032 timeframe in order to meet the longer distance requirements of select vehicle applications.[11,12,13]

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 batteries with energy cells (described in HD GHG Phase 3 RIA Chapter 1.7.2), where the fuel cell and the battery were sized based on the demands of the vehicle. In HD TRUCS, the fuel cell system (i.e., fuel cell stacks plus balance of plant, or BOP) was sized at either the 90th percentile of power required for driving the ARB transient cycle or to maintain a constant highway speed of 75 mph with 80,000-pound gross combined vehicle weight (GCVW). The 90th percentile power

[11] 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://anl.app.box.com/s/an4nx0v2xpudxtpsnkhd5peimzu4j1hk/file/1406494585829.

[12] Note that ANL's analysis defines a fuel cell hybrid EV (FCHEV) as a battery-dominant vehicle with a large energy battery pack and a small fuel cell, and a fuel cell EV (FCEV) 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 large battery with energy cells. The approach we took is intended to cover a wide range of vehicle applications however it results in a conservative design, as it relies on a large fuel cell and a larger energy battery. As manufacturers design FCEV for specific HD applications, they will likely end up with a more optimized lower cost designs. Battery-dominant FCHEVs and fuel cell-dominant technologies with power batteries may also be feasible in this timeframe but were not evaluated in HD TRUCS.

[13] FEV Consulting. "Heavy Duty Commercial Vehicles Class 4 to 8: Technology and Cost Evaluation for Electrified Powertrains—Final Report". Prepared for EPA. March 2024.

requirement was used to size the fuel cells of vocational vehicles and day cab tractors, and the 75 mph power requirement was used to size the fuel cells of sleeper cab tractors.

As explained below, we revised our sizing methodology for the fuel cell system and the FCEV batteries in the final rule version of HD TRUCS.

To avoid undersizing the fuel cell system, we oversized the fuel cell stack by an additional 25 percent to allow for occasional scenarios where the vehicle requires more power (e.g., to accelerate when the battery state of charge is low, to meet unusually long grade requirements, or to meet other infrequent extended high loads like a strong headwind) and so the fuel cell can operate within an efficient region. This size increase we included in the final rule version of HD TRUCS can also improve fuel cell stack durability and ensure the fuel cell stack can meet the power needs throughout the useful life. This is the system's net peak power, or the amount available to power the wheels.[14] The fuel cell stack generates power, but some power is consumed to operate the fuel cell system before it gets to the e-motor. Therefore, we increased the size of the system by an additional 20 percent[15] to account for operation of balance of plant components that ensure that gases entering the system are at the appropriate temperature, pressure, and humidity and remove heat generated by the stack. This is the fuel cell stack gross power.

The larger fuel cell can allow the system to operate more efficiently based on its daily needs, which results in less wasted energy and lower fuel consumption. This additional size also adds durability, which is important for commercial vehicles, by allowing for some degradation over time. We determined that with this upsizing, there is no need for a fuel cell system replacement within the 10-year period at issue in the HD TRUCS analysis.

In HD TRUCS, the battery power accounts for the difference between the peak power of the e-motor and the continuous power output of the fuel cell system. We sized the battery to meet these power needs in excess of the fuel cell'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).

Since a FCEV operates like a hybrid vehicle, where instantaneous power comes from a combination of the fuel cell stack and the battery, the battery is sized smaller than a battery in a BEV, which can result in more cycling of the FCEV battery. Thus, we reduced the FCEV battery's depth of discharge from 80 percent in the NPRM to 60 percent in the final rule version of HD TRUCS to reflect the

[14] Net system power is the gross stack power minus balance of plant losses. This value can be called the rated power.
[15] Huya-Kouadio, Jennie and Brian D. James. "Fuel Cell Cost and Performance Analysis: Presentation for the DOE Hydrogen Program; 2023 Annual Merit Review and Peer Evaluation Meeting". Strategic Analysis. June 6, 2023. Available online: https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review23/fc353_james_2023_o-pdf.pdf.

usage of a hybrid battery more accurately. This means the battery is oversized by in HD TRUCS to account for potential battery degradation over time.[16]

As discussed in HD GHG Phase 3 RIA Chapter 2, the 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 battery electric vehicle (BEV) to meet peak power needs of a vehicle, which is the maximum requirement 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.

Reviewer Comment: Similarly, I also don't understand the FCEV Fuel Cell sizing. Why is the fuel cell for (for example) the 82_TractorDCCl8_R sized at less than the power it takes to maintain 75mph? Why is the fuel cell sized at less than the power it takes to grade climb at 25mph? This spreadsheet chooses whichever of the power calculations is less (cycle power, or 75mph cruise), why shouldn't it choose whichever is more? The vehicles in this spreadsheet are not full function ZEVs, and do not have performance comparable to the conventional vehicle, which weakens the case for their comparability.

EPA Response:

As explained in the previous response, we revised our sizing methodology for the fuel cell system in the final rule version of HD TRUCS.

Reviewer Comment: Do the FCEV cost models include the power DCDC converter? It appears not. This component converts/boosts fuel cell output electrical potential to match the battery potential (which is often substantially higher). DOE references used here do not seem to include any such costs in their models of HD FCEVs, but that is an error in their understanding of HD FCEVs. Right now, LD FCEV OEMs include/integrate these components in their inverter to share cooling plates, wiring, containment), but that is not the case right now for HD DC-DC converters, motors and inverters. EPA should be explicit about what is included in the cost modeling, and what its costs are.

EPA Response:

In the final version of HD TRUCS, we included costs for the power converter and electric accessories, including DC-DC converters, electric accessories, and vehicle propulsion architecture (VPA). This is described in HD GHG Phase 3 RIA Chapter 2.5.2.

As described in HD GHG Phase 3 RIA Chapter 2.4.3.2, the power converter and electric accessories costs in the HD TRUCS for both the proposal and final rule came from the "Autonomie Out Import" tab of ANL's 2022 BEAN tool.[17] For the

[16] Ceschia, et. al. "Optimal Sizing of Fuel Cell Hybrid Power Sources with Reliability Consideration". Energies, Volume 13, Issue 13. 2020. Available online: https://www.mdpi.com/1996-1073/13/13/3510.

[17] Argonne National Laboratory. VTO HFTO Analysis Reports – 2022. "ANL – ESD-2206 Report – BEAN Tool – MD HD Vehicle Techno-Economic Analysis.xlsm". Available online: https://anl.app.box.com/s/an4nx0v2xpudxtpsnkhd5peimzu4j1hk/folder/242640145714.

final version of HD TRUCS, we updated the term Power Electronics to Power Converter, which represents the cost of a DC-DC converter ($1500 in 2020$).[18] DC-DC converters transfer energy (i.e., they “step up” or “step down” voltage) between higher- and lower-voltage systems, such as from a high-voltage battery to a common 12V level for auxiliary uses.[19] We identified an additional cost in BEAN that we added as a second DC-DC converter, which we call an Auxiliary Converter.[20] We also revised the Electric Accessories costs to include both “ElecAccessory” ($4500 in 2020$) and vehicle propulsion architecture (VPA) costs ($186 in 2020$) from ANL’s 2022 BEAN. These values, as shown below in Table 1, were converted to 2022$ and include the BEV learning effects included in RIA Chapter 3.2.

Table 1 Direct Manufacturing Costs of Components (2022$)

MY	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Power Converter ($)	1677	1577	1501	1440	1391	1349
VPA	208	196	186	179	173	167
Electric Accessories ($)	5032	4731	4502	4321	4174	4048

Reviewer 3: Dr. William de Ojeda

Reviewer Comment: "The organization and content of TRUCS is noteworthy. The authors have provided an extensive list of applications, each very well represented. TRUCS looks at improving fuel efficiency and reducing GHG emissions based on engineering principles. The description of the technologies, particularly the state-of-art, of ICE, BEV and FCEV is quite impressive.

TRUCS notes that other technologies have been set aside owing to them not being ready for deployment. It is important to emphasize that new technologies need to be scientifically sound and ready for deployment for assessment under TRUCS. The technology readiness level needs to be assessed. BEV and Fuel Cells in this market segment do have a range of unknowns, if anything because of very limited real-life experience (extended field trials, hot-cold conditions, altitude). The product-to-market needs be practical, safe, and cost effective. It is important that the technologies presented here consider the complex challenges and operating conditions seen by the carriers. The tool would be significantly enhanced if:

- it provided a tab describing the technical specifications, performance characteristics of today’s available BEV and FCEV entries-to-market in the MD-HD segment.

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[18] In the 2022 version of BEAN, the “BEAN results” tab, this is also represented as “pc2 DC/DC booster”.

[19] Oak Ridge National Laboratory and National Renewable Energy Laboratory. 2019 ORNL/SPR-2020/7. “Medium- and Heavy-Duty Vehicle Electrification: An Assessment of Technology and Knowledge Gaps”. Available online: https://info.ornl.gov/sites/publications/Files/Pub136575.pdf.

[20] In the 2022 version of BEAN, the “Cost & LCOD & CCM” tab, this is called a “pc1 DC/DC ESS”. In the “Autonomie Out” tab, this is linked to a DC/DC converter cost.

• cross references made available to understand the performance benchmarks of these technologies in real-world operating conditions."

EPA Response:
We note that for the final rule, we evaluate a wide range of technologies inside HD TRUCS, including ICE vehicles, plug-in hybrids, BEVs, and FCEVs. Instead of including a tab with a market assessment of today's BEVs and FCEVs, we have included in RIA Chapter 1 an assessment of the current state of BEV, FCEV, and ICE technologies.

The primary performance benchmark we used was to evaluate BEVs and FCEVs such that they operate similar to today's ICE vehicles. In sizing the BEV and FCEV components, we used data covering average daily vehicle miles traveled (VMT) and the maximum power among the peak power requirement generated from the following performance targets: the peak required during the ARB transient cycle, 0-30 mph acceleration times, 0-60 mph acceleration times, and maintaining speed at 6 percent grade.

Reviewer Comment: Realistic adoption timelines are critical. User should be careful on these inputs. Premature timelines and non-fully vetted technologies will lead to high financial losses by the carriers.

EPA Response:
We applied a constraint within the original version of HD TRUCS that limited the maximum penetration of the BEV and FCEV technologies to 80 percent for any given vehicle type. This limit was developed after consideration of the actual needs of the purchasers related to two primary areas of our analysis. First, this 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 manufacturers 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 will need such specifications. Therefore, the ZEVs we analyzed and have used for the feasibility and cost projections for the proposal and final rule in this timeframe are likely not appropriate for 100 percent of the vehicle applications in the real-world. Our second consideration for including a limit for BEVs and FCEVs is that we recognize that there are a wide variety of real-world operations 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.

We re-evaluated the maximum penetration constraints for the final version of HD TRUCS. The constraints discussed above, such as the methodology to size the batteries and the recognition of the variety of real-world applications of heavy-duty trucks, still apply to the final rule analysis. Furthermore, we are taking a phased-in approach to the constraints to recognize that the ZEV market will take time to develop. We broadly considered the lead time necessary to increase heavy-duty battery production, which shows a growth in the planned battery production capacity from now through 2031 and other issues like critical minerals, and for manufacturers to design, develop, and manufacture ZEVs. We also have generally accounted for the time required for infrastructure, including the potential distribution grid buildout through 2032 as informed by the DOE's TEIS and discussed in HD GHG Phase 3 RIA Chapter 2.6.4. We see a similar trend in the growth of the infrastructure to support H2 refueling for FCEVs, as discussed in RIA Chapter 1.8.3.6. In recognition of these considerations, for the final version of HD TRUCS we applied more conservative maximum constraints. We limited the maximum penetration of the ZEV technologies in HD TRUCS for the final rule to 20 percent in MY 2027 and 70 percent in MY 2032.

Reviewer Comment: "A big unknown in real world use will be the impact these technologies will have in downtime and operational disruption. Tool will be enhanced if:

- Provide repair times and costs associated with these new technologies.
- Currently, input tab provides four entries on repairs, but these are not associated with new technologies, but for tractor and vocational vehicles in general."

EPA Response:
We do not expect maintenance downtime to be greater for ZEVs than for ICE vehicles; additionally, ZEVs will generally need less maintenance than ICE vehicles. We have included the cost of vehicle maintenance and repair, which includes costs for both ICE and ZEV vehicles.

It is generally typical for more expensive vehicles to have a higher cost to repair and thus have higher insurance premiums. For the final version of HD TRUCS, we included annual insurance costs based on the upfront cost differences among the technologies. We believe this is a reasonable approach to estimate the differences in annual insurance premiums, including differences associated with higher up-front, components, and repair costs. This value was added as an additional operating cost in the final version of HD TRUCS.

Reviewer Comment: These spreadsheets are VERY comprehensive. The authors have put a huge amount to work and detail on these sheets. It is very impressive.

EPA Response:
Thank you for the generous feedback.

Reviewer 4: Dr. Efstathios Michaelides

Reviewer Comment: The tool utilizes a simple payback period, which does not take into account the current value of future cash streams. This method is biased towards large future revenues. Decisions in industry (and this is more prevalent in inflationary periods) are made using the NPV (net present value), and the APW (annualized present worth).

I recommend that the tool uses either a APW or the " PV-payback" method in which future cash streams are discounted by the user's discount rate. The users will have to input their own corporations discount rates.

> EPA Response:
> The commenter is correct that the tool utilizes a simple payback period. We have done so because this tool is not intended for use by individual companies to make purchasing decisions. The tool was developed to assess the BEV and FCEV component and operating costs.

Reviewer Comment: There is a gross inconsistency in the calculated values for batteries under cold and hot weather. Columns L-Q of the FCEV sheet have the same name as columns O-T of the BEV sheet. However, the numbers in the columns (for the same vehicles and with the same units – kWh/day) are entirely different.

Recommendation: Check all the sheets and results for consistency. Make sure the tool is internally consistent.

> EPA Response: The columns referred to by the commenter represent the power required from the battery in the FCEV. Since the batteries in FCEVs have the same characteristics as batteries for BEVs, for battery conditioning, we used the methodology described in HD GHG Phase 3 RIA Chapter 2.4.1.1.2 for BEVs to estimate the energy consumption of the battery. In HD TRUCS, the FCEV battery power accounts for the difference between the peak power of the e-motor and the continuous power output of the fuel cell system. We sized the battery to meet these power needs in excess of the fuel cell'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). Since a FCEV operates like a hybrid vehicle, where instantaneous power comes from a combination of the fuel cell stack and the battery, the battery is sized smaller than a battery in a BEV, which is why the battery demand values on the FCEV tab is smaller.
>
> In addition, we have conducted additional quality assurance evaluations to ensure the results are internally consistent.

Reviewer Comment: The battery length is not given. From the volume (column AH) one may deduce the length. However, it appears that the batteries are very long (some 27' with L/W ratios close to 60). How will these stacks fare in a moving vehicle with vibrations? Also there are no EV commercial batteries with such shapes.

Recommendation: First: put width, depth and volume in the same units for consistency (now it is inches, feet and cubic meters). Second: Check these dimensions are correct using data from battery manufacturers. If possible, state what type and model of batteries the results are based on.

EPA Response:

We have taken a different approach to assess the packaging of batteries in BEVs where we compare the volume of each battery with comparable current BEVs in the market today and base our analysis on this information. As described in HD GHG Phase 3 RIA Chapter 2.9.1, we found that of the 101 vehicles that we are considering as BEVs, three vehicles had batteries that were greater than 15% larger than a comparable battery in a current BEV and five vehicles (including the three with batteries greater than 15% increase in battery size) had batteries that were 10% larger than comparable current BEVs.[21] Of the vehicles that had a 10% greater battery size than current BEVs, one is a coach bus that we instead evaluate as a fuel cell vehicle, two are sleeper cab tractors, one is a shuttle bus, and one is a transit bus. We conducted further analysis of specific vehicles, including an evaluation of battery volume with NiMn battery chemistry, which has a higher specific energy than the average battery analyzed in HD TRUCS and therefore requires less packaging volume.

Reviewer Comment: Columns T and U list the max. power and the "size" of the fuel cell in kW. However, the size is less than the max. power. What does this mean?

Recommendation: Clarify any assumptions here or write a manual for the entire tool that clarifies all assumptions.

EPA Response:

The "size" of the fuel cell stack is the peak power of the fuel cell stack measured in kW. It is equal to the maximum power required to meet the ARB Transient Cycle, 0-30 mph acceleration, 0-60 mph acceleration, and maintain a cruise speed at 6% grade. This is shown on tab A2_Power Sizing, columns S through W.

