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SUMMARY

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Martin C. Offutt
Analyst in Energy Policy

Hydrogen-Fueled Medium- and Heavy-Duty Vehicles (MHDVs): Overview, Deployment Activities, and Considerations for Congress

Fuel cell-electric vehicles consume hydrogen and atmospheric oxygen to provide electric power, turning a motor while giving off only heat and water. The recent rise in fuel cell-electric vehicles is often focused on light-duty vehicles (i.e., cars), and at the end of 2023, 16,900 were registered in the United States. Vehicle manufacturers are nonetheless announcing demonstrations of small numbers of hydrogen-fueled medium- and heavy-duty vehicles (MHDVs or "trucks")—on-road vehicles weighing from 10,000 pounds up to 80,000 pounds, with cargo, for long-haul applications. These vehicles take advantage of the performance of the fuel cell powertrain including emitting no pollutants.

MHDVs provide services essential to economic activity, including goods movement, passenger mobility, refuse collection and hauling, cement mixing/delivery, and so forth. Fuel cell-electric trucks can provide these services as an emissions-free alternative to their gasoline and diesel counterparts but have costs as much as two to three times as high. Globally, fuel cell-electric trucks lag their light-duty counterparts in adopting fuel cell-electric powertrains by more than three to one, according to data from the International Energy Agency. The U.S. Department of Energy's (DOE's) *U.S. National Clean Hydrogen Strategy and Roadmap* envisages hydrogen-fueled MHDVs as a way of decarbonizing an energy application that, according to DOE, is otherwise "difficult to electrify."

A number of programs funded in the Infrastructure Investment and Jobs Act (IIJA; P.L. 117-58) and P.L. 117-169, known as the Inflation Reduction Act of 2022 (IRA), support the development and commercialization of hydrogen-fueled MHDVs. The IIJA funded the Regional Clean Hydrogen Hubs at $8 billion and specified that at least one hub be based on the transportation sector. According to news reports in March 2025, DOE was considering whether to discontinue funding for some of the seven announced hydrogen hubs. Additional funding sources for MHDVs that could be applied to hydrogen-fueled vehicles include, but are not limited to, the Clean Heavy-Duty Vehicles Program ($1 billion, IRA); the Reduction of Truck Emissions at Port Facilities Grant Program ($400 million, IIJA); and the Port Infrastructure Development Program ($2.25 billion, IIJA, and over $500 million from annual appropriations from FY2022 through FY2024). A January 2025 executive order, "Unleashing American Energy," and DOE's reported plans to review all post-election awards may also impact funding for clean energy and hydrogen.

Bills introduced in the 118th Congress that addressed hydrogen-fueled MHDVs included H.R. 3447, which would have added a weight allowance for hydrogen fuel cell MHDVs on the Interstate Highway System; the Hydrogen for Trucks Act of 2023, S. 648, and the Hydrogen for Trucks Act, H.R. 6871, both of which would have funded a demonstration program, including refueling of fuel cell-electric trucks; and the Hydrogen for Ports Act of 2023, S. 647, and the Hydrogen for Ports Act, H.R. 6872, both of which would have authorized a grant program to support purchase of trucks for hauling offloaded cargo within a port (i.e., drayage) and other shore-side hauling needs.

If Congress concludes that the continued development and deployment of hydrogen-fueled MHDVs is warranted, it might consider the following legislative options:

- adding a weight allowance for fuel cell MHDVs, as in H.R. 3447 (118th Congress), similar to the existing allowance for natural gas and battery-electric vehicles;
- legislating the incentives in the National Highway Traffic Safety Administration fuel consumption standards for MHDVs that provide credits for advanced vehicle technology such as fuel cell-electric trucks;
- offering incentives that encourage early deployment of fuel cell-electric MHDVs by fleets operating in the long-haul and regional-haul goods movement business; and
- providing tax relief for purchase of power equipment on board the vehicle that provides electric power through a fuel cell.

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Introduction

The recent rise in hydrogen fuel cell-electric vehicles (FCEVs) is often focused on light-duty vehicles (LDVs, i.e., cars), and there were 16,900 fuel cell-electric LDVs registered in the United States at the end of 2023.[1] Vehicle manufacturers are nonetheless announcing demonstration of small numbers of hydrogen fuel cell medium- and heavy-duty vehicles (MHDVs, or "trucks"), which are vehicles 10,000 pounds (lb.) or heavier, including cargo, such as delivery trucks, refuse haulers, tow trucks, and motor coaches.[2] In small demonstration programs, the fuel cell-electric powertrain has been shown to be generally adaptable to the requirements of these vehicles and may carry with it certain advantages, such as superior torque when moving from a standstill (i.e., "launch"), lower noise, and no tailpipe emissions. Early deployment is focusing on whether hydrogen fuel cell-electric MHDVs could provide onboard fuel storage to satisfy the necessary refueling range and have the cargo space- and weight-capacity to move goods. Programs and policies in the United States and in other countries focus on hydrogen-fueled MHDVs as a means of reducing fossil fuel use to decarbonize transportation.

FCEVs have been sold, leased, or demonstrated in sizes ranging from light-duty vehicles up to Class 8 tractor-trailer combination vehicles with gross vehicle weight (GVW) ratings[3] of up to 80,000 lb. FCEVs use a fuel cell to power an electric motor and to drive other loads such as accessories and parasitic loads—the pumps, compressors, and fans necessary for vehicle operation. In the fuel cell most commonly found in vehicles, the polymer electrolyte membrane or proton-exchange membrane (PEM) fuel cell, hydrogen stored on board combines with atmospheric oxygen to provide electric power while giving off only heat and water.[4] When referring to fuel cells hereinafter, the report is understood to be talking about hydrogen-fueled PEM.

The current rolling stock of MHDVs, especially the tractor-trailers with GVW rating of 80,000 lb., rely predominantly on diesel fuel.[5] Increasingly, the federal government, states, and private enterprise have been supporting the commercialization of MHDVs that use alternative fuels and noncombustion powertrains, including those with fuel cells. Fuel cell-electric MHDVs are currently limited to concept vehicles and small demonstrations and retail sales. Analyses and demonstrations have shown that fuel cell-electric MHDVs in certain weight classes could have vehicle performance attributes that offer a viable alternative to internal combustion engine-vehicles.

FCEVs require fuel and an infrastructure to deliver that fuel to a convenient dispensing point. Accomplishing this may require a change from the topology of today's hydrogen transmission

[1] U.S. Department of Energy (DOE), Alternative Fuels Data Center (AFDC), "Hydrogen Vehicles Registered in 2023," https://afdc.energy.gov/transatlas#/?fuel=HY&view=vehicle_count. "Light-duty vehicles" generally refers to cars but, in some contexts, has a more rigorous definition.

[2] Some sources refer to any non-passenger vehicle that is 8,500 pounds (lb.) or heavier as a "heavy-duty vehicle" for simplicity. See, for example, 81 *Federal Register* 73484 (October 25, 2016).

[3] The gross vehicle weight (GVW) ratings are specified by the manufacturers to be the loaded weight of a single vehicle. These include the weight of the empty vehicle plus the weight of fluids, passengers, and cargo. 49 C.F.R. §§523.2 and 571.3; 49 U.S.C. §32901; DOE, AFDC, *Vehicle Weight Classes and Categories*, https://afdc.energy.gov/data/10380.

[4] National Research Council and National Academy of Engineering, *The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs* (National Academies Press, 2004).

[5] Diesel Technology Forum, "New Analysis Shows How Diesel, Natural Gas, Electric and Gasoline Power the Nation's Commercial Truck, Transit and School Bus Fleets," press release, July 13, 2022, https://enginetechforum.org/press-releases/posts/new-analysis-shows-how-diesel-natural-gas-electric-and-gasoline-power-the-nations.

and delivery methods, which were built to deliver large amounts of hydrogen to small numbers of industrial users. Widespread use of hydrogen faces challenges of scaling up for industrial production, mobilizing capital, obtaining permits and regulatory approvals, and building or retrofitting facilities to use or make hydrogen. In vehicle applications, recent fuel prices have ranged from $16 per kilogram (/kg) in early 2022 to $35/kg in late 2024, dispensed at the refueling station, whereas, to be competitive with incumbent technologies, the price of dispensed hydrogen would need to be in the range of $4/kg to $5/kg.[6]

The report begins with an overview of the characteristics of MHDVs generally; the federal programs focused on deployment of MHDVs; the technical requiements and status of fuel cell-electric MHDVs, including a comparison to battery-electric MHDVs and diesel MHDVs; and vehicle cost. The report then turns to recent developments in programs aimed at deployment of fuel cell-electric MHDVs and bills in the 118th Congress that addressed deployment. The report concludes with issues Congress may consider.

Status and Characteristics of MHDVs

Variety and Configuration of MHDVs

MHDVs provide services essential to economic activity, including goods movement, passenger mobility, refuse collection and hauling, cement mixing and delivery, and so forth. To be capable of these tasks, MHDVs are built with a wide variety of chassis sizes and shapes, engines, weights (from 10,000 lb. to 80,000 lb., counting cargo), and body types.[7] Often, the original equipment manufacturer (OEM or, sometimes, simply the "OE") makes the chassis before an after-market upfitter adds a modified body to meet the needs of the customer. For example, heavy-duty pickup truck chassis can be upfit to become motor coaches or shuttle buses.[8] The various missions of MHDVs call for different vehicle attributes, and the existence of numerous MHDV chassis and body combinations frustrate attempts at generalizing.

The discussion in this report focuses on two commonly used trucks that make up large fleets. Small trucks for parcel delivery are in the Class 4 vehicle category—14,001 lb. to 16,000 lb., including cargo.[9] At the other extreme are long-haul Class 8, articulated tractor-trailer combination vehicles—a powered tractor connected to a non-powered multi-axle *semi-trailer*[10]—some of which travel at cruise conditions (e.g., a constant speed of 55 mph or 65 mph) for several hundred miles per day. Further information on the weight classes used for highway operation and for fuel economy may be found at the Department of Energy's (DOE's) Alternative Fuels Data Center.[11]

[6] Daniel Weeks and Santiago Canel Soria, "California Hydrogen Pump Prices for Light-Duty Vehicles Reach New Highs," *S&P Global*, October 1, 2024. CRS converted the values given for dollars per gallon-gasoline-equivalent at 1-for-1 to get dollars per kilogram-hydrogen. DOE, AFDC, *Fuel Properties Comparison*, https://afdc.energy.gov/fuels/properties?fuels=HY&properties=energy_ratio.

[7] 49 C.F.R. §565.15 and 49 U.S.C. §32901(a)(7). The weights are GVW ratings and include the weight of fluids, passengers, and cargo. DOE, AFDC, *Vehicle Weight Classes and Categories*, https://afdc.energy.gov/data/10380.

[8] Ford Motor Company, *Commercial Upfits*, 2025, https://www.fordpro.com/en-us/upfit/.

[9] See 49 C.F.R. §565.15 for the list of vehicle classes by GVW rating.

[10] Semi-trailers are called that because their axle and wheel configuration does not allow them to roll unless hitched to a tractor. Federal regulations generally allow semi-trailers on roads, and, as to length, require that regulations issued by states cannot restrict the length to below 48 feet or the limit in effect on December 1, 1982, whichever is greater. 23 C.F.R. §658.13.

[11] DOE, AFDC, *Vehicle Weight Classes and Categories*, https://afdc.energy.gov/data/10380.

There were roughly 4 million trucks in fleets in 2021, counting Class 3, 4, and 5 vehicles and government, rental and commercial concerns.[12] The ownership of Class 7 and Class 8 tractors can range from small independent operators to large for-hire and private or government fleets that have several thousand or more tractors.[13] There were roughly 154,000 Class 7 tractors and 2.5 million Class 8 tractors in use during 2021.[14]

Operations

Fuel Consumption and Range

Among MHDVs, the dominant consumer of energy is the Class 8 tractor, typically pulling 53-foot semi-trailers to move goods. Together with the lighter Class 7 tractor, these are responsible for three-quarters of diesel fuel consumption in on-road vehicles (a designation that includes cars).[15] The remaining MHDV fuel is consumed by vehicles that in some cases can have substantial power requirements for controlling cargo temperature, performing vocational activities such as lifting a worker in a bucket to perform repair services, winching a stuck vehicle, mixing concrete, and other functions. In some instances, the energy requirements necessitate installing an auxiliary power unit (APU) on board the vehicle.[16]

Class 8 tractor-trailers travel varying distances in a day.[17] Regional-haul Class 8 vehicles average 430 miles daily, according to one study that looked at eight cases.[18] Long-haul Class 8 vehicles are notionally those vehicles that travel point-to-point, for example, from a port complex to a distribution center. Regional haul vehicles may also travel point-to-point, making the distinction between regional and long haul somewhat artificial. *Drayage trucks* generally include on-road vehicles of 26,000 lb. GVW rating and above whose activities include operating in or transiting the boundary of a port or railyard for the purpose of moving containers or bulk cargo.[19] A Class 8 drayage truck might travel 150 miles in a single day, according to Toyota.[20]

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[12] S. Davis and R. Boundy, *Transportation