SUMMARY OF U.S. EPA HEAVY-DUTY PHASE 3 GHG PROPOSAL

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On April 12, 2023, the U.S. EPA announced the Phase 3 proposal for reduction of greenhouse gas emissions from heavy-duty vehicles. Written comments are due through June 16th, 2023.

Link to the proposal and supporting documents.

What's changing	What's not
• Revised GHG standards for MY 2027 HD vehicles, new GHG standards for MYs 2028 through 2032 • Apply to heavy-duty vehicles > 14,000 lbs GVWR • End to credit multipliers for BEVs and PHEVs starting MY 2027	• CO_2 emission standards for HD engines • Revisions to nitrous oxide (N2O), methane (CH4) • Trailer standards

The proposal establishes new CO_2 standards for MY 2028 through MY 2032. These are derived from MY 2027 standards and reducing the limit according to the ZEV adoption rates projected to be feasible. Thus, CO_2 standard for MY 2028 = MY 2027 Standard x (100% - projected ZEV share for MY 2028). As such it is useful to first look at the projected ZEV adoption rates.

BENEFITS

Primarily through transitioning to ZEVs, the Phase 3 rule is expected to cumulatively reduce tailpipe GHG emissions by 2.3 billion tons over 2027 – 2055. Over 95% of the reductions are associated with CO_2 emissions, and the rest with methane and N_2O reductions.

The shift to electricity as fuel is estimated to increase the upstream CO_2 emissions cumulatively by 0.4 billion tons from 2027 to 2055, resulting in a net reduction in GHG emissions on a well-to-wheel basis of 1.9 billion tons over the same time.

Cumulative GHG Change from 2027 to 2055 in billion metric tons		
Tailpipe GHG	Upstream GHG	Net GHG Change
- 2.3	+ 0.4	- 1.9

The reduced fuel consumption will also result in reduced criteria pollutants. In 2055, emissions of NOx are estimated to reduce by 28%, $PM_{2.5}$ by 39%, VOC by 37%, and SO_2 by 31%.
The present value of net benefits to society are estimated at ~ $320 billion through 2055, more than 5 times the cost in vehicle technology and associated electric vehicle supply equipment (EVSE) combined.

ZEV ADOPTION

The EPA notes that in MY 2021, 1,163 HD BEVs were certified, representing 0.2% of the HD market. No FCEVs were certified. However, rapid growth in the ZEV market is expected due to the financial stimulus through IRA.

Table below lists the EPA estimated ZEV adoption rates, as one potential technology pathway to meet the CO_2 standards. EPA has also included and is seeking comment on slower adoption rates leading to less stringent CO_2 standards and a more stringent case, aligned with California's ACT rule. For all cases, manufacturers can choose other pathways with improved ICE technologies, hybridization, and ZEVs.

ZEV Adoption Rates	2027	2028	2029	2030	2031	2032
LHD Vocational	22%	28%	34%	39%	45%	57%
MHD Vocational	19%	21%	24%	27%	30%	35%
HHD Vocational	16%	18%	19%	30%	33%	40%
MHD All Cab and HHD Day Cab Tractors	10%	12%	15%	20%	30%	34%
Sleeper Cab Tractors	0%	0%	0%	10%	20%	25%
Heavy Haul Tractors	0%	0%	0%	11%	12%	15%

As reference baseline, the EPA estimates that California's ACT rule will lead to a nationwide ZEV adoption to reach ~ 9% by the end of this decade for Class 4 – 8 vocational vehicles, and 3% for Class 7 – 8 tractors.

PROPOSED CO_2 STANDARDS

Tractor CO_2 standards for each model year have been calculated by multiplying the CO_2 emissions standard for MY 2027 with the fraction of ICE-powered vehicles for that respective year. The fraction of ICE-powered is one minus the ZEV adoption rate in the table above.

For vocational vehicles, there is an additional complexity in terms of computing the credits to be provided for a ZEV, considering that those would be different depending on the application (urban/regional/multi-purpose) and whether it replaces a compression- or spark-ignition engine powered vehicle. A change is made which sets the CI engine multi-purpose use as the default standard based on which credits are calculated.

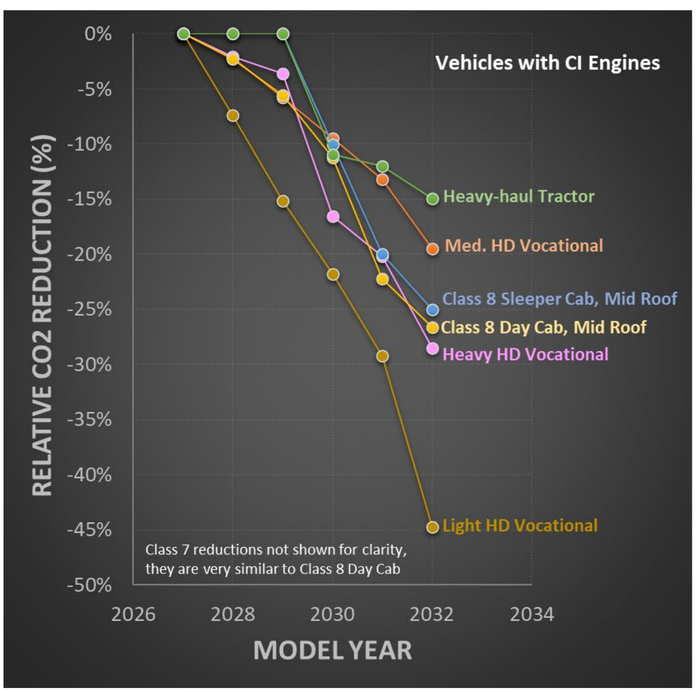
Table below summarizes the resulting CO_2 standards for vehicles with CI & SI engines, along with the relative reductions through MY 2032. As expected, the required reductions are higher for lighter vehicles, reflecting the greater expected penetration of ZEVs in those categories.

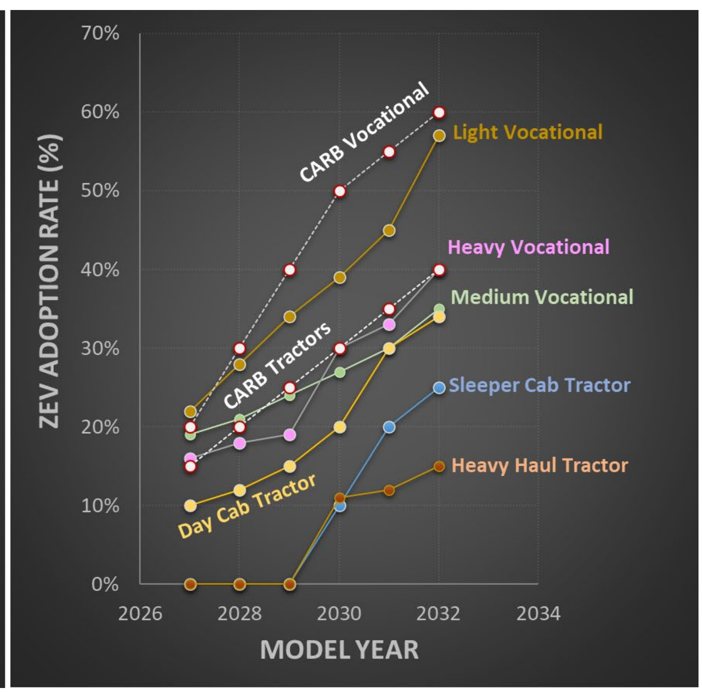
CO_2 Standards, g-CO_2/ton-mi	2027	2028	2029	2030	2031	2032+	% Reduction 2027 – 2032

CI, LHD Vocational*	257	238	218	201	182	142	45%
CI, MHD Vocational*	190	186	179	172	165	153	19%
CI, HHD Vocational*	193	189	186	161	154	138	28%
CI, Class 7 All Cab Styles	93.1	91	87.9	82.7	72.4	68.2	27%
CI, Class 8 Day Cab, Mid Roof**	70.2	68.6	66.3	62.3	54.6	51.5	27%
CI, Class 8 Sleeper Cab, Mid Roof**	69.6	69.6	69.6	62.6	55.7	52.2	25%
CI, Heavy-Haul Tractor	48.3	48.3	48.3	43	42.5	41.1	15%
SI, LHD Vocational*	299	280	260	243	224	184	39%
SI, MHD Vocational*	223	219	212	205	198	186	17%

*For the vocational, table above lists the standards for "multi-purpose" use, while there are other standards for urban (higher CO_2 limits) and regional (lower CO_2 limits) subcategories.
**For day and sleeper cabs, table above lists the standards for mid roof, the proposal includes other standards for low roof (lower limits) and high roof (higher limits).

Here is a graphical summary of the proposed baseline standards and the projected ZEV adoption in various subcategories, along with a comparison with electrification rates in California's Advanced Clean Trucks rule.



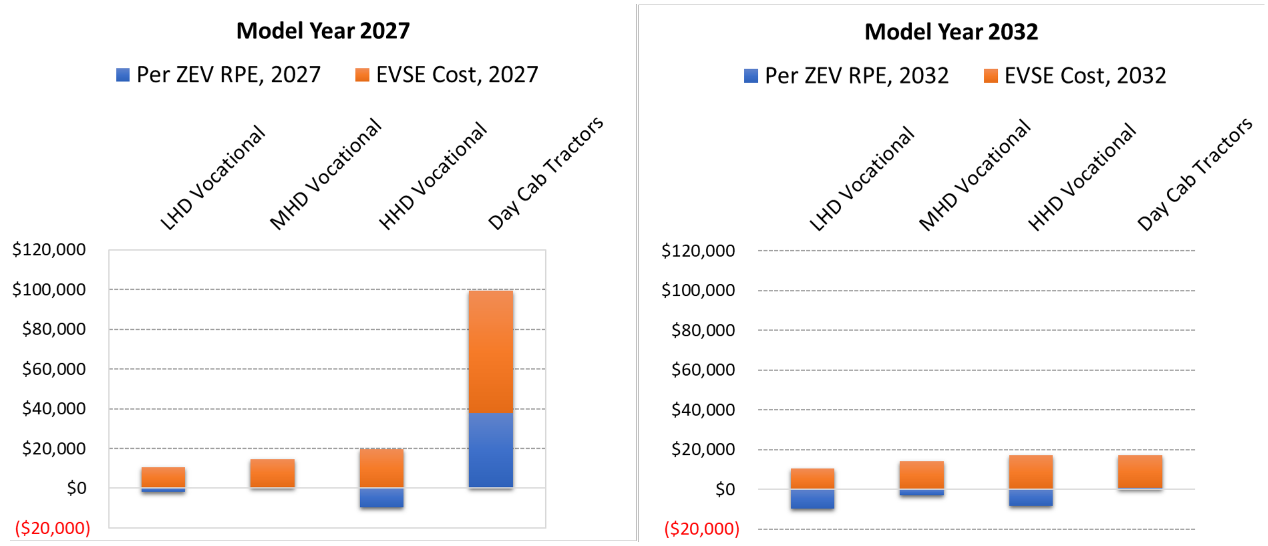


HEAVY-DUTY TECHNOLOGY RESOURCE USE CASE SCENARIO (HD TRUCS)

A new tool, Heavy-Duty Technology Resource Use Case Scenario (HD TRUCS), was developed to evaluate HD ZEV technologies and costs.

- It was applied to 101 different vehicle types and 22 applications.

- Only BEVs considered from MY 2027-29. FCEVs assumed to lag in terms of market share and cost competitiveness compared to BEVs in early years and considered only after MY 2030 for select applications requiring longer distances and heavier loads.
- Inflation Reduction Act (IRA): The following provisions of the IRA were used in HD TRUCS modeling -
  (1) ''Advanced Manufacturing Production Credit'' of up to $45 per kWh tax credits for batteries produced and raw materials sourced in the U.S. (it is split into $35 for battery cells and $10 per kWh for modules)
  (2) "Qualified Commercial Clean Vehicles," tax credit of $40,000 was applied to upfront HD vehicle cost.
- The estimated incremental cost of ZEVs and the charging hardware to the end purchaser are shown below. For a day cab tractor, the additional cost is expected to reduce from ~ $100,000 in MY 2027 to ~ $17,000 in MY 2032 (i.e., an 83% reduction) due to economies of scale and learning.



- The additional cost of ZEVs is expected to be offset by reduced operational costs:
  - Maintenance and repair costs: 67 ¢/mi for vocational and short-haul, 25 ¢/mi for long-haul diesels. Compared to ICE, costs for BEVs and FCEVs were scaled down to 71% and 75%, respectively.
  - Fuel costs: Diesel price averaged over 10 years was used. Electricity price was assumed to be at commercial end-use rate, taken from DOE Annual Energy Outlook 2022. Price of H_2 assumed to reduce from $6.1 /kg-$H_2$ to $4 /kg-$H_2$ beyond 2030.
- Payback time was assumed to be the most relevant metric to determine ZEV uptake. ZEV adoption rate was assumed to be 80% for immediate payback, reducing to 18% for a 2 – 4 year payback and no adoption for payback time greater than 15 years. The payback period is estimated at 3 years for vocational vehicles and 8 years for day cab tractors in MY 2027. Light HD vocational vehicles are expected to have a payback of 1 year in MY 2032.

ASSESSMENT OF ENABLING TECHNOLOGIES AND COMPONENTS

<u>Internal combustion engines</u>: Technology package considered for tractors and vocational trucks

- Improved aerodynamics
- Low rolling resistance tires
- Tire inflation systems
- Efficient engines

- Stop/start
- Cylinder deactivation
- Hybridization
- Improved transmissions, drivetrains, & accessories
- Weight reduction
- Idle reduction
- H_2-ICE

Batteries

- Energy consumption was calculated for baseline operation, HVAC, and thermal management of batteries below 55 F (1.9%) and above 80 F (4.2%). Heat pumps are projected to more efficient and dominant technology for cabin temperature control.
- Battery size was estimated based on energy consumption above and targeting a 90th percentile VMT for each application. The size was adjusted upward to account for inefficiencies of batteries, inverters, and motors (~87% system efficiency), usable charge (80%) and deterioration (oversizing by 20%).
- Battery packs are expected to improve with time. Battery pack-level specific energy is assumed to increase from 199 Wh/kg in 2027 to 223 Wh/kg in 2032. Pack level energy density is assumed to increase from 496 Wh/L in 2027 to 557 Wh/L in 2032.
- Including the IRA incentives described above, battery pack cost was assumed to decrease from $145/kWh in 2027 to $111/kWh in 2032, expressed in 2021$.
- Other costs included: E-drive @ $20/kW in 2027 reducing to $15/kW in 2032, on-board charger @ $38 in 2027 reducing to $29 in 2032.
- Battery raw materials: The assessment concludes that battery raw materials will be increasingly sources domestically due to the IRA and other government incentives and re-shoring of supply chain underway.
- Total battery demand for HD transport is projected at 17 GWh by MY 2027 and 36 GWh by MY 2032. In contrast, light- and medium duty vehicles are projected to require up to 1,000 GWh battery capacity starting MY 2031. By 2050, battery recycling capacity is expected to 25 – 50% of total lithium demand.

Charging infrastructure

- The electricity demand due to heavy-duty electrification is expected to increase by 2.7% in the roughly three decades of 2027 - 2055, and not expected to pose a challenge to grid stability. The increase in 1992 – 2021 was 25%, as reference.
- Charging is assumed to occur primarily at private depots. Cost of charging infrastructure was included for AC Level 2 (19.2 kW) and 50 kW, 150 kW, and 350 kW DC fast charging (DCFC) – and not for public charging.
- Available time for charging is assumed to be 12 hours based on collected data.
- Charging infrastructure costs range from $10,541 for Level 2 to $162,333 for 350 kW DCFC charger for one vehicle per port and reduced by 50% for 2 vehicles per port.
- Costs for upgrades at utility (e.g. transformers) are not included.

Fuel cells

- Fuel cells are assumed to use Proton exchange membrane (PEM) technology.
- Fuel cell stack sized to meet 90% percentile of power required for driving the ARB transient cycle or for long-haul trucks to maintain a constant highway speed of 75 mph while loaded at 80,000- pound gross combined vehicle weight (GCVW)
- Fuel cell efficiency (chemical energy stored in H_2 to useful work) was assumed to increase from 64.5% in 2027 to 66% in 2032.
- Fuel cell stack costs assumed to reduce from $242/kW in 2027 to $185/kW in 2032

- H2 fuel tank costs reduce from $801/kg-H2 in 2027 to $612/kg-H2 in 2032
- On-board H2 capacity is not expected to be a concern given the current state-of-art for 350 and 700 bar tanks and even liquid H2 technology. Refill times are in minutes, also not a concern.

H_2-ICE

- CO_2 emissions from ICEs using neat H_2 are deemed to be zero (neat refers to fuels with no carbon – pilot diesel injection does not count)
- Manufacturers are not required to perform any engine testing for CO_2 emissions
- H_2-ICE would be required to meet the criteria pollutant requirements

COMPLIANCE, FLEXIBILITIES AND TEST PROCEDURES

- Compliance is based on tailpipe CO2 emissions. Upstream emissions from refinery and electricity generation are estimated but not included in standards.
- Vehicle manufacturers would continue to demonstrate that they meet emission standards using EPA's Greenhouse gas Emissions Model (GEM)
- The Averaging, Banking and Trading (ABT) program is retained from GHG Phase 2. Manufacturer can use credits, generated when CO_2 emissions are below the standards for vehicle families, to offset higher emissions from vehicles in same averaging set.
- Earned credits in HD GHG Phase 2 can be carried over into Phase 3 for the existing credit life of 5 years. Credit deficits must be resolved within 3 years (as before).
- Advanced technology credit multipliers for HD plug-in hybrid (3.5) and battery electric vehicles (4.5) to be phased out after MY 2026, one year earlier than in current regulations. For fuel-cell vehicles, credit multiplier of 5.5 continues to apply through MY 2027.
- Cylinder Deactivation: Vehicles with engines that include full cylinder deactivation during coasting to receive 1.5% credit. Both exhaust and intake valves must be closed during deactivation to receive the credit.

Battery Durability Monitoring

- Considering the known degradation of batteries with time, EPA is proposing new battery durability monitoring for HD BEVs and PHEVs beginning with MY 2027. It would require manufacturers of BEVs and PHEVs to develop and implement an on-board state-of-certified-energy (SOCE) monitor that can be read by the vehicle user.
- EPA is not proposing specific durability testing requirements in this rule.
- No durability monitoring requirements for FCEVs proposed at this time.

Battery and FCEV component warranty

- Note there is no change to the existing emission-related warranty periods.
- No new battery warranty requirements proposed for PHEVs – hybrid systems are considered as emission-related components.

- BEV and FCEV batteries and associated electric powertrain components will be covered by the existing regulations' emissions warranty periods of 5 years or 50,000 miles for Light HDV and 5 years or 100,000 miles for Medium HDV and Heavy HDV.