Chapter 2 of the HD GHG Phase 3 RIA describes our technology assessment for the final version of HD TRUCS including the methodologies and assumptions.

Reviewer Comment: Column W features the H2 mass. The values for some vehicles are very high (more than 30 kg). This entails very high pressures and volume of tanks. If hydrates are used very high weight.

Recommendation: Explain the pressure of H2 and check whether or not a commercial size H2 tank of this size is available.

EPA Response:

Some existing fuel cell buses use compressed hydrogen gas at 350 bar (~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

[21] Miller, Neil. See Memorandum to docket EPA-HQ-OAR-2022_0985. BEV Battery Packaging Analysis. March 3, 2024.

extended driving range.[22] As described in HD GHG Phase 3 RIA Chapter 1.7.3, we used storage tanks with gaseous hydrogen at 700 bar in our analysis. To inform the final version of HD TRUCS, we contracted FEV to conduct a packaging analysis for Class 8 long-haul FCEVs that store 700-bar gaseous hydrogen onboard.[23] FEV found ways to package six hydrogen tanks to deliver up to a 500-mile range using a sleeper cab with a 265-inch wheelbase. All tanks could be installed at the back of the cab and the batteries mounted outside of the frame rails, or four of the tanks could be behind the cab and two tanks mounted to the side frame under the cab if the battery pack can be placed between the frame rails.

Reviewer Comment: It is not certain from where the inputs in column C are adopted. However, reaching adoption rates as high as 80% within 9 years is extremely optimistic.

Recommendation: Explain your assumptions in a manual.

EPA Response:
We have made a number of changes to the adoption rates for the final version of HD TRUCS. The final adoption rates are shown below in Table 2 and are more conservative than the values used in the original version of HD TRUCS. The development of this schedule is discussed in HD GHG Phase 3 RIA Chapter 2.7.

Table 2 Payback Schedule Used in the Final Rule HD TRUCS

Payback Bins	MY 2027	MY 2030	MY 2032
<0	20%	37%	70%
0-1	20%	37%	70%
1-2	20%	37%	70%
2-4	20%	26%	39%
4-7	14%	14%	14%
7-10	5%	5%	5%
> 10	0%	0%	0%

Reviewer Comment: Line 23: The payback of BEV is 13 years and of FCEV 887 years. Why the adoption rate is 55% by 2032?

Recommendation: Explain your computations and all assumptions in a manual.

EPA Response:
The 55% adoption rate for the coach buses in the original version of HD TRUCS cited by the commenter was reflective of a FCEV in MY 2032. In that model year

[22] 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.
[23] FEV Consulting. "Heavy Duty Commercial Vehicles Class 4 to 8: Technology and Cost Evaluation for Electrified Powertrains—Final Report". Prepared for EPA. March 2024.

in the original HD TRUCS, the coach bus FCEV paid back in the first year after considering the IRA Vehicle Tax Credit of $40,000.

For the final version of HD TRUCS, we have modeled one coach bus as a FCEV and one as a BEV that utilizes public en-route charging. Using these designs and the other updates to HD TRUCS, such as including insurance costs, Federal Excise Tax, and state taxes, we now project the MY 2032 BEV and the FCEV coach bus pay back in four years with a 14% adoption rate.

1.b: Please identify any general flaws inherent in the scope of the tool. Do you feel the results would be altered if the scope were more limited or expanded? Please explain.

Reviewer 1: Dr. Baha Al-Alawi

Reviewer Comment: The tool could benefit from expanding and disaggregating. National run will not work but running over each state or at least dividing the states into regions (for example: by policy, or market) will better simulate each state's ZEV penetration.

EPA Response:
The purpose of this tool is to evaluate the vehicles on a nationwide level because it is being used to support a federal rulemaking. It is outside of the scope of this tool to evaluate ZEV adoption state-by-state.

Reviewer Comment: The tool excludes many of the needed qualitative parameters that form vehicles purchase decisions. Brand loyalty is one; word of mouth and technology reputation are another.

EPA Response:
We have revised our payback analysis based on the National Renewable Energy Laboratory's (NREL's) TEMPO model, as discussed in HD GHG Phase 3 RIA Chapter 2.7. TEMPO is "a transportation demand model that covers the entire U.S. transportation sector" including the medium- and heavy-duty market. Inputs to the model include vehicle cost and performance, fuel costs, charging and refueling availability, and travel behavior. The model receives this information and applies a technology adoption based on market segment, vehicle technology, scenario year, and vehicle class as a part of the outputs for TEMPO. The model uses a logit formulation to describe a relationship between purchaser adoption and aforementioned inputs, cost coefficients and financial horizon. The TEMPO model specifically evaluates HD ICE vehicles, BEVs, and FCEVs, which aligns with the technologies we are evaluating with the payback period curve. Our assessment is that the TEMPO model is more transparent than the approach we used for the original HD TRUCS. We also found NREL's TEMPO model and approach to be robust.

Our revised payback analysis does not quantitatively assess word of mouth or reputation. We do not have sufficient information on these factors to include in this assessment.

Reviewer Comment: Incorporating some scenario runs is needed to cover region and market variation. Maybe EPA can create and name some scenarios for the model to run. Such scenarios have a set of input data and options that can be populated and selected using micro.

EPA Response:
The purpose of this tool is to evaluate the vehicles on a nationwide level because it is being used to support a federal rulemaking. It is outside of the scope of this tool to evaluate ZEV adoption by region.

Reviewer Comment: To model the TCO and technology penetration, the parameters need to be simulated before they are calculated. The tool tends to calculate (average), but it needs to simulate the operation and performance annually. Each vehicle needs to be simulated each year with that specific year's data (vehicle, market, and regulation)

EPA Response:
For the final version of HD TRUCS, fuel/charging and operating costs are calculated on an annual year-by-year basis that take into account the vehicle miles traveled decrease as the vehicle ages. We also have added an analysis of TCO to the final version of HD TRUCS to complement the payback analysis.

Reviewer 2: Dr. Thomas Bradley

Reviewer Comment: This tool does not address PHEVs. In my opinion, PHEVs should be considered for cost/benefit analysis.

EPA Response:
We have added a tab to evaluate PHEVs in the final version of HD TRUCS.

Reviewer Comment: The appendices do not seem to be available except in this spreadsheet, although they are referenced to be in the EPA dockets. I searched in the EPA dockets, and could not find the right files. https://www.epa.gov/dockets.

EPA Response:
The HD GHG Phase 3 Regulatory Impact Analysis for the final rule include appendices in Chapter 2. This document is included in Docket # EPA-HQ-OAR-2022-0985 available at www.regulations.gov.

Reviewer Comment: "I am concerned about the purposes and defensibility of the adoption modeling portions of this work. I have a couple of general points:

1) The reference that seems to be the primary source for this work is un-googleable. Mitchell, George. Memorandum to docket EPA-HQ-OAR-2022-0985. "" ACT Research Co. LLC. ""Charging Forward"" 2020-2040 BEV & FCEV Forecast & Analysis, updated

December 2021. I cannot find this reference, but we have all done these kinds of models before, so I am not requesting an interpretation of the methods, but I am interested in why this paper was so important and influential. Why are Equation 2-61 and Table 2-72 removed in the DRIA? Is this model proprietary?

2) This payback period to adoption calculation is pretty naïve. We all realize how difficult doing these adoption models are, but this model seems particularly simple.

3) In particular, the adoption modeling is not even listed as one of the “Fundamental Questions for HD Vehicles” that is posed in the accompanying documentation PPT that was provided by EPA. Is there a way to not translate the technical results of the TRUCS model into the metrics of adoption. Instead, if the objective is to demonstrate the near-term TCO-parity of a variety of EVs, then no adoption modeling is required.

In summary, the relatively weak adoption model has the potential to weaken the relatively strong TCO and technical modeling effort. "

EPA Response:
We have made a number of updates to the adoption curves used in the final version of HD TRUCS. These are detailed in the HD GHG Phase 3 RIA Chapter 2.7 and noted in previous responses in this document.

Reviewer 3: Dr. William de Ojeda

Reviewer Comment: "The tax credits appear to be a very big factor. A basic assessment would point out that the greater market penetration, the credit should be reduced to alleviate government and eventually tax payer expense. In most cases, it amounts to 50% - nearly 100% of the cost.

As an example:

07T_Box

BEV credit is $15k (out of $26k)

FCEV credit is $40k (out of $41k)

For this reviewer, this is rather disconcerting. We are told that these are federal incentives, but the study here should in his opinion should focus on the technical merits of the new products being promoted.

Tool update recommendation:

• Credits should be thought through. The results are rather meaningless if the greatest contributor to the payback is provided by financial incentives.

• In the reviewer’s opinion it credits should be removed or provide a toggle switch to de-activate.

• Emphasize the technical merits of the technology."

EPA Response:

In considering the costs of the rule, as EPA is obliged to do by law, it would be misleading not to account in some manner for the effects of the laws that affect those costs.

Section 13502 of the IRA[24] (Section 45X of the Internal Revenue Code, or "45X") provides tax credits from CY 2023 through CY 2032 for the production and sale of battery cells and modules. These include the cell and module production tax credit of up to $45 per kWh available to manufacturers under 45X, and the additional tax credit for 10 percent of the production cost of (a) critical minerals and (b) electrode active materials available to manufacturers under 45X. The 45X credit provides a $35 per kWh tax credit for U.S. manufacture of battery cells, and an additional $10 per kWh for U.S. manufacture of battery modules. 45X also provides a credit equal to 10 percent of the manufacturing cost of electrode active materials and another 10 percent for the manufacturing cost of critical minerals if produced in the U.S. The credits phase out from 2030 to 2032 (with the exception of the 10 percent for critical minerals, which continues indefinitely). For the final version of HD TRUCS, we worked with the Department of Energy and Argonne National Lab (ANL) to update our assessment of U.S. battery manufacturing facilities and to account for gradual ramp-up of these facilities over time.

In addition, IRA section 13403, "Qualified Commercial Clean Vehicles," (codified in the Internal Revenue Code as section 45W) creates a tax credit for the purchase or lease of a qualified commercial clean vehicle.[25] In our HD TRUCS analysis, we included in our quantitative analysis the IRA battery tax credit this vehicle tax credit. 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, plug-in hybrid electric vehicles (PHEVs) and FCEVs.

The credit is available from CY 2023 through 2032, which overlaps with the model years for which we are analyzing in HD TRUCS (MYs 2027–2032), so we included the tax credit in our calculations for each of those years in HD TRUCS. For BEVs, the tax credit is equal to the lesser of: (A) 30 percent of the BEV cost, or (B) the incremental cost of a BEV 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

[24] Inflation Reduction Act of 2022, Pub. L. No. 117-169, 136 Stat. 1818 (2022). Available online: https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf.

[25] Inflation Reduction Act of 2022, Pub. L. No. 117-169, 136 Stat. 1818 (2022). Available online: https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf.

costs $350,000 and a comparable ICE vehicle costs $150,000[26] the tax credit would be the lesser of: (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.

In order to estimate the impact of this tax credit in our feasibility analysis for BEVs, 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 were reduced by the amount of the battery tax credit in IRA section 13502. We calculated the purchaser's incremental cost of BEVs 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 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 Class 4–8 BEVs 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 Class 3 and below), and determined that this assumption is reasonable based on our review of the literature on the costs of BEVs.[27]

Reviewer 4: Dr. Efstathios Michaelides

Reviewer Comment: "The tool tries to model all types of vehicles with the same methods/equations.

Recommendation: Split it into three tools for smaller, medium size (weight) and large vehicles and use appropriate modeling.

EPA Response:

HD TRUCS evaluates the design features needed to meet the energy and power demands of various HD vehicle types. We created 101 representative vehicles in HD TRUCS that cover the full range of weight classes within the scope of the final standards (i.e., 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 total energy and power demands per vehicle type based on everyday use of HD vehicles, ranging from moving goods and people to

[26] 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.

[27] 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.

mixing cement. We then identified the technical properties required for a BEV or FCEV to meet the operational needs of a comparable ICE vehicle.[28] The total ZEV baseline energy is the summation of axle energy, regenerative braking energy, and the energy required to operate the power take off (PTO).

The methods and equations we used appropriately account for differences in vehicle weights. Baseline energy consumption is based largely on results from EPA's GEM model (see HD GHG Phase 3 RIA Chapter 2). ZEV baseline energy includes the energy at the axle required to move the vehicle, impacts of regenerative braking (for vehicles with an electric motor), and the additional energy required from power take-off (PTO) units, if applicable. We used EPA's GEM model to simulate road load power requirements for various duty cycles using the default road load profiles to estimate work performed by HD vehicles. GEM does this by modeling physical characteristics of a vehicle that include vehicle mass, frontal area, tire rolling resistance, tire size, gear ratio, accessory loads, as well as reductions in power demand for weight reduction and other technologies that reduce demand from the vehicle. We used the engine fuel maps and the vehicle technology inputs to GEM developed to support the MY 2027 HD GHG Phase 2 vehicle standards. Each of these inputs to GEM, including the drive cycles the energy is calculated over, vary by vehicle type and vehicle weight class.

1.c: Are all appropriate inputs for the tool being considered? Conversely, are all inputs considered in the tool appropriate? Please cite any particular inputs or assumptions made by the tool that you feel are inappropriate or likely to bias the results and how they could be remedied, with particular emphasis on sources of information used in determining material prices, manufacturing burdens and other key factors.

Reviewer 1: Dr. Baha Al-Alawi

Reviewer Comment: The tool does have some annual data, such as VMT, but it then calculates the TCO based on the average over the life of the vehicle. This is due to the structure of the tool.

EPA Response:
We have revised HD TRUCS to evaluate operating costs on a year-by-year basis. This approach more accurately captures changes in annual miles traveled, maintenance and repair costs, and changes to fuel and charging costs that vary by

[28] 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 and diesel engines are more efficient than SI engines.

either the age of the vehicle or the calendar year of analysis. We also use this same approach to evaluate TCO in the final version of HD TRUCS.

Reviewer Comment: The tool is missing qualitative parameters. Rational and irrational decision-making could be simulated if qualitative parameters were considered. [considered in economic analysis?--explain]

EPA Response:
While we agree that purchasing decision-making can be influenced by rational and irrational decisions, we do not have sufficient information to model such behavior.

Reviewer Comment: The limitation of the inputs is due to the limitation of the tool: national level, no annual simulation, no dynamic market and policy data feed.

EPA Response:
The purpose of this tool is to evaluate the vehicles on a nationwide level because it is being used to support a federal rulemaking. We made revisions to the final version of HD TRUCS evaluate operating costs on a year-by-year basis.

Reviewer 2: Dr. Thomas Bradley

Reviewer Comment: The price of diesel fuel (C35) seems to be in error (or excluding taxes?). What is present now is $3.15 per gal. The 2022 and 2023 AEO projections are closer to $3.55 (2022), and 3.92 (2023). I also question the idea that long-term diesel prices are going to increase at a rate less than inflation, but that is a complaint about EIA, not this tool.

https://www.eia.gov/outlooks/aeo/data/browser/#/?id=12-AEO2023

https://www.eia.gov/outlooks/aeo/data/browser/#/?id=12-AEO2022

I highly recommend revising this value to adhere to the references cited.

EPA Response:
We revised the diesel fuel prices in the final version of HD TRUCS to those projected by the Energy Independence Administration's Annual Energy Outlook (AEO) 2023 Reference Case scenario, the latest information available. EIA is the recognized official source for such projections.

Reviewer Comment: The off-board charger/EVSE costs are extraordinarily expensive. I see the references in the DRIA, but I don't think that the $10k installation cost for level 2 EVSE is an accurate representation of current costs, and the higher power charging costs referenced here are 10x too high. We now don't need to rely on DOE models for these costs, the real-world costs are public. For example, $42k per connector @250kW.

https://www.autoblog.com/2022/09/21/electric-car-charging-station-costs/

EPA Response:

We note that the article cited by the commenter also states that the quoted value "compares with $100,000 to $250,000 per connector across competitors in the European Union and North America."

To reflect the diversity in anticipated depot infrastructure costs, we considered a range of hardware and installation costs for each charging type in our analysis. For the original version of HD TRUCS, we developed the DCFC EVSE costs from a 2021 study (Borlaug et al. 2021) specific to heavy-duty electrification at charging depots. The study estimated the cost for procuring and installing 50 kW EVSE to be $30,000–$82,000 per port, the cost for 150 kW EVSE to be $94,000–$148,000 per port, and the cost for 350 kW EVSE to be $154,000–$216,000 per port.[29,30] We revised the costs used in the final version of HD TRUCS 150 kW and 350 kW to those from a 2023 NREL report (Wood et al. 2023),[31] which estimated combined hardware and installation costs to range from $112,200–$196,200 per 150 kW EVSE port and from $180,100–$285,300 per 350 kW EVSE port.[32] Considering the midpoints of these ranges, the EVSE costs in Wood et al. 2023 are about 25% higher than those in Borlaug et al. 2021.[33] Most of the literature on Level 2 EVSE costs is for power levels common for light-duty vehicle charging. For example, the ICCT study estimated hardware costs for networked 6.6 kW ports to be about $3,000 with approximately another $2,000–$4,000 per port for installation.[34] We expect higher costs for higher-power Level 2 charging equipment. An RMI study showed a spread of hardware costs from $2,500 for a 7.7 kW charger to $4,900 for a 16.8 kW charger, with one outlier over $7,000 (for 14.4 kW).[35] A guide by the Vermont Energy Investment Corporation (VEIC), which engaged in an electric school bus pilot, estimates that equipment and installation for high-powered Level 2 EVSE could range from $4,200 to over $21,000.[36] Consistent with the original version of HD TRUCS, we selected a range of $10,000 to $20,000 per EVSE port for our final version of HD

[29] Costs are expressed in 2019 dollars. We did not include the cost that may be incurred if a depot owner decides to install a separate meter for EVSE. These costs ($1,200–5,000) are relatively small compared to EVSE procurement and installation costs and would be even smaller on a per port basis if spread across multiple EVSE ports.

[30] 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). Available online: https://www.nature.com/articles/s41560-021-00855-0.

[31] This report did not include costs for 50 kW EVSE ports.

[32] Wood, Eric et al. "The 2030 National Charging Network: Estimating U.S. Light-Duty Demand for Electric Vehicle Charging Infrastructure." 2023. Available online: https://driveelectric.gov/files/2030-charging-network.pdf.

[33] Wood et al. 2023 cites multiple sources for EVSE cost ranges including Borlaug et al. 2021. The difference in EVSE costs was estimated from values as presented in the papers without adjusting for dollar years. Costs in Borlaug et al. are expressed in 2019 dollars whereas we treat values from Wood et al. as 2022 dollars.

[34] Nicholas, Michael. "Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas". The International Council on Clean Transportation. 2019. Available online: https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf.

[35] Nelder, Chris and Emily Rogers. "Reducing EV Charging Infrastructure Costs". Rocky Mountain Institute. 2019. Available online: https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf.

[36] Vermont Energy Investment Corporation. "Electric School Bus Charging Equipment Installation Guide". August 2017. Available online: https://www.veic.org/Media/Default/documents/resources/reports/electric-school-bus-charging-equipment-installation-guide.pdf.

TRUCS. Table 3 shows the resulting hardware and installation costs for EVSE before and after applying the IRA tax credit.[37]

The IRA extends and modifies a federal tax credit under section 30C of the Internal Revenue Code that could cover up to 30 percent of the costs for businesses to procure and install EVSE on properties located in low-income or non-urban census tracts (subject to a total cap of $100,000 per item) if prevailing wage and apprenticeship requirements are met.[38] The tax credit is available through 2032. To reflect our expectation that this tax credit—as well as grants, rebates, or other funding available through the IRA—could significantly reduce the overall infrastructure costs paid by BEV and fleet owners for depot charging, including a new DOE analysis[39] of the average value of the 30C tax credit for HD charging infrastructure, we have updated the depot EVSE costs to reflect a quantitative assessment of average savings from the tax credit.

As noted above, the 30C tax credit could cover up to 30 percent of the costs for fleets or other businesses to procure and install EVSE on properties located in low-income or non-urban census tracts if prevailing wage and apprenticeship requirements are met. DOE projects that businesses will meet prevailing wage and apprenticeship requirements in order to qualify for the full 30 percent tax credit[40] and estimates that 60 percent[41] of depots will be located in qualifying census tracts based on its assessment of where HD vehicles are currently registered, the location of warehouses and other transportation facilities that may serve as depots, and the share of the population living in eligible census tracts. Taken together, DOE estimates an average value of this tax credit of 18 percent of the installed EVSE costs at depots. We apply this 18 percent average reduction to the EVSE costs used in HD TRUCS, as shown below in Table 3.

[37] Values in the literature cited for Level 2 EVSE costs are assumed to be in 2019 dollars.

38 IRA Section 13404, "Alternative Fuel Refueling Property Credit" under section 26 U.S. Code §30C, referred to as 30C in this document.

[39] DOE. "Estimating Federal Tax Incentives for Heavy Duty Electric Vehicle Infrastructure and for Acquiring Electric Vehicles Weighting Less Than 14,000 Pounds." Memorandum. March 11, 2024.

40 As noted in DOE's assessment, the "good faith effort" clause applicable to the apprenticeship requirement suggests that it is unlikely that businesses will not be able to meet it and take advantage of the full 30 percent tax credit (if otherwise eligible).

41 This estimate may be conservative as DOE notes that its analysis did not factor in that fleets may choose to site depots at charging facilities in eligible census tracts to take further advantage of the tax credit. In addition, we note that DOE estimated 68 percent of heavy-duty vehicles are registered in qualifying census tracts suggesting the share of EVSE installations at depots that are eligible for the 30C tax credit could be higher.

Table 3 Combined Hardware and Installation Costs per EVSE Port (in 2022$)

Charging Type	Cost Before Tax Credit	Cost After Tax Credit
Level 2—19.2 kW	$16,991	$13,932
DCFC—50 kW	$63,432	$52,014
DCFC—150 kW	$154,200	$126,444
DCFC—350 kW	$232,700	$190,814

Reviewer Comment: The on-board charging costs references ANL Bean, which is (and has been for years) in error in asserting a $38 cost for on-board charging. EPA's own studies of LDV charging equipment shows that the ID4 CCS 6.6-150kW charger costs ~$600. This is a bad reference and a bad data point that does not represent the state of the field.

EPA Response:

For the final version of HD TRUCS, we have increased the on-board charger costs to $600 in MY 2027. We then calculated the MY 2028-2032 costs using the BEV learning curve shown in HD GHG Phase 3 RIA Chapter 3.2.1.

Reviewer Comment: I AM GOING TO PUT THIS IN CAPS BECAUSE THIS IS A REAL PROBLEM OF CONSISTENCY. This study does not reference equivalent sources of information for electricity, hydrogen and diesel costs. The electricity and diesel costs are referencing existing and projected costs (EIA), and the hydrogen costs are referencing very optimistic costs (ANL's unreferenced projection, with ANL's 2050 price promoted here to a 2032 price). It is easy to point to the current state of hydrogen prices which are 5-7x what is presented in Inputs Sheet, A52. H2 costs have been increasing for the last decade.

https://www.hydrogeninsight.com/transport/exclusive-fresh-blow-for-hydrogen-vehicles-as-average-pump-prices-in-california-rise-by-a-third-to-all-time-high/2-1-1351675

Also, please don't use Bean's projections for diesel and electricity either. They are also unreferenced, and represent an unrealistic view of what electricity (in particular) will cost in the future.

EPA Response:

For the final version of HD TRUCS, we did not rely on ANL's BEAN tool for diesel, electricity, or hydrogen costs (though we do find the tool to be valuable for other purposes, as described in more detail in HD GHG Phase 3 RIA Chapter 2).

The diesel fuel prices for each year are those projected by the Energy Independence Administration's Annual Energy Outlook (AEO) 2023 Reference Case scenario, the latest information available. EIA is the recognized official source for such projections. We have used AEO Reference Case scenarios in each of our HD vehicle GHG emission standards rulemakings to date and are continuing to do so for this work.

For the final version of HD TRUCS, we differentiate between depot charging and public charging when assigning charging costs. We also have updated the charging costs for the final version of HD TRUCS. As described in RIA Chapter 2.4.4.2, we modeled future electricity prices, as charged by utilities, that account for the costs of BEV charging demand and the associated distribution system upgrade costs. We do this in three steps: 1) we model future power generation using the Integrated Planning Model (IPM), 2) we estimate the cost of distribution system upgrades associated with charging demand through the DOE Transportation Electrification Impact Study (TEIS),[42] and 3) we use the Retail Price Model (RPM) to project electricity prices accounting for both (1) and (2). The resulting national average retail prices, which include distribution upgrade costs, were used as a basis for the charging costs in HD TRUCS. We also included EVSE maintenance costs based on the estimate from a recent ICCT paper[43] of 0.52 cents per kWh. Our public charging price additionally includes the amortized cost of public charging equipment and land costs for the station; we project that third parties may install and operate these stations and pass costs onto BEV owners via charging costs. For public charging, we use a total charging cost of 19.6 cents per kWh, from the previously mentioned ICCT paper and as recommended by DTNA, for 2027. We adjust it for future years according to the results of the IPM Retail Price Model.

EPA discusses the issue of hydrogen cost in detail in the HD GHG Phase 3 RIA Chapter 2.5.3.1, which includes a review of literature. We note here in summary that our original estimate of a retail hydrogen price of $4 per kg in 2030 was adjusted higher in this final version of HD TRUCS to $6 per kg in 2030 and dropping to $4 per kg in 2035. This is intended to reflect a price that fleet owners would pay at hydrogen refueling stations.

We understand that the hydrogen price in California spiked recently, from an average of $14.95 per kg in the second quarter of 2022 to $36 per kg in August 2023. According to the State, causes include supply chain constraints, hydrogen supply disruptions, and equipment failures, and the State is taking actions to address these issues, some of which are still related to COVID-19 pandemic-related slowdowns.[44] S&P Global found that key challenges affecting hydrogen supply and prices in California reflect an immature FCEV fueling infrastructure market. According to data collected by S&P Global, fuel availability and price volatility have not been issues for transit bus FCEVs because transit agencies structure long-term fixed hydrogen price supply contracts to meet their needs. Transit agencies require more fuel and more station operations and maintenance

[42] National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, Kevala Inc., and U.S. Department of Energy. "Multi-State Transportation Electrification Impact Study: Preparing the Grid for Light-, Medium-, and Heavy-Duty Electric Vehicles". DOE/EE-2818. U.S. Department of Energy. March 2024. ("TEIS").
[43] Hussein Basma, Claire Buysee, Yuanrong Zhou, and Felipe Rodriguez. "Total Cost of Ownership of Alternative Powertrain Technologies for Class 8 Long-haul Trucks in the United States." April 2023. Available online: https://theicct.org/wp-content/uploads/2023/04/tco-alt-powertrain-long-haul-trucks-us-apr23.pdf.
[44] Crowell, et. al. "Joint Agency Staff Report on Assembly Bill 8: 2023 Annual Assessment of the Hydrogen Refueling Network in California". CEC/CARB. December 2023. Available online: https://www.energy.ca.gov/sites/default/files/2023-12/CEC-600-2023-069.pdf.

(O&M) so are less risk-prone than smaller stations for light-duty vehicles.[45] We expect that as hydrogen production develops to meet higher levels of demand required by HD FCEVs, there will be fewer issues with supply. Another challenge identified in California is the equipment failures at stations. California issued a solicitation to support O&M, along with a manufacturing grant to produce hydrogen refueling equipment, and they entered into a contract to conduct surveys to investigate issues further.[46] DOE is also funding efforts to advance research, development, demonstration, and deployment of technologies for HD FCEV stations and to address station reliability issues.[47,48] We expect equipment failures will decrease over time as both manufacturers and operators of equipment gain experience with it while bringing it to scale. The modeled potential compliance pathway in the final rule includes an early market level of FCEV adoption, which allows for growth in technology maturity before and during the 2030 to 2032 timeframe and prior to more widespread adoption in later years. We anticipate that infrastructure concerns can be addressed to meet the needs of an early market HD FCEV fleet by 2030.

Reviewer Comment: More philosophically, there is a disconnect between the cost of components here and the quantities of these applications. Every HD ICEV bus application uses the Cummins 5.4l engine because it can be produced in quantities. When we are talking about custom motors built for a quantity of a few thousand. The costs of production in ANL studies are in 100s of thousands. One of the major problems with HD vehicles is their limited production volumes relative to LDVs. The methods of this analysis does not address this. For example, the DCDC converter for Class 8 trucks will be a ~800VDC to 24VDC DC-DC converter, incompatible with LDV applications and with other HD applications. This system will never be sold at >100,000 units per year. Is that enough to realize the mass production cost point comparable to the LDV cost data that is used in this model? The learning curve model that is documented in section 3.2.1 does not account for how segmented the HD vehicle fleet is and will be in a world with multiple powertrain configurations. Not all components in the fleet will

[45] Canel Soria, Santiago and Daniel Weeks. "Feature: Logistical woes and high pump prices stall California H2 market development". S&P Global: Commodity Insights. January 25, 2024. Available online: https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/012324-logistical-woes-and-high-pump-prices-stall-california-h2-market-development.

[46] Crowell, et. al. "Joint Agency Staff Report on Assembly Bill 8: 2023 Annual Assessment of the Hydrogen Refueling Network in California". CEC/CARB. December 2023. Available online: https://www.energy.ca.gov/sites/default/files/2023-12/CEC-600-2023-069.pdf.

[47] U.S. Department of Transportation, Hydrogen and Fuel Cell Technologies Office. "DOE Announces $59 Million to Advance National Clean Hydrogen Strategy". December 15, 2023. Available online: https://www.energy.gov/eere/fuelcells/articles/doe-announces-59-million-advance-national-clean-hydrogen-strategy#:~:text=DOE%20Announces%20%2459%20Million%20to%20Advance%20the%20National%20Clean%20Hydrogen%20Strategy,-December%2015%2C%202023&text=The%20Department%20of%20Energy%20(DOE,of%20affordable%20clean%2Dhydrogen%20technologies.

[48] National Renewable Energy Lab. "News Release: Predictive Model Could Improve Hydrogen Station Availability". September 18, 2023. Available online: https://www.nrel.gov/news/press/2023/news-release-predictive-model-could-improve-hydrogen-station-availability.html.

realize the same learning curves, and some BEV components will never realize mass scale.

There is another critique here of applying the same learning curves to both BEV and FCEV powertrains, when FCEVs will have lower production volumes.

EPA Response:

Cost reduction via learning-by-doing is a well-established phenomenon having been studied for over 50 years with some of the earliest works dating to World War II.[49] Therefore, we know that learning-by-doing occurs and will continue to occur in the HD industry given the level of competition and the ingenuity of its employees and, we suspect, regardless of the number of parts in a given system. Our learning-by-doing is not a means of addressing economies of scale. Our learning-by-doing is exactly that, learning-by-doing and is not meant to reflect cost changes associated with economies of scale.

One key point is estimating at what speed that learning will occur. Traditionally, cost-reductions on the order of 80 percent to 90 percent are expected to occur with each doubling of cumulative production. In other words, if a widget costs $100 to make in year one with production of 100 units, then the cost could be expected to reduce to $80 to $90 by the time 200 units have been produced.[50]

Due to modeling constraints and the difficulty in applying learning effects as a function of sales within a model that adjusts sales based on learning effects, we have traditionally applied learning impacts using static learning factors applied to a given cost estimate as a means of reflecting learning-by-doing effects on future costs. [51] Further, we have traditionally applied those static learning factors across regulatory scenarios even though, as in the original version of HD TRUCS, a higher sales penetration of BEV and FCEV—i.e., advanced—technology in the would arguably result in more rapid learning relative to a no-action scenario where less penetration of those technologies is projected. Because the learning effects are static, the next key point becomes a matter of estimating where on the learning curve a technology is considered to be. In other words, is a technology on the early steeper portion of the learning curve or on the later, flatter portion of the learning curve. In the original version of HD TRUCS, we estimated that ICE technology was on the flatter portion of the curve, given that most ICE technologies have been in production for many years, and that advanced technologies like BEV and FCEV technologies were on the steeper portion. We continue with that approach in the final version, although we have shifted the learning effects for advanced technology in a manner consistent with the comment. More specifically, we apply the same learning curve in the final version

[49] See “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.

[50] Ibid.

[51] See the 2010 light-duty greenhouse gas rule (75 FR 25324, May 7, 2010); the 2012 light-duty greenhouse gas rule (77 FR 62624, October 15, 2012); 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); the 2014 light-duty Tier 3 rule (79 FR 23414, April 28, 2014); the heavy-duty NOx rule (88 FR 4296, January 24, 2023).

of HD TRUCS for BEVs and FCEVs but on a portion of the curve that is less steep (flatter) in MY 2027 and later than we used in the original version.

EPA acknowledges the uncertainties with forecasting the rate of learning. It is possible that manufacturers will learn more quickly than we anticipate, causing costs to be lower than we projected. It is also possible that manufacturers will learn more slowly than anticipated. Considering all these uncertainties, the historical data on learning in the HD and motor vehicle markets over time, as well as the significant forces driving increased producing of HD BEV and FCEV and thus their learning in the future, EPA's technical judgment is that the learning factors we have applied are reasonable.

Reviewer Comment: The costs of positive temperature coefficient (PTC) dissipation resistors for high SOC regen-braking need to be modeled if the batteries for rural route vehicles are as small as is represented here.

EPA Response:
For the final version of HD TRUCS, we added an additional constraint for minimum battery sizing, such that no vehicle in HD TRUCS is designed for less than 100 miles of range, i.e., any vehicle with 90th percentile VMT of less than 100 miles in our analysis has been assigned a sizing VMT of 100 miles. This has led to an increase in battery sizes for those vehicles which had the smallest batteries in the original HD TRUCS version. Therefore, we do not believe that PTC resistors will be needed.

Reviewer 3: Dr. William de Ojeda

Reviewer Comment: Battey cost at $145/kWh is lower than projections established by reviews such as the greencarcongress [see reference below].

EPA Response:
For the final version of HD TRUCS, we re-evaluated our values used for battery cost in MY 2027 based on consideration of comments provided by stakeholders in response to the NPRM, as well as additional studies provided by the FEV and the Department of Energy BatPaC model.

FEV conducted a technology and cost study for a variety of powertrains as applicable to Class 4, 5, 7, and 8 heavy-duty vehicles.[52] Powertrains included BEVs and FCEVs, in addition to other ICE technologies. Vehicles studied include Class 4-8 box trucks, step vans, buses, vocational vehicles, and tractors. FEV also costed three (15L (Class 8), 10L (Class 7), 6.6L (Class 4/5)) diesel ICE powertrains that would meet the emission standards as required by the HD2027 Low NOx Rule and the Phase 2 CO_2 emission standards in MY 2027. These are used to calculate the incremental cost of the alternative powertrain to the current day powertrain. The direct manufacturing costs for the battery packs ranged

[52] FEV Consulting. "Heavy Duty Commercial Vehicles Class 4 to 8: Technology and Cost Evaluation for Electrified Powertrains—Final Report". Prepared for EPA. March 2024.

between $128 and $143/kWh for MY 2027. We used an average value of $135.50/kWh as the representative cost projected by FEV.

To support the final rulemaking analysis, Argonne National Laboratory (ANL) conducted modeling of light, medium-, and heavy-duty battery costs using their BatPaC model.[53] ANL conducted a detailed analysis of battery costs in which they utilized the current version of BatPaC to estimate future battery pack costs by taking into account mineral price forecasts from leading analyst firms, and a technology roadmap of production and chemistry improvements likely to occur over the time frame of the rule.

To update our estimate of current and future battery pack costs, we worked with the Department of Energy and Argonne National Laboratory to develop a year-by-year projection of battery costs from 2023 to 2035, using specific inputs that represent ANL's expert view of the current state-of-the-art and of the path of future battery chemistries and the battery manufacturing industry. By default, BatPaC estimates only a current-year battery production cost and does not support the specification of a future year for cost estimation purposes. However, some parameters can be modified within BatPaC to represent anticipated improvements in specific aspects of cell and pack production. For example, cell yield is controlled by an input parameter that can be modified to represent higher cell yields likely to result from learning-by-doing and improved manufacturing processes. ANL identified several parameters that could similarly represent future improvements. This allowed ANL to estimate future pack costs in each of several specific future years from 2023 to 2035, allowing cost trends over time to be characterized by a mathematical regression.

A major element of the approach was to select BatPaC input parameters to reflect current and future technology advances and calculate the cost of batteries for different classes of vehicles at their anticipated production volumes. Material cost inputs to the BatPaC simulations were based on forecasted material prices by Benchmark Mineral Intelligence. That is, pack costs were estimated from current and anticipated future battery materials, cell and pack design parameters, and market prices and vehicle penetration. Pack cost improvements in future years were represented at three levels: manufacturing (increasing cell yield and plant capacity), pack (reducing cell and module numbers and increasing cell capacity), and cell (changing active material compositions and increasing electrode thickness). The simulations yielded battery pack cost estimates that can be represented by correlations for model years 2023 to 2035.

The ANL battery cost explicitly represents the most recent trends and forecasts of future mineral costs and also are an outcome of basing the future costs on a specific set of technology pathways instead of applying a year-over-year cost reduction rate. Most other forecasts of future battery costs, including those that we cited in the proposal, are based largely on application of a historical year-over-year cost reduction rate (i.e., learning rate), without reference to the specific

[53] Argonne National Laboratory. Cost Analysis and Projections for U.S.-Manufactured Automotive Lithium-ion Batteries. February 2024.

technology pathways that might lead to those cost reductions. ANL's approach is consistent with that of the Mauler paper,[111] which also identified and modeled a specific set of technology pathways. EPA acknowledges one potential criticism of such an approach is that it may lead to conservative results, because it excludes the potential effect of currently unanticipated or highly uncertain developments that may nonetheless come to fruition. On the other hand, basing the costs on specific high confidence pathways allows the basis of the projections to have greater transparency.

Accordingly, the ANL battery costs are responsive to many of the comments we received. First, the ANL work accounts more explicitly for the potential effect of critical mineral prices on the cost of batteries over time. We worked with ANL to make available medium- and long-term mineral price forecasts from Benchmark Mineral Intelligence, a leading minerals analysis firm. These were then used to estimate electrode material prices over the years of the ANL analysis. Second, as one outcome of this change, in the early years of the program, our battery cost inputs are now in closer agreement with the 2022 BNEF battery price survey, which commenters mentioned.

Additionally, the 5.1 version of BatPaC used in this analysis includes several significant feature updates that improve its ability to estimate pack manufacturing costs in realistic production scenarios. This version accounts for cell production volume and pack production volume separately, allowing economy of scale for cells and packs to be considered independently. This allows the analysis to use pack production volumes that are more representative of the annual production of a single pack design, while continuing to operate cell production at full plant capacity to provide cells for other product lines.

The ANL analysis provided EPA with several battery pack direct manufacturing costs as a function of model year and battery capacity (kWh), for both nickel-based (NMC) chemistry and iron-phosphate based (LFP) chemistry. We used a weighted average of ANL's costs for LFP and NMC batteries, with a 50/50 weighting. LFP is expected to increase in the future, due to its lower cost and absence of the critical minerals such as cobalt, manganese, and nickel. Our assessment is that on average the battery pack costs from the ANL study most representative of our average HD TRUCS vehicle types is an average of the heavy-duty 190, 220, and 250 kWh battery packs. Based on a linear interpolation of ANL's 2026 and 2030 costs, we used a value of $101.75 as the ANL battery pack direct manufacturing cost for MY 2027.[54]

We considered a wide range of MY 2027 battery pack costs ranging from the $183/kWh cited by manufacturers in comments to $101.75/kWh projected in ANL's BatPaC model for HD battery packs for the final rule. In our analysis, we primarily relied on ANL's BatPaC model results. However, we also accounted for the data provided in comments and the recent FEV cost study. Based on our engineering judgement, we applied a weighting of 60% for the BatPac results in

[54] Argonne National Laboratory. Cost Analysis and Projections for U.S.-Manufactured Automotive Lithium-ion Batteries. February 2024. Appendix A1, Page 38.

our assessment. We then attributed a 10% weighting to the FEV value of \$135.50/kWh, 10% weighting to the EMA value of \$183/kWh, 10% weighting of MFN's value of \$148.74/kWh (converted from 2021\$ supplied in comments to 2022\$), and 10% weighting to a value of \$123.42/kWh based on EDF's comment citing a study conducted by Roush (which provided a 2030 value of \$106/kWh, which we back-learned using the learning scalars shown in RIA Chapter 3.2). Based on this assessment, we project a battery pack cost value for MY 2027 of \$120/kWh (2022\$).

Reviewer Comment: The cost of electricity is key. A consensus, including personal experience, the charging rates can differ widely depending on where the vehicles need to be charged. Fast charging fees can be several factors greater than low-peak demand.

EPA Response:
For the final version of HD TRUCS, we differentiate between depot charging and public charging when assigning charging costs. We also have updated the charging costs for the final version of HD TRUCS. As described in RIA Chapter 2.4.4.2, we modeled future electricity prices, as charged by utilities, that account for the costs of BEV charging demand and the associated distribution system upgrade costs. We do this in three steps: 1) we model future power generation using the Integrated Planning Model (IPM), 2) we estimate the cost of distribution system upgrades associated with charging demand through the DOE Transportation Electrification Impact Study (TEIS),[55] and 3) we use the Retail Price Model (RPM) to project electricity prices accounting for both (1) and (2). The resulting national average retail prices, which include distribution upgrade costs, were used as a basis for the charging costs in HD TRUCS. We also included EVSE maintenance costs based on the estimate from a recent ICCT paper[56] of \$0.0052 per kWh. Our public charging price additionally includes the amortized cost of public charging equipment and land costs for the station; we project that third parties may install and operate these stations and pass costs onto BEV owners via charging costs. For public charging, we use a total charging cost of 19.6 cents per kWh from the ICCT paper, for 2027. We adjust it for future years according to the results of the IPM Retail Price Model.

Reviewer Comment: Operating costs come very low.

EPA Response:
As noted in previous responses and detailed in HD GHG Phase 3 RIA Chapter 2, we made a number of revisions to HD TRUCS related to fuel costs, charging

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55 National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, Kevala Inc., and U.S. Department of Energy. "Multi-State Transportation Electrification Impact Study: Preparing the Grid for Light-, Medium-, and Heavy-Duty Electric Vehicles". DOE/EE-2818. U.S. Department of Energy. March 2024. ("TEIS").
56 Hussein Basma, Claire Buysee, Yuanrong Zhou, and Felipe Rodriguez. "Total Cost of Ownership of Alternative Powertrain Technologies for Class 8 Long-haul Trucks in the United States." April 2023. Available online: https://theicct.org/wp-content/uploads/2023/04/tco-alt-powertrain-long-haul-trucks-us-apr23.pdf.

costs, insurance costs, vehicle ZEV registration fees, and maintenance and repair costs.

Reviewer Comment: This sheet is very well laid out and organized. The creators of TRUCS have placed a huge amount of work put in to consolidate all this information.

EPA Response:
Thank you for the comment.

Reviewer Comment: These sheets are very descriptive. As noted above, the work to consolidate all this information is very impressive.

EPA Response:
Thank you for the comment.

Reviewer Comment: "The model uses projected values of specific energy and energy density that increase at approximately over 2% per year. Projecting this type of sustained improvement may be overly optimistic.

Fuel cell efficiencies, as in the case of the BAT above, reports an increasing over time, with numbers above 65%. These numbers tend to be surprisingly high. See reference below from a mayor OEM on their reported efficiencies.

On the other hand, ICE efficiencies are retained as is. Should this technology be given the opportunity to report on their own development capability, and harvest their fruits from recent efforts under programs such as the DOE Supertruck?

Recommendations:

- Place ‘flat’ trends over time, unless there is solid evidence for them.

- Place a balanced approach across the three technology paths: if optimistic forecasts are given to one, give these to all (e.g., ICE)."

EPA Response:
We have revised the specific energy and energy density in the final version of HD TRUCS such that they are constant over the model years assessed in the tool (MYs 2027-2032). We also have revised the fuel cell powertrain efficiency to the values shown in Table 4, which are lower than those used in the original version of HD TRUCS.

Table 4 Powertrain Efficiencies for FCEV

GEM Energy ID	Combined inverter, gearbox, e-motor and FC system efficiency
C7_DC_HR	56%
C8_DC_HR	56%
C8_HH	56%
C8_SC_HR	57%
C8_SC_HR_CdA036	57%
C8_DC_HR_CdA036	56%
C7_DC_HR_CdA036	56%
HHD_R	56%
HHD_M	54%
HHD_U	51%
MHD_R	54%
MHD_M	52%
MHD_U	51%
LHD_R	54%
LHD_M	52%
LHD_U	51%
RV	54%
School Bus	51%
Coach Bus	56%
Emergency	51%
Concrete Mixer	51%
Transit Bus	51%
Refuse Truck	51%

Reviewer 4: Dr. Efstathios Michaelides

Reviewer Comment: "The speed of the vehicle is not considered. However, the power needed is proportional to the cube of the speed (V^3) and the heat transfer is proportional to the speed. The average values in the tool (e.g. miles/kWh or kWh/mile) are gross simplifications that add to the tool inaccuracy.

Recommendation: let the user specify a typical speed and develop models with reference to the speed. For calculations see: Thermodynamics and Energy Consumption of Electric Vehicles, Energy Conversion and Management, 2020, 203, 112246. "

EPA Response:

The energy required to operate the vehicle in HD TRUCS is calculated in EPA's Greenhouse Gas Emissions model (GEM).[57] GEM simulates the vehicle based on its vehicle characteristics and over three drive cycles – the ARB Transient cycle, a 55 mph cruise cycle with road grade, and a 65 mph cruise cycle with road grade. GEM calculates the power each second along the drive trace which has a different vehicle speed. Additional information is available in HD GHG Phase 3 RIA Chapter 2.4.1.2 and 2.8.5.4.

Reviewer Comment: If the vehicle speed is included in the computations, you will need two more parameters, the friction coefficient (tires with road) and the aerodynamic drag coefficient. These can be found in textbooks.

EPA Response:

The coefficient of drag and tire rolling resistance for each vehicle type modeled in GEM and used in the HD TRUCS tool is shown in Table 5.

[57] U.S. EPA. Greenhouse Gas Emissions Model. Available online: https://www.epa.gov/regulations-emissions-vehicles-and-engines/greenhouse-gas-emissions-model-gem-medium-and-heavy-duty#phase-2-final.

Table 5 Vehicle Parameters in GEM

GEM Energy ID	Coef. of Drag Area (m2)	Steer Axle Tire Rolling Resistance Coefficient (N/kN)	Drive Axle 1 Tire Rolling Resistance Coefficient (N/kN)	Drive Axle 2 Tire Rolling Resistance Coefficient (N/kN)	Drive Axle Tire Size (rev/mile)
C8_SC_HR	5.26	5.6	5.8	5.8	512
C8_SC_HR_CdA036	3.53	5.6	5.8	5.8	512
C8_DC_HR	5.67	5.6	5.8	5.8	512
C8_DC_HR_CdA036	3.53	5.6	5.8	5.8	512
C7_DC_HR	5.67	5.6	5.8	NA	512
C8_HH	6.21	5.8	6.2	6.2	512
HHD_R	NA	7.7	7.7	7.7	496
HHD_M	NA	7.7	7.7	7.7	496
HHD_U	NA	7.7	7.7	7.7	496
MHD_R	NA	7.7	7.7	NA	517
MHD_M	NA	7.7	7.7	NA	557
MHD_U	NA	7.7	7.7	NA	557
LHD_R	NA	7.7	7.7	NA	670
LHD_M	NA	7.7	7.7	NA	670
LHD_U	NA	7.7	7.7	NA	660
RV	NA	5.8	5.8	NA	517
School Bus	NA	5.9	6.3	NA	557
Coach Bus	NA	5.8	5.8	5.8	496
Emergency	NA	6.4	8.1	8.1	496
Mixer	NA	6.7	7.2	7.2	496
Transit Bus	NA	6.7	6.8	NA	517
Refuse Truck	NA	6.7	6.8	6.8	496

Reviewer Comment: "The discount rate of the owner is not included.

Recommendation: Consider having an input with this rate to discount future cash flows."

EPA Response:

We did not include a discount rate in the HD TRUCS. For the most part, we are analyzing vehicles over a relatively short period of time. Discount rates are considered in the overall program costs so are calculated outside of HD TRUCS as described in HD GHG Phase 3 RIA Chapter 3.

1.d: Are the assumptions embedded in the tool that affect projected cost or performance reasonable? Such assumptions might include learning curve, economies of scale, scaling parameters such as weight and power, material costs, and infrastructure cost.

Reviewer 1: Dr. Baha Al-Alawi

Reviewer Comment: The tool estimates technology incremental costs using the components costs approach and pre-specified major components costs. This is the best approach and is widely used. Such estimation needs to be validated with current technology retail prices. Based on my work developing BEV components cost study, battery prices vary by OEM due to many factors, including battery quantity purchased, source of battery (China or U.S.), OEM battery, or purchased. Battery retail prices vary from $315/kWh to $600/kWh.

EPA Response:

For the final rule, we re-evaluated our values used for battery cost in MY 2027 based on consideration of comments provided by stakeholders, as well as additional studies provided by the FEV and the Department of Energy BatPaC model.

FEV conducted a technology and cost study for a variety of powertrains as applicable to Class 4, 5, 7, and 8 heavy-duty vehicles.[58] Powertrains included BEVs and FCEVs, in addition to other ICE technologies. Vehicles studied include Class 4-8 box trucks, step vans, buses, vocational vehicles, and tractors. FEV also costed three (15L (Class 8), 10L (Class 7), 6.6L (Class 4/5)) diesel ICE powertrains that would meet the emission standards as required by the HD2027 Low NOx Rule and the Phase 2 CO_2 emission standards in MY 2027. These are used to calculate the incremental cost of the alternative powertrain to the current day powertrain. The direct manufacturing costs for the battery packs ranged between $128 and $143/kWh for MY 2027. We used an average value of $135.50/kWh as the representative cost projected by FEV.

To support the final rulemaking analysis, Argonne National Laboratory (ANL) conducted modeling of light, medium-, and heavy-duty battery costs using their BatPaC model.[59] ANL conducted a detailed analysis of battery costs in which they utilized the current version of BatPaC to estimate future battery pack costs by taking into account mineral price forecasts from leading analyst firms, and a technology roadmap of production and chemistry improvements likely to occur over the time frame of the rule.

To update our estimate of current and future battery pack costs, we worked with the Department of Energy and Argonne National Laboratory to develop a year-

[58] FEV Consulting. "Heavy Duty Commercial Vehicles Class 4 to 8: Technology and Cost Evaluation for Electrified Powertrains—Final Report". Prepared for EPA. March 2024.

[59] Argonne National Laboratory. Cost Analysis and Projections for U.S.-Manufactured Automotive Lithium-ion Batteries. February 2024.

by-year projection of battery costs from 2023 to 2035, using specific inputs that represent ANL's expert view of the current state-of-the-art and of the path of future battery chemistries and the battery manufacturing industry. By default, BatPaC estimates only a current-year battery production cost and does not support the specification of a future year for cost estimation purposes. However, some parameters can be modified within BatPaC to represent anticipated improvements in specific aspects of cell and pack production. For example, cell yield is controlled by an input parameter that can be modified to represent higher cell yields likely to result from learning-by-doing and improved manufacturing processes. ANL identified several parameters that could similarly represent future improvements. This allowed ANL to estimate future pack costs in each of several specific future years from 2023 to 2035, allowing cost trends over time to be characterized by a mathematical regression.

Additional discussion on the sources of information we used to develop the BEV component costs are included in RIA Chapter 2.4.3 and for FCEV component costs in RIA Chapter 2.5.2.

Reviewer Comment: The performance of BEV changes dramatically based on the region due to load, route, and HVAC needs. This needs to be considered but can be if the tool is restructured to simulate different regions.

EPA Response:

The purpose of this tool is to evaluate the vehicles on a nationwide level because it is being used to support a federal rulemaking. It is outside of the scope of this tool to evaluate ZEV adoption by region or by state.

For each HD TRUCS vehicle type, we determined the baseline energy consumption requirement that will be needed for ZEVs. We used EPA's GEM model to simulate road load power requirements for various duty cycles using the default road load profiles to estimate work performed by HD. ZEV baseline energy includes the energy at the vehicle axle required to move the vehicle down the road, the impact of regenerative braking[60], and PTO energy. The resulting ZEV baseline energy requirements are shown in RIA Chapter 2.1 for each of the HD TRUCS vehicle types.

Other factors can impact energy consumption and power in a manner that may be different among ICE vehicles, BEVs, and FCEVs. Therefore, we also consider the energy demand for heating, ventilation, and air conditioning (HVAC) and additional powertrain-specific impacts on energy consumption and power. For more detail, please refer to RIA Chapter 2.2.2. For instance, we do recognize that HVAC is not evenly used across the nation so reflect a range of ambient temperatures in our calculations.

[60] Regenerative braking is the process of slowing down a moving vehicle by using the vehicle's electric motor as a brake. This process allows the vehicle's electric motor to generate electricity which is then stored in the vehicle's battery and increases the net efficiency of the vehicle.

Reviewer Comment: A high percentage of MHDV fleets have less than 5 vehicles. Infrastructure needs, levels, and costs vary. Large fleets might need large-scale private infrastructure, but small fleets might benefit from available and public infrastructure. Saying that the costs need to be different and can be understood if we know the mix of fleets.

EPA Response:

For this final version of HD TRUCS, we project that most vocational vehicles and certain day cab tractors—those with return-to-base operations—will rely on depot charging. We estimate upfront capital hardware and installation costs for depot charging to fulfill each BEV's daily charging needs off-shift with the appropriately sized EVSE.[61] This approach reflects our expectation that many heavy-duty BEV owners will opt to purchase and install sufficient EVSE ports at or near the time of vehicle purchase to ensure that operational needs are met. Starting in MY 2030 in our final version of HD TRUCS, we project en-route charging at public stations will be used by eight BEV types: long-haul vehicles (both sleeper cab and long-range day cab tractors) and coach buses. MY 2030 is the year when we project there will be sufficient public charging infrastructure for HD vehicles for the projected utilization of such technologies under the modeled potential compliance pathway. See RIA Chapter 1.6. We assign higher charging costs to vehicles using public charging stations to reflect our expectation that upfront capital costs and operating expenses for public EVSE[62] will be passed onto customers, in addition to the electricity prices.

We acknowledge that even vehicles which predominantly rely on depot charging may utilize some public charging, for example on high travel days. This could allow fleet owners to purchase lower-power EVSE and reduce upfront depot infrastructure costs. In addition, we recognize that not all BEV owners may choose to procure and install their own EVSE. Some fleets may opt for lease agreements or alternative business models such as charging as a service, in which a third-party provider owns, operates, and maintains the charging equipment for a monthly (or other recurring) fee. Given the uncertainty around uptake and costs of these alternatives to depot charging at this early market stage, we chose to account for the hardware and installation costs of EVSE sized to meet BEV needs upfront in our analysis.

Depot and public charging infrastructure will vary depending on the number of vehicles that stations are designed to accommodate and their expected duty cycles, site conditions, and the charging preferences of BEV owners. See RIA Chapters 2.6.2 and 2.6.3 for details about our depot and public charging analyses.

Reviewer 2: Dr. Thomas Bradley

[61] We sized EVSE to meet vehicles' daily electricity consumption (kWh/day) based on the sizing VMT, as described in RIA Chapter 2.2.1.2.2.

[62] En-route charging could occur at public or private charging stations though, for simplicity, we often refer to en-route charging as occurring at public stations.

Reviewer Comment: "Both the "electric accessories" and "power electronics" costs do not scale in this spreadsheet with vehicle type. That is a poor assumption and does not represent the way that these vehicles get built in practice.

For example, in many of these applications, the requirements of the electric HVAC system (an electric accessory) will be very different. For example, transit buses require passenger compartment HVAC systems that are 10x the power of the HVAC system required for a cab-only application such as Tow truck. The writeup on P176 of the RIA is not clear as to whether HVAC is considered an "electric accessory" or not. In general, there will be HV electric accessories (HVAC, air compressors, battery HVAC) in future BEVs/FCEVs.

Similarly, the 12V (and 24V) loads of these vehicles will also be very different between applications (Shuttle bus 12V load will be much less than the Class 8 Tractor 24V load). The ICE Class 8 tractor can have a 24V accessory load of 12kW (500A@24v) The EV Class 8 tractor will have those same LV loads (~12kW) plus battery ventilation fans, and underhood ventilation fans, and more that are also not modeled as LV loads here.

I don't see how the assumption that "electric accessories" and "power electronics" costs do not scale is defensible for this model.

> EPA Response:
> HD TRUCS is an analytic tool for assessing heavy-duty vehicle suitability, cost, and payback comparisons between BEV and FCEV technologies relative to a comparable ICE vehicle. We sized vehicle components that are unique to ZEVs to meet the work demands of each representative vehicle. We determined the cost of each powertrain component based on sizing to assess the difference in total powertrain costs between the ICE and ZEV powertrains.
>
> In the final version of HD TRUCS, we have added an "auxiliary converter" for BEVs and FCEVs. This cost does vary by vehicle category. For example, the Class 8 transit bus has the highest cost, followed by the school bus. See Table 2-53 in RIA Chapter 2.
>
> We note that in calculating the BEV energy consumption, the heating and cooling consumption reflect the size of the cabin. Similarly for FCEVs, the energy consumption reflects the cabin size for cooling. This impacts both the upfront cost of the BEVs and FCEVs because it leads to an increase in the battery or fuel cell stack size. This impact varies by vehicle cabin size. It also leads to an increase in operating costs for BEVs and FCEVs, which also vary by vehicle cabin size.

Reviewer Comment: This model assumes that some of these HD vehicles will use multispeed gearboxes in addition to final drives. This assumption (which seems to be inherited from BEAN) is not representative of the state of the art. Only transit buses (in my experience) are using multispeed gear boxes because of their large size and high start torque requirements. None of the BEV Class 8 tractors available use gear boxes to my knowledge. I recommend that EPA include gearboxes only in extraordinary applications such as HH tow or dump. For example, there is no need for a multispeed gear box in a class 6 school bus, and the cost of this component should not be allocated to BEV school buses.

EPA Response:
Gearbox and final drive units are used to reduce the speed of the motor and transmit torque to the axle of the vehicle. In the final version of HD TRUCS, the cost of the gearbox varies depending on the vehicle weight class and duty cycle. In our assessment, all light heavy-duty BEVs will be direct drive and have no transmission and no cost, in keeping with ANL's 2022 BEAN model. We disagree with the commenter's assessment that none of the Class 8 BEVs use a gearbox. For example, the Volvo VNR vocational vehicles and tractors use a 2-speed automated gearbox.[63] Also, Eaton offers gearboxes for heavy-duty electric vehicles.[64] Therefore, for the final version of HD TRUCS, we mapped the gearboxes in BEAN from the "Autonomie Out Import" tab to the appropriate medium heavy-duty and heavy heavy-duty vehicles in HD TRUCS.

Reviewer Comment: There seems to be a calculation problem in the column AF of both these sheets. For example, both 50B_School_Cl8_U, and 51B_School_Cl6-7_U should have a multispeed gearbox, but only 51B_School_Cl6-7_U is allocated the 62kg mass of the gearbox.

EPA Response:
We appreciate you pointing out the errors in HD TRUCS. We have made corrections to address this issue in the final version.

Reviewer 3: Dr. William de Ojeda

Reviewer Comment: "The program is very complete and assumptions are reasonable. The tool takes into consideration the use case scenario (miles driven, drive cycle, energy required, climate control), technical characteristics (size of battery and impact on cargo space, weight impact, and charging frequency), and a broad and complete cost analysis (including cost of fuel, of the powertrain, and maintenance and repair).

The above comment is balanced with notes set in section 1e below, that deals with data not so readily available."

EPA Response:
EPA appreciates the comment regarding HD TRUCS and would like to note that we have, since this review, continued to improve and refine the input assumptions to render the most robust results.

[63] Volvo Trucks. Available online: https://www.volvotrucks.us/trucks/vnr-electric/specifications/.
[64] Eaton. Available online: https://www.eaton.com/content/dam/eaton/products/emobility/power-systems/eaton-ev-transmissions-brochure-emob0003-en.pdf.

Reviewer Comment: Section does a good job illustrating the costs. As an example of the FCEV, the study included the FC stack, E Motor, H2 Tank, Battery, Power Electronics, gear box, final drive.

EPA Response:
EPA appreciates the comment regarding HD TRUCS and would like to note that we have, since this review, continued to improve and refine the input assumptions so as to render the most robust results.

Reviewer 4: Dr. Efstathios Michaelides

Reviewer Comment: The cost estimates in this section are mostly obtained from "Adapted from ANL BEAN 2021" with the note "Linearly interpolated from BEAN." A glance at that website and the ANL tool proves that the numbers are laden with very high uncertainty and that the data are not linear with time.

Recommendation: Check the data inputs, correct for non-linear effects and (most important) determine the uncertainty of the inputted data and report somewhere in the tool.

EPA Response:
The cost information used in HD TRUCS was collected from literature, from DOE's National Lab analyses, and from a study conducted by FEV for EPA. We are confident the costs used in the analysis are reasonable for determining a possible adoption scenario. The final version of HD TRUCS has a number of improvements to the original version that were made based on consideration of stakeholder comments and additional information. See HD GHG Phase 3 RIA Chapter 2 for further detail.

Reviewer Comment: The "On Board Charging efficiency" values are extremely high. The tool cites the NREL report (Booker et al. 2020). However, the report (Table 15) indicates a charger efficiency of 86% in 2021, possibly improving to 90% in 2035. Also see N. Kong, 2018, Exploring Electric Vehicle Battery Charging Efficiency, The National Center for Sustainable Transportation, U-C Davis, California, September 2018. Charging rates as low as 80% were observed in this experimental study.

The fast-charging efficiency of EVs is much lower in the range 70-80% (see Alfred Rufer, Energy storage – systems and components, CRC Press, 2018 chapter 3.)

Recommendation: Use realistic values for the "On Board Charging efficiency" and clearly specify that they pertain to slow (7-8 hour) charging.

EPA Response:
The charging efficiency estimates in HD TRUCS are used to estimate how many

hours it would take to charge a vehicle sufficiently to cover its expected daily electricity consumption and determine the associated operating costs. The time it takes to recharge with each of four EVSE types: Level 2—19.2 kW, DCFC—50 kW, DCFC—150 kW, DCFC—350 kW is calculated in HD TRUCS. We adjust the estimated electricity consumption upward to account for charging losses from the wall to the battery. While these losses may vary by charging type and other factors, as a simplifying assumption, we assign the same losses for all charging types. We use a charging efficiency of 89.3%, as determined by the product of the AC/DC converter efficiency of 94% and a battery charge and discharge efficiency of 95% from the MOVES model.

Reviewer Comment: The "Fuel cell efficiency" values adapted from "Adapted from Autonomie 2021" are high and do not include the efficiency degradation because of membrane clogging. Those who are familiar with the performance of PEM-FC know that PEM cells need frequent purging with timescale of hours (see "Performance degradation of a proton exchange membrane fuel cell with dual ejector-based recirculation, Energy Conversion and Management, Volume 12, December 2021, 100114."

The long-term degradation effects are more important because they require regeneration of the membranes. See "The influence of degradation effects in proton exchange membrane fuel cells on life cycle assessment modelling and environmental impact indicators, International Journal of Hydrogen Energy, Volume 47, Issue 57, 5 July 2022, Pages 24223-24241)

Recommendation: Include realistic PEM efficiencies (molten cell fuel cells are too dangerous to be used on road vehicles) and introduce the costs of gas purging and membrane regeneration (every six months).

EPA Response:

We agree the fuel cell efficiency values used in the original version of HD TRUCS were too high and therefore reduced them by eight percent to reflect an average operating efficiency instead of peak efficiency. This was based on a review of DOE's 2019 Class 8 Fuel Cell Targets. DOE has an ultimate target for peak efficiency of 72 percent, which corresponds to an ultimate fuel cell drive cycle efficiency of 66 percent. This equates to an 8 percent difference between peak efficiency and drive cycle efficiency at a more typical operating power. Therefore, to reflect system efficiency more accurately at a typical operating power, we applied the 8 percent difference to the peak efficiency estimate in the original version of HD TRUCS. For the final version, the operational efficiency of the fuel cell system (i.e., represented by drive cycle efficiency) is about 61 percent. Please see RIA Chapter 2.5.1.2.1 for additional detail.

For the final version of HD TRUCS, we combined the revised fuel cell system efficiency value with the BEV powertrain efficiencies (i.e., the combined inverter, gearbox, and e-motor efficiencies). Final FCEV powertrain efficiencies range from 51 to 57 percent.

Consistent with our approach for ICEs and BEVS, we did not include the costs for fuel cell system replacement within our analysis. We upsized the fuel cell system such that the addition of cells add durability so that replacement will not be necessary in the 10-year assessment period considered in the HD TRUCS analysis.[65]

We did include maintenance and repair and insurance costs for FCEVs, as described further in RIA Chapter 2.5.3.

Reviewer Comment: The temperature dependence of the battery holding capacity and their self-discharge are not taken into account. Batteries exhibit reduced SOC at both high and low temperatures (see A Review on Temperature-Dependent Electrochemical Properties, Aging, and Performance of Lithium-Ion Cells. Batteries 2020, 6, 35. https://doi.org/10.3390/batteries6030035)

Recommendation: Consult the literature and the charts of battery manufacturers and include this effect (not using the average temperature of a location).

EPA Response:
We included additional energy for conditioning the battery to maintain an acceptable battery temperature in our analysis for sizing the batteries and for operating costs. Furthermore, we considered the impact of deterioration on battery size. This is discussed in RIA Chapter 2.4.1.

The battery conditioning energy requirements are determined as a percent of total battery size. Similar to the methods used for HVAC, we determined the VMT-weighted battery conditioning loads associated with requirements to heat the battery in cold operating temperatures (below 55 °F) and cool the battery during operations in warm temperatures (over 75 °F for the final version of HD TRUCS). 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 determined a VMT-weighted power consumption value for battery heating and cooling based on the MOVES HD VMT distribution and used this to determine the appropriate battery sizing requirements and electricity consumption.

Reviewer Comment: At $3.15/gal ($2021) and range 3.15-$3.27 the diesel price is rather low. There is a great deal of uncertainty here and this should be clarified in the Introduction. See E.E. Michaelides, 2018, Energy, the Environment and Sustainability, CRC Press, Chapter 9.

Recommendation: Use realistic prices (or allow the user to input prices) and comment on their uncertainty.

[65] The interim target fuel cell system lifetime for a Class 8 tractor-trailer is 25,000 hours, which is equivalent to more than 10 years if a vehicle operates for 45 hours a week for 52 weeks a year.

EPA Response:

We used the DOE Energy Information Administration's (EIA's) Annual Energy Outlook (AEO) 2023 for diesel price. For the transportation sector, the reference case projection for diesel fuel for on-road use is shown in Table 6 in 2022$.[66] This value includes Federal and state taxes but excludes county and local taxes.

Table 6 AEO 2023 Reference Case Diesel Price (2022$)

Calendar Year	Diesel Price ($/gal)
2027	3.74
2028	3.63
2029	3.65
2030	3.65
2031	3.67
2032	3.69
2033	3.71
2034	3.71
2035	3.74
2036	3.74
2037	3.76
2038	3.78
2039	3.78
2040	3.79
2041	3.81

Reviewer Comment: At $0.1063 to $0.1069/kWh the price of electricity is very low. Currently the average price is $0.151 (bureau of labor statistics https://www.bls.gov/regions/midwest/data/averageenergyprices_selectedareas_table.htm) and customers currently pay more than $0.165 in the charging stations along the highways. Also, the electricity price increases significantly with the fraction of renewables and should reach $0.22 by 2035. See E.E. Michaelides, 2018, Energy, the Environment and Sustainability, CRC Press, Chapter 9.

Recommendation: Use realistic prices (or allow the user to input prices) and comment on their uncertainty.

EPA Response:

For the final version of HD TRUCS, we differentiate between depot charging and public charging when assigning charging costs. We also have updated the charging costs for the final version of HD TRUCS. As described in RIA Chapter

[66] U.S. Energy Information Administration. Annual Energy Outlook 2023. Table 57: Components of Selected Petroleum Product Prices. Diesel Fuel End User Price. Last accessed on 12/2/2023 at https://www.eia.gov/outlooks/aeo/data/browser/#/?id=70-AEO2023&cases=ref2023&sourcekey=0.

2.4.4.2, we modeled future electricity prices, as charged by utilities, that account for the costs of BEV charging demand and the associated distribution system upgrade costs. We do this in three steps: 1) we model future power generation using the Integrated Planning Model (IPM), 2) we estimate the cost of distribution system upgrades associated with charging demand through the DOE Transportation Electrification Impact Study (TEIS),[67] and 3) we use the Retail Price Model (RPM) to project electricity prices accounting for both (1) and (2). The resulting national average retail prices, which include distribution upgrade costs, were used as a basis for the charging costs in HD TRUCS. We also included EVSE maintenance costs based on the estimate from a recent ICCT paper[68] of $0.0052 per kWh. Our public charging price additionally includes the amortized cost of public charging equipment and land costs for the station; we project that third parties may install and operate these stations and pass costs onto BEV owners via charging costs. For public charging, we use a total charging cost of 19.6 cents per kWh, from the ICCT paper, for 2027. We adjust it for future years according to the results of the IPM Retail Price Model.

Table 7 Retail Electricity Prices for select years (2022 cents/kWh) [69,70]

2027	2028	2030	2035	2040	2045	2050	2055
11.8	11.8	11.3	11.2	11.1	10.8	10.4	10.4

Reviewer Comment: The COP of the heat pump or a/c system is high. I presume that the reference "Adapted from Basma H et al" refers to the 2020 paper "Comprehensive energy modeling methodology for battery electric buses," in which the conditions for the heating COP were taken from the weather in France. However, winter temperatures in New York, Boston, Chicago, Minneapolis, etc. are much lower and the COP deteriorates. Similarly, in the South during hot weather days.

Recommendation: Find better data or (preferably) adjust the COP value with the lowest temperature expected in the area.

EPA Response:

To estimate HVAC energy consumption of ZEVs in HD TRUCS, we performed a literature and market review. Even though there are limited real-world studies, we

[67] National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, Kevala Inc., and U.S. Department of Energy. "Multi-State Transportation Electrification Impact Study: Preparing the Grid for Light-, Medium-, and Heavy-Duty Electric Vehicles". DOE/EE-2818. U.S. Department of Energy. March 2024. ("TEIS").

[68] Hussein Basma, Claire Buysee, Yuanrong Zhou, and Felipe Rodriguez. "Total Cost of Ownership of Alternative Powertrain Technologies for Class 8 Long-haul Trucks in the United States." April 2023. Available online: https://theicct.org/wp-content/uploads/2023/04/tco-alt-powertrain-long-haul-trucks-us-apr23.pdf.

[69] IPM and the RPM were run for select years between 2028 and 2050. We used linear interpolation for electricity prices between model run years from 2028–2050. We kept electricity prices constant for 2050+ and assumed the 2027 price was the same as 2028. We converted outputs of the RPM from 2019$ to 2022$.

[70] The results from the RPM (along with input files used for power sector modeling) discussed here are available in the docket. (See Evan Murray. Memorandum to Docket EPA-HQ-OAR-2022-0985. "Files from IPM Runs Supporting FRM Modeling." March 2024.)

agreed with the HVAC modeling approach described in Basma et. al.[71] This physics-based cabin thermal model considers four vehicle characteristics: the cabin interior, walls, and materials, as well as the number of passengers. The authors modelled a Class 8 electric transit bus with an HVAC system consisting of two 20 kW-rated reversible heat pumps, an air circulation system, and a battery thermal management system. The HVAC control strategy is a traditional on-off controller. The modeled power demand as a function of ambient temperature for the Class 8 transit bus is shown in Figure 2. In response to our request for data in the NPRM on HVAC loads for BEVs, we received additional modeling data from one commenter that included HVAC loads for European long-haul tractors. We found the new data to be corroborative with our HVAC loads and the sleeper cab scaling factor; therefore, we continued to use the same HVAC power demand model in the final version of HD TRUCS.

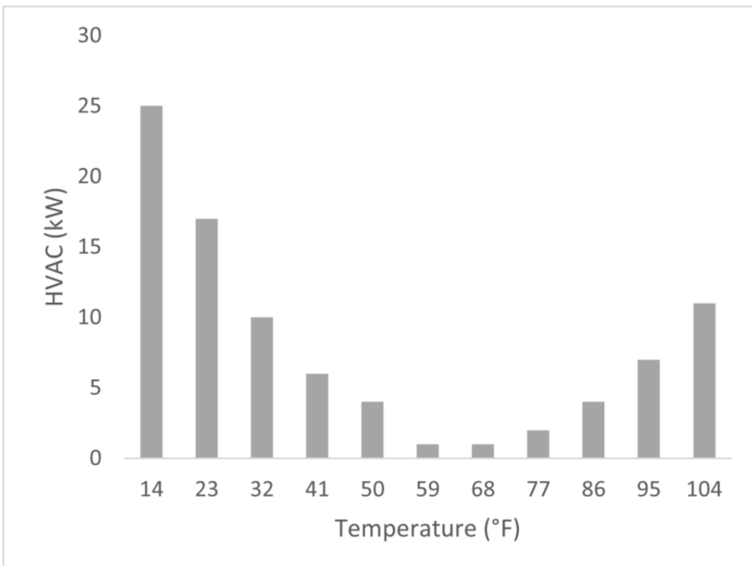

Figure 2 Modeled HVAC Power Demand of a Class 8 Transit Bus as a Function of Ambient Temperature

We recognize that HVAC is not evenly used across the nation. For example, some regions will be more reliant on heater use while others may depend more on air conditioning. The energy used for HVAC consumption in HD TRUCS is HVAC energy consumption using Basma for power demand at a specific temperature and weighted by the percent HD VMT traveled at a specific temperature range.[72] To properly account for the temperature variation throughout the nation and throughout the year, we calculated the percent of HD VMT for several temperature bins as available from MOVES; this national distribution of VMT as a function of temperature is shown in Figure 3. For the final version of HD

[71] 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.

[72] 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.

TRUCS, we created three separate bins - one for heating (<55 °F), one for cooling (>75 °F), and one for a temperature range that requires only ventilation (55-75 °F). The results of the VMT-weighted HVAC power demand for a Class 8 Transit Bus for each of the HVAC temperature bins are shown in Table 8. 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 each specific temperature range, as shown in Table 9.

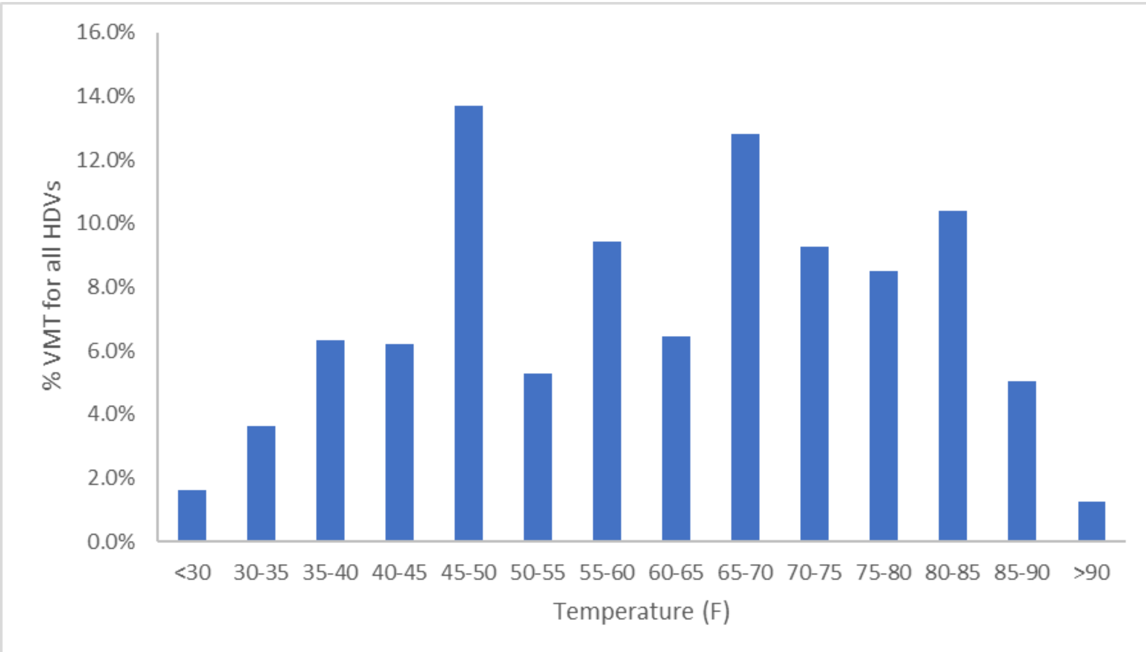

Figure 3 MOVES National VMT Distribution as a Function of Temperature for 2b-8 HD Vehicles

Table 8 HD TRUCS HVAC Power Consumption of a Class 8 Transit Bus

	Temperature (°F)	Consumption (kW)
Heating	<55	5.06
Ventilation	55-75	0.00
Cooling	>75	2.01

Table 9 Distribution of VMT for HD TRUCS Temperature Bins

Temperature Bins	Heating <55 °F	55-75 °F	Cooling >75 °F
% VMT	37%	16%	47%

Reviewer Comment: In addition to the above comment. The SOC of several types of batteries (including Li-ion) drops at very low temperature. Check what happened in Minneapolis this winter, when the range of EVs dropped precipitously.

Recommendation: Adjust the model and the data for very high and very low temperatures.

EPA Response:
BEVs have added energy requirements for heating and cooling of the vehicles as well as maintaining a constant temperature (conditioning) of the battery pack. The national average heating and cooling requirements are determined from the MOVES HD vehicle VMT distribution as a function of outside temperature, as well as the energy consumptions for HVAC and battery conditioning, detailed description can be found in RIA Chapter 2.2.2.2. From MOVES, these values are broadly grouped into temperature ranges in Table 10 with average HVAC in kW and battery conditioning as function size of the battery.

Table 10 Energy Consumption as a Function of Temperature Bins

Temperature Bins (°F)	% VMT Distribution	HVAC Power Consumption (kW)	Battery Conditioning (% of Battery)
<55	37%	5.06	1.9%
55-75	16%	-	-
>75	47.3%	2.01	3.0%

1.e: Where EPA has concluded that applicable data is meager or unavailable, and consequently has made assumptions to frame approaches and arrive at solutions, do you agree that the assumptions are appropriate and reasonable? If not, and you are able to do so, please suggest alternative assumptions that might lead to more reasonable or accurate tool inputs.

Reviewer 1: Dr. Baha Al-Alawi

Reviewer Comment: Approach: Including only TCO and Payback period as the main and only parameters to forecast ZEVs is not accurate. Some studies used TCO/payback to estimate the penetration, whereas others used qualitative parameters like our work (CALSTART Global drive to zero). But our work was based on the regulation and using ambitious targets. The work we did for California Corridor, NY, BYD, and federal policy was based on both TCO/Payback and the other qualitative parameters. Please refer to the above questions and overall summary for my recommendations.

EPA Response:
We agree with the comment that using only TCO or payback as the only parameter to forecast ZEVs is not sufficient and that is why we included unique caps for MY 2027, MY 2030 and MY 2032. We limited the maximum penetration

of the ZEV technologies in HD TRUCS to 20 percent in MY 2027, 37 percent in MY 2030 and 70 percent in MY 2032 for any given vehicle type. These caps reflect consideration of and address concerns about infrastructure readiness, willingness to purchase, and critical mineral and supply chain availability, reflecting that infrastructure. technology familiarity, and material availability will have more limitations in MY 2027 (and thus taking a conservative approach to the levels of the caps in those earlier model years) but will be further developed by MY 2032, while also capping each vehicle type in HD TRUCS below the proposed value of 80 percent utilization of ZEV technologies including in MY 2032.

Reviewer 2: Dr. Thomas Bradley

Reviewer Comment: The motor cost is far too high due to using an outdated reference. Instead, reference that UBS (https://neo.ubs.com/shared/d1wkuDlEbYPjF/) has done motor cost breakdowns and FEV has done motor cost breakdowns under contract to EPA that find that LDV motors are costing <$5/kW, and less than $10/kW including inverter, controller, motor, and transaxle. This ANL/Bean data is outdated, old and should be deprecated in favor of modern cost breakdown data.

EPA Response:
For the final version of HD TRUCS, we considered several e-motor costs. The analysis was complicated because several sources did not include a $ per kW cost for only the e-motor. Roush reports e-motor costs of $8/kW for 2030 and 2032, much lower than EPA's value used in the original HD TRUCS. An ICCT report projected cost reductions of 60 percent by 2030 and that further projected that the price of electric powertrain systems, including the transmission, motor, and inverter, would reach $23/kW.

For the final version of HD TRUCS, we maintained the direct manufacturing cost for the e-motor (including the inverter) that we used for the original HD TRUCS, but converted it to 2022$. The e-motor costs in HD TRUCS come from ANL's 2022 BEAN tool[73] as "Integrated Traction Drive Cost" values in the Vehicle Assumptions tab.[74,75] The MY 2027 value of $21/kW is a linear interpolation of the average of the high- and low-tech scenarios for 2025 and 2030, adjusted to 2022$.

Reviewer 3: Dr. William de Ojeda

[73] These values did not come directly from the "Autonomie Out Import" tab but can be calculated from fields on the "Autonomie Out Import" tab.
[74] Our assumption is that ANL's integrated cost includes the inverter and the motor.
[75] Argonne National Laboratory. VTO HFTO Analysis Reports – 2022. "ANL – ESD-2206 Report – BEAN Tool – MD HD Vehicle Techno-Economic Analysis.xlsm". Available online: https://anl.app.box.com/s/an4nx0v2xpudxtpsnkhd5peimzu4j1hk/folder/242640145714.

Reviewer Comment: "This is a difficult section to comment on. The tabs “inputs” lists a large sample of technologies and performance benchmarks based on 2021 benchmarks.

References are provided for each entry. Some are not available readily (there is a cost to access the reference). Overall, the references are limited.

Some of the inputs and assumptions are a bit surprising. Below are some examples.

• Material costs. H2 fuel tank cost is set at $801/kg. With a cost reduction to $612/kg in a 5-year time period. Studies shows that costs are likely to increase rather than decrease in the next foreseeable years due to resource limitations, dependency on foreign markets.

• Component costs. Motor costs show a rapid decline. What size and use are referred to for these motors?

• Power electronics show a reduction from $1581 to $628. Based on our experience, our manufacturing teams have encountered cost rises of 30% and greater in the last two years with a preoccupying shortage and long lead times. This has had a significant compromise to our competitive ability.

Alternatively, TRUCS could offer as default:

• the current cost value,

• provide a better assessment, not afraid to project higher costs than todays."

EPA Response:
RIA Chapter 2.4.3 and 2.5.2 summarize the component costs for BEVs and FCEVs used in the final versions of HD TRUCS. These values were determined after considering the comments to the proposal and the latest data from literature.

Onboard hydrogen storage cost projections vary widely in the literature. The values we used in the original version of HD TRUCS ranged between $660/kg in MY 2030 and $612/kg in MY 2032. Onboard gaseous hydrogen tank costs are dependent on manufacturing volume. We reviewed the ICCT paper that several commenters referenced and contracted with FEV[76] to independently evaluate onboard hydrogen storage tanks costs for 2027 (2022$) based on manufacturing volume, and EPA conducted an external peer review of the final FEV report.[77]

We established the MY 2032 onboard storage tank DMCs using cost projections from FEV and ICCT. We weighted FEV’s work twice as much as ICCT’s because it was primary research and because some of the volumes associated with the costs in ICCT’s analysis were not transparent. We note that this method of weighting primary research more heavily than secondary research is generally appropriate for assessing predictive studies of this nature; indeed, it is consistent

[76] FEV Consulting. “Heavy Duty Commercial Vehicles Class 4 to 8: Technology and Cost Evaluation for Electrified Powertrains—Final Report”. Prepared for EPA. March 2024.
[77] ICF. “Peer Review of HD Vehicles, Industry Characterization, Technology Assessment and Costing Report”. September 15, 2023

with what ICCT itself did. For FEV's work, we selected costs for approximately 10,000 units per year in MY 2032, for a DMC of $504 per kg. For ICCT's work, we used the 2030 value of $844 per kW for MY 2032, since 2030 was the latest year of values referenced by ICCT from literature. Our weighted average yielded a MY 2032 fuel cell system DMC of $617 per kW. Using our learning rates shown in RIA Chapter 3.2.1, this yields a cost of $659/kg in MY 2030 and $636/kg in MY 2031.

The direct manufacturing cost for the e-motor (including the inverter) in HD TRUCS from ANL's 2022 BEAN tool[78] as "Integrated Traction Drive Cost" values in the Vehicle Assumptions tab.[79,80] The e-motor costs range from $21 per kW in MY 2027 to $17 per kW in MY 2032. The motor sizes range between 203 to 551 kW, depending on the vehicle.

The direct manufacturing costs for the power converter, vehicle propulsion architecture, and electric accessories are shown below in Table 11.

Table 11: Direct Manufacturing Costs (2022$)

MY	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Power Converter ($)	1677	1577	1501	1440	1391	1349
VPA	208	196	186	179	173	167
Electric Accessories ($)	5032	4731	4502	4321	4174	4048

Reviewer 4: Dr. Efstathios Michaelides

Reviewer Comment: "All the data used are available (not meager or unavailable) but they are laden with very high uncertainty, which propagates in the results of the tool. As stated above the costing methodology is not appropriate because it does not take into account the time value of money and the time value for the user (user's discount rate). Recommendation: Instead of alternative assumptions include a payback time based on a discount factor the user inputs and include an uncertainty analysis to show the users the range of their cost, rather than a single value (e.g., the payback period is x years +- y years. "

EPA Response:

We understand the point of the comment from the reviewer that each of these inputs have a range of uncertainty. EPA is relying on the best available data as inputs to the HD TRUCS model. See HD GHG Phase 3 RIA Chapter 2. We have received many comments on the inputs to HD TRUCS and to the HD GHG Phase 3 NPRM. These include comments on costs, factors affecting costs and HD

[78] These values did not come directly from the "Autonomie Out Import" tab but can be calculated from fields on the "Autonomie Out Import" tab.

[79] Our assumption is that ANL's integrated cost includes the inverter and the motor.

[80] Argonne National Laboratory. VTO HFTO Analysis Reports – 2022. "ANL – ESD-2206 Report – BEAN Tool – MD HD Vehicle Techno-Economic Analysis.xlsm". Available online: https://anl.app.box.com/s/an4nx0v2xpudxtpsnkhd5peimzu4j1hk/folder/242640145714.

TRUCS inputs that recommend both lower and higher costs than what were in the original version of HD TRUCS. We have carefully considered all comments, and we have incorporated many suggested changes to the inputs and modeling that are used to estimate the cost of future ZEVs.

1.f: Are the results expected of the tool appropriate for the given scope, assumptions, and inputs? Is appropriate validation made on the costing methodology and results? Please expand on any recommendations that you would make for analyses of tool results.

Reviewer 1: Dr. Baha Al-Alawi

Reviewer Comment: Vehicle vocations (type) Registration/Sales: You may compare registration and sales data simulated in the tool with the existing U.S. vehicles. U.S. MHDVs (IHS (S&P) Polk DMV registration data) Van/Truck/Bus/Tractors vehicles under each GVWR class are available and come by state, Class (Class 2b-8), vocation, make/model, MY, VIN… I suggest comparing such data to the modeled vehicle data. MHDV sales data is not linear but changes year by year due to many factors: please look at our work (we are publishing the 3ed market update report in a couple of weeks:

Baha Al-Alawi, Owen MacDonnell, Ross McLane, and Kevin Walkowicz, Market Update, Zeroing in on Zero-Emission Trucks, CALSTART, July 2022

Baha Al-Alawi, Owen MacDonnell, Ross McLane, and Kevin Walkowicz, Zeroing in on Zero-Emission Trucks, CALSTART, January 2022

EPA Response:
For the original version of HD TRUCS, EPA calculated sales percentages for each vehicle application using certification data from MY 2019 and MOVES 3.R1 new vehicle sales data. For the final version of HD TRUCS we have updated our approach for calculating the sales percentages for each vehicle application to use the most recent available data: MY 2021 sales of new vehicles in the latest version of MOVES that is being used in conjunction with the final rule.

Reviewer Comment: Vehicle fuel/energy economy/efficiency: The tool included a very rich analysis of these numbers, but these values change with time, by vehicle make and model. Battery size, system, and vocation will impact these numbers. At least compare the used numbers to values from real-life numbers (or reported by OEMs). Again these numbers will be impacted by route and location, so having the ability to simulate different scenarios over different regions will help.

EPA Response:
Real world adoption of ZEV may be different than the scenario we project. Manufacturers will develop vehicle make and model optimized for users resulting in different capabilities than we project. Our analysis is a possible scenario

although we recognize differences may be seen as manufacturers produce vehicles with lower CO2 emissions to meet future emission standards. HD TRUCS looks at macro changes such as ambient temperature impact and vehicle use type (regional, urban, multipurpose).

FEV conducted a technology and cost study for a variety of powertrains as applicable to Class 4, 5, 7, and 8 heavy-duty vehicles. This study included product produced or soon to be produced by OEMs. The study was comprehensive and looked at the hardware specifications as well as the underlying assumptions that tied the vehicle capabilities to the hardware applied. Powertrains included BEVs and FCEVs, in addition to other ICE technologies. Vehicles studied include Class 4-8 box trucks, step vans, buses, vocational vehicles, and tractors. This analysis was considered in our development of the final version of HD TRUCS, as described in HD GHG Phase 3 RIA Chapter 2.

Reviewer Comment: VMT: real miles travel is different, but many models and studies use an estimate. Based on my experience collecting HVIP California ZEV telematics data, ZEV VMT is very low (near zero sometimes); this is sad since we assume that ZEVs will replace gasoline/diesel fuel with electric energy, and that will reduce GHG. So at least let us investigate the current VMT for vehicles by GVWR and vocation and then look if we can verify that ZEV will have the same VMT.

EPA Response:

At this point in time, there is not sufficient HD ZEV VMT available to assess the future VMT of ZEVs. The purpose of HD TRUCS is to determine the ZEV powertrain components required to conduct the same work that is being done by HD vehicles. VMT is one way to consider heavy-duty vehicle activity. In HD TRUCS, VMT is used to determine the daily and yearly use or operation of a vehicle, to size BEV battery packs, H2 storage tanks for FCEVs, and other components, and to estimate depot infrastructure needs. We relied on multiple sources to determine the VMT applied in HD TRUCS for each vehicle. The sources for daily VMT we considered were based on our assessment of data availability. We have listed them in order of publication date, the level of detail included in the data, and whether the data was collected from in-use vehicles: NREL's FleetDNA[81] database, a University of California, Riverside[82] (UC-Riverside) database, the Department of Transportation's Bureau of Transportation Statistic's 2002 Vehicle Inventory and Use Survey[83] (2002 VIUS), California Air

[81] NREL. Fleet DNA: Commercial Fleet Vehicle Operating Data. Available online https://www.nrel.gov/transportation/fleettest-fleet-dna.html

[82] Zhang, Chen, Karen Ficenec, Andrew Kotz, Kenneth Kelly, Darrell Sonntag, Carl Fulper, Jessica Brakora, Tiffany Mo, and Sudheer Ballare. 2021. Heavy-Duty Vehicle Activity Updates for MOVES Using NREL Fleet DNA and CE-CERT Data. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-79509. https://www.nrel.gov/docs/fy21osti/79509.pdf.

[83] United States Census Bureau. 2002 Vehicle Inventory and Use Survey. Available online https://www.census.gov/library/publications/2002/econ/census/vehicle-inventory-and-use-survey.html.

Resource Board (CARB) Large Entity Reporting[84], or independent sources, as discussed in RIA Chapter 2.2.1.2.

Reviewer Comment: After having vehicle count, fuel/energy efficiency, and VMT (for each vehicle vocation), you may estimate fuel/energy consumption and compare it to the reported U.S. MHDV (transportation) Gasoline, Diesel, and electricity consumption. This will help to verify the numbers. Making a conclusion on fuel/energy demand needs to be supported. We have done such work in Colorado:

Michael Somers, Liaw Batan, Baha Al-Alawi and Thomas Bradley, A Colorado-specific life cycle assessment model to support evaluation of low-carbon transportation fuels and policy, Environmental Research: Infrastructure and Sustainability, December 2021

EPA Response:
A detailed comparison of the onroad national gasoline and diesel fuel consumption estimated by MOVES is compared to the consumption levels estimated by Federal Highway Administration (FHWA) based on fuel tax data. MOVES4.R3 contains updated energy consumption rates for HD BEVs. MOVES calculates HD BEV energy consumption using the Energy Efficiency Ratio (EER) of a BEV to a diesel vehicle so that the energy consumption of a HD BEV can be calculated using diesel energy consumption rates. The EER for a BEV is generally greater than 1, indicating that BEVs are more energy efficient than their diesel counterparts.

Reviewer Comment: VMT: real miles travel is different, but many models and studies use an estimate. Based on my experience collecting HVIP California ZEV telematics data, ZEV VMT is very low (near zero sometimes); this is sad since we assume that ZEVs will replace gasoline/diesel fuel with electric energy, and that will reduce GHG. So at least let us investigate the current VMT for vehicles by GVWR and vocation and then look if we can verify that ZEV will have the same VMT.

EPA Response:
At this point in time, there is not sufficient HD ZEV VMT available to assess the future VMT of ZEVs. The purpose of HD TRUCS is to determine the ZEV powertrain components required to conduct the same work that is being done by HD vehicles. VMT is one way to consider heavy-duty vehicle activity. In HD TRUCS, VMT is used to determine the daily and yearly use or operation of a vehicle, to size BEV battery packs, H2 storage tanks for FCEVs, and other components, and to estimate depot infrastructure needs. We relied on multiple sources to determine the VMT applied in HD TRUCS for each vehicle. The sources for daily VMT we considered were based on our assessment of data availability. We have listed them in order of publication date, the level of detail included in the data, and whether the data was collected from in-use vehicles:

[84] CARB. Large Entity Fleet Reporting. Available online https://ww2.arb.ca.gov/sites/default/files/2022-02/Large_Entity_Reporting_Aggregated_Data_ADA.pdf.

NREL's FleetDNA[85] database, a University of California, Riverside[86] (UC-Riverside) database, the Department of Transportation's Bureau of Transportation Statistic's 2002 Vehicle Inventory and Use Survey[87] (2002 VIUS), California Air Resource Board (CARB) Large Entity Reporting[88], or independent sources, as discussed in RIA Chapter 2.2.1.2.

Reviewer Comment: After having vehicle count, fuel/energy efficiency, and VMT (for each vehicle vocation), you may estimate fuel/energy consumption and compare it to the reported U.S. MHDV (transportation) Gasoline, Diesel, and electricity consumption. This will help to verify the numbers. Making a conclusion on fuel/energy demand needs to be supported. We have done such work in Colorado:

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[85] NREL. Fleet DNA: Commercial Fleet Vehicle Operating Data. Available online https://www.nrel.gov/transportation/fleettest-fleet-dna.html

[86] Zhang, Chen, Karen Ficenec, Andrew Kotz, Kenneth Kelly, Darrell Sonntag, Carl Fulper, Jessica Brakora, Tiffany Mo, and Sudheer Ballare. 2021. Heavy-Duty Vehicle Activity Updates for MOVES Using NREL Fleet DNA and CE-CERT Data. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-79509. https://www.nrel.gov/docs/fy21osti/79509.pdf.

[87] United States Census Bureau. 2002 Vehicle Inventory and Use Survey. Available online https://www.census.gov/library/publications/2002/econ/census/vehicle-inventory-and-use-survey.html.

[88] CARB. Large Entity Fleet Reporting. Available online https://ww2.arb.ca.gov/sites/default/files/2022-02/Large_Entity_Reporting_Aggregated_Data_ADA.pdf.

of a BEV to a diesel vehicle so that the energy consumption of a HD BEV can be calculated using diesel energy consumption rates. The EER for a BEV is generally greater than 1, indicating that BEVs are more energy efficient than their diesel counterparts.

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EPA Response:
At this point in time, there is not sufficient HD ZEV VMT available to assess the future VMT of ZEVs. The purpose of HD TRUCS is to determine the ZEV powertrain components required to conduct the same work that is being done by HD vehicles. VMT is one way to consider heavy-duty vehicle activity. In HD TRUCS, VMT is used to determine the daily and yearly use or operation of a vehicle, to size BEV battery packs, H2 storage tanks for FCEVs, and other components, and to estimate depot infrastructure needs. We relied on multiple sources to determine the VMT applied in HD TRUCS for each vehicle. The sources for daily VMT we considered were based on our assessment of data availability. We have listed them in order of publication date, the level of detail included in the data, and whether the data was collected from in-use vehicles: NREL's FleetDNA[iv] database, a University of California, Riverside[v] (UC-Riverside) database, the Department of Transportation's Bureau of Transportation Statistic's 2002 Vehicle Inventory and Use Survey[vi] (2002 VIUS), California Air Resource Board (CARB) Large Entity Reporting[vii], or independent sources, as discussed in RIA Chapter 2.2.1.2.

Reviewer Comment: After having vehicle count, fuel/energy efficiency, and VMT (for each vehicle vocation), you may estimate fuel/energy consumption and compare it to the reported U.S. MHDV (transportation) Gasoline, Diesel, and electricity consumption. This will help to verify the numbers. Making a conclusion on fuel/energy demand needs to be supported. We have done such work in Colorado:

Michael Somers, Liaw Batan, Baha Al-Alawi and Thomas Bradley, A Colorado-specific life cycle assessment model to support evaluation of low-carbon transportation fuels and policy, Environmental Research: Infrastructure and Sustainability, December 2021

EPA Response:
A detailed comparison of the onroad national gasoline and diesel fuel consumption estimated by MOVES is compared to the consumption levels estimated by Federal Highway Administration (FHWA) based on fuel tax data. MOVES4.R3 contains updated energy consumption rates for HD BEVs. MOVES

calculates HD BEV energy consumption using the Energy Efficiency Ratio (EER) of a BEV to a diesel vehicle so that the energy consumption of a HD BEV can be calculated using diesel energy consumption rates. The EER for a BEV is generally greater than 1, indicating that BEVs are more energy efficient than their diesel counterparts.

Reviewer Comment: Technology incremental costs: The real retail price of ZEV varies due to different factors and using the $/kWh is easy for modelers but not accurate. Having real retail prices with low, average, and high is one way to do it, but this needs some work serving the market. CARB has the OEMs components costs, but it is confidential. CALSTART has HVIP incentives, and ZEV delivered price data. Please refer to HVIP and ZETI and reach out to CARB: https://californiahvip.org/

EPA Response:
We agree that pricing is complex and varied. Component cost data was collected from literature, from DOE's National Lab analyses, and from a study conducted by FEV for EPA for use in HD TRUCS. For the final version of HD TRUCS, we re-evaluated our values used for battery cost in MY 2027 based on consideration of comments provided by stakeholders, as well as additional studies provided by the FEV and the Department of Energy BatPaC model. FEV conducted a technology and cost study for a variety of powertrains as applicable to Class 4, 5, 7, and 8 heavy-duty vehicles. Powertrains included BEVs and FCEVs, in addition to other ICE technologies. Vehicles studied include Class 4-8 box trucks, step vans, buses, vocational vehicles, and tractors. FEV also costed three (15L (Class 8), 10L (Class 7), 6.6L (Class 4/5)) diesel ICE powertrains that would meet the emission standards as required by the HD2027 Low NOx Rule and the Phase 2 CO_2 emission standards in MY 2027. EPA has carefully considered information made available to EPA. Thus, while we acknowledge that future projections inherently are subject to uncertainties, EPA has carefully analyzed the uncertainties and identified the considerations we found persuasive.

Reviewer 2: Dr. Thomas Bradley

Reviewer Comment: See above for some questioning of the results for specific submodels.

EPA Response:
See previous responses above.

Reviewer 3: Dr. William de Ojeda

Reviewer Comment: The TRUCS tool is overall quite complete and comprehensive. It is a result of a very thorough modeling of three technology paths.
The results the tool provides 'reasonable' projections that reflect the input values.
Two items however appear a discordant as indicated below:

1. Including incentives can make the interpretation of the results "biased", as the cost-to-the consumer is in many of the presented categories severely tilted due to this category. In effect the most significant entry is the incentive itself.
2. The projected cost reduction in many of the BEV and FCEV technologies over time appears to be widely exaggerated. Much of the materials used here are coming from non-US sources and it is likely that costs will rise over time [1].
3. Providing prescribed schedules of adoption rate are rather a "guess" game and could be set aside.
In summary, the study could and possibly should:
- focus on the technical merits of the technologies.
- Refrain from overly optimistic forecasts, either stay as is, or even provide negative trends as we are experiencing today.

EPA Response:
Including incentives is an integral part of this analysis. While there are challenges facing greater adoption of heavy-duty ZEV technologies, the IRA provides many financial incentives to overcome these challenges and thus provides support for the utilization of HD vehicle technologies with the potential for large reductions in greenhouse gas emissions during the MYs analyzed in HD TRUCS. The IRA incentives are intended and expected to increase adoption of BEV and FCEV technology in the heavy-duty sector. The IRA offers sizeable tax incentives for domestic production of batteries and critical minerals, including production tax credits that apply to domestically produced cells, modules, and packs, electrode active materials, and critical minerals, that can reduce battery manufacturing costs.

See our previous responses relative to BEV and FCEV component costs and HD GHG Phase 3 RIA Chapter 2.

Reviewer 4: Dr. Efstathios Michaelides

Reviewer Comment: "The results are appropriate for the scope of the tool. However, the assumptions of the tool (and the numerical values of the inputs) are not clear and need to be specified.

Recommendation: Produce a "manual" (or report) that explains everything. "

EPA Response:
EPA thanks the commentor for their input. We have included descriptions and sources that informed our updates to HD TRUCS in the HD GHG Phase 3 RIA Chapter 2.

Questions about Editorial Content:

2.a: Is sufficient detail provided in the body for a reader familiar with the subject report to understand the process and conclusions? Please specify any specific content that you recommended be added or removed.

Reviewer 1: Dr. Baha Al-Alawi

Reviewer Comment: The tool needs a manual on how to use it and create scenarios supported by examples.

EPA Response:
Thank you for the suggestion. Developing a manual or providing examples to create other scenarios is beyond the scope of the tool currently since the tool is designed primarily to support HD GHG Phase 3 rulemaking. HD GHG Phase 3 RIA Chapter 2 includes information similar to a manual, including the equations and methods used in the tool. However, we will consider adding them into future versions.

Reviewer Comment: The process of the tool functions needs to be illustrated and included in the Introduction tab.

EPA Response:
Thank you for the suggestion. We have added more detail on the process to the Introduction and Table of Contents tabs in HD TRUCS. Please also see HD GHG Phase 3 RIA Chapter 2 for more information on the functions and equations used in the tool.

Reviewer Comment: Step by step on how to use the tool could be included within the tool. I recommend using illustrations (screenshots) of each input/output.

EPA Response:
Thank you for your comment. We have added more detail on how to use the tool in the Introduction and Table of Contents worksheets in HD TRUCS and in HD GHG Phase 3 RIA Chapter 2.

Reviewer Comment: Drop-down and control options need to be included, maybe include a list of options for each parameter that the users are able to change.

EPA Response:
Thank you for the suggestion. We have clarified in the Table of Contents tab in HD TRUCS that the values in the Input tab can changed by the user. The user is able to enter a value for each of the parameters on this tab. We only have included a drop-down option for the analysis year in the Summary tab.

Reviewer Comment: Results: you might have two results tabs, one with illustration and another one with data.

EPA Response:
Thank you for this suggestion. This is beyond the scope of the tool at this time. However, we will consider adding a second results tab into future versions.

Reviewer 2: Dr. Thomas Bradley

Reviewer Comment: Yes, the model is well-supported by the documentation in the RIA

EPA Response:
Thank you for the comment.

Reviewer 3: Dr. William de Ojeda

Reviewer Comment: Under column GEM Energy ID, there is reference to the "A1c_GEM_ID XXX", but it is not clear how to access the content for this description.

Can this be provided?

EPA Response:
The Table of Contents tab in HD TRUCS notes that, "Appendix sheets (e.g., "A1c_GEM_ID") are hidden, to use hyperlinks, please unhide respective sheets."

Reviewer Comment: Under column "10 year average Daily Operational VMT" (also the case elsewhere here), the program accesses the "1_Veh Prop tab". If this input is overwritten in the spreadsheet it does not affect the calculations. Is this intended? Values can be adjusted in the 1_Veh Prop sheet with a results being updated in Summary, but this is cumbersome. Recommendation:

- retain the program's default values as reference and allow the user to vary these while retaining easy access to the reference values.

EPA Response:
Thank you for the suggestion, but this is not functionality that we are adding at this time.

Reviewer Comment: Tab "change the value in the input tab" goes to the input tab, without regard to the value being consulted. Recommendation:

- Link to, the corresponding CELL in the input tab (e.g., operation hours, battery cost, electricity price, etc.)

EPA Response:
Thank you for the comment. This is not functionality that we are changing at this time.

Reviewer Comment: "Return to Table of Contents" link does not work

EPA Response:
Thank you. This has been fixed in the final version of HD TRUCS.

Reviewer Comment: The user can toggle between ZEV suitability of EV vs FCEV, this giving different estimates over the adoption rates.

- Why provide this toggle switch? Are not both ZEV able?
- What guidance indicators are provided to make this selection?

EPA Response:
We assigned, as default values, FCEV technology for select applications that travel long distances. Please see HD GHG Phase 3 RIA Chapter 2 for more details on the vehicle technology for the HD TRUCS vehicle types in these scenarios.

Reviewer Comment: The table for Adoption Rates by Payback Years show a note "change values here", but it is not clear how and where these assumptions are applied in. Changings these values did not affect payback. Recommendation:

- provide an explanation on how the payback and adoption rates affect the estimates in TRUCS.

EPA Response:
Changing the adoption rate percentages (shaded in purple) in the "Adoption Rate by Payback Years" table on the "Summary" tab changes the "ZEV Adoption Rates by Vehicle Type" columns, which can also be found on the "Summary" tab.

Reviewer 4: Dr. Efstathios Michaelides

Reviewer Comment: The "list of acronyms" hyperlink is not functional. Acronyms are missing.

EPA Response:
Thank you for the comment. The functionality has been restored in the final version of HD TRUCS and the acronym list has been improved. We note there is also a broader acronym list in HD GHG Phase 3 RIA Appendix D.

Reviewer Comment: Reference is made to "ZEV technologies." If this acronym is "zero emissions vehicles" it is a misnomer (they do consume energy and the electricity power plants emit emissions).

Caution: A google search for "ZEV technologies" leads to a firearms company in Washington State. It appears the term is a trademark of the firearms corporation. I recommend removal/change of the term.

EPA Response:
We use the term zero-emission vehicle (ZEV) technologies throughout HD TRUCS to refer to technologies that result in zero tailpipe emissions, and vehicles that use these ZEV technologies, including BEVs and FCEVs, we refer to

collectively as ZEVs. ZEV is a term that many of the users of HD TRUCS will be familiar with so we will continue to use it.

Reviewer Comment: A great deal of information (especially values of variables) is missing.

Recommendation: A short manual to explain all variables, inputs and methodology.

EPA Response:
Thank you for this suggestion. We have added a list of acronyms on tab "A98_Acronyms." In addition, RIA Chapter 2 has descriptions of the variables, inputs and methodology used in HD TRUCS.

2.b: Please comment on any editorial issues that should be addressed in the tool, including any comments on general organization, pagination, or grammar and wording.

Reviewer 1: Dr. Baha Al-Alawi

Reviewer Comment: None provided

Reviewer 2: Dr. Thomas Bradley

Reviewer Comment: "Fuel cell stack tractors" is strange wording. I think that we mean fuel cell stack and BOP?

EPA Response:
Thank you for the observation. The "fuel cell stack tractors" cells in the Inputs tab of HD TRUCS have been removed to avoid confusion and because there is only one set of fuel cell costs in use.

Reviewer Comment: There is a row here for charging efficiency. This seems repetitious with A12-A15 of the same sheet. What is the difference?

EPA Response:
The value has been clarified on the "Inputs" tab of the final version of HD TRUCS.

Reviewer Comment: Are the headings in this spreadsheet wrong? Are they presenting FCEV adoption rates in the BEV sheet? See H3, H4, where it reads "2027 FCEV Adoption Rates"

EPA Response:
Thank you for the observation. We have updated the headings to match the BEV Adoption Rates in those cells.

Reviewer 3: Dr. William de Ojeda

Reviewer Comment: Study does a good job to reflect the diverse nature of the heavy-duty vehicle market.

> EPA Response:
> Thank you for the comment.

Reviewer Comment: "The organization is well done given the application is EXCEL.

There are many ways to approach the user interaction. From personal experience, having provided several similar applications to customers based on EXCEL with user defined inputs, interaction with data sources from the field, one could offer suggestions to improve this interface. Given the time limitation associated with the present review, two noted:

- allow the program to be more interactive upfront, without having to access separate tabs for inputs.

- focus on a given application rather than having so many reports in front of the user. The physical space available in the spreadsheets could be better consolidated this way."

> EPA Response:
> Thank you for your suggestions. We have revised HD TRUCS to include the inputs all on the Inputs tab for the final version. Because HD TRUCS is an analytic tool for assessing heavy-duty vehicle suitability, cost, and payback comparisons between BEV and FCEV technologies as compared to a comparable ICE vehicle, based on data and resources available to EPA at the time of the analysis, it is necessary to include each of the reports for all of the different types of vehicles However, we will consider improving the user interface in future versions of HD TRUCS.

Reviewer Comment: "The study focuses on the implementation of BEV and FCEV. This is a growing and transformational field, and significant assumptions are provided to show their potential energy impact.

These technologies are compared to a fixed ICE benchmark.

The latter technology (ICE), if allowed, would bring its own improved results. The hybridization of ICE and introduction of range extenders would be a significant improvement. Projections in this category are actually more realistic and provide higher confidence levels than the projection provided by the BEV and FCEV owing to several project demonstrators such as the DOE Supertruck program. There could be a more balanced approach across the technology field."

EPA Response:
The final version of HD TRUCS has a number of improvements to the original version that were made based on consideration of stakeholder comments and additional information. It is used to evaluate ICE vehicles, BEV, FCEVs, and PHEVs and could be adapted to evaluate other technologies. Outside of HD TRUCS, we have evaluated other technologies as part of our HD GHG Phase 3 final rulemaking, as discussed in RIA Chapter 2.11.

Reviewer 4: Dr. Efstathios Michaelides

Reviewer Comment: Recommendation: Since the "Main section" in the tool is not defined, use the phrase: "User should start with the Summary and Inputs sheets."

EPA Response:
Thank you for the recommendation. We have revised the wording in the final version of HD TRUCS.

Reviewer Comment: Recommendation: Define "upfront technology costs"

EPA Response:
We have clarified the definition of "upfront technology costs" in HD GHG Phase 3 RIA Chapter 2 and in the "A3a_Upfront_PT" and "A3b_Upfront_Veh" tabs in the final version of HD TRUCS.

Reviewer Comment: Recommendation: use a comma (,) before and after a dependent clause that starts with the word "which."

EPA Response:
Thank you for the recommendation.

Reviewer Comment: Sometimes the "Oxford comma" (comma before "and") is used and sometimes it is not. Revise for consistency.

EPA Response:
Thank you for the recommendation.

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[i] Burnham, Andrew, David Gohlke, Luke Rush, Thomas Stephens, Yan Zhou, Mark A. Delucchi, Alicia Birky, Chad Hunter, Zhenhong Lin, Shiqi Ou, Fei Xie, Camron Proctor, Steven Wiryadinata, Nawei Liu, and Madhur Boloor. "Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains". April 2021. Accessible online: https://publications.anl.gov/anlpubs/2021/05/167399.pdf.

[ii] Burnham, et al uses 2019$ in this report. See page 22 of https://publications.anl.gov/anlpubs/2021/05/167399.pdf.

[iii] Argonne National Laboratory. VTO HFTO Analysis Reports – 2022. "ANL – ESD-2206 Report – BEAN Tool – MD HD Vehicle Techno-Economic Analysis.xlsm". Available online: https://anl.app.box.com/s/an4nx0v2xpudxtpsnkhd5peimzu4j1hk/folder/242640145714.

[iv] NREL. Fleet DNA: Commercial Fleet Vehicle Operating Data. Available online https://www.nrel.gov/transportation/fleettest-fleet-dna.html

[v] Zhang, Chen, Karen Ficenec, Andrew Kotz, Kenneth Kelly, Darrell Sonntag, Carl Fulper, Jessica Brakora, Tiffany Mo, and Sudheer Ballare. 2021. Heavy-Duty Vehicle Activity Updates for MOVES Using NREL Fleet DNA and CE-CERT Data. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-79509. https://www.nrel.gov/docs/fy21osti/79509.pdf.

[vi] United States Census Bureau. 2002 Vehicle Inventory and Use Survey. Available online https://www.census.gov/library/publications/2002/econ/census/vehicle-inventory-and-use-survey.html.

[vii] CARB. Large Entity Fleet Reporting. Available online https://ww2.arb.ca.gov/sites/default/files/2022-02/Large_Entity_Reporting_Aggregated_Data_ADA.pdf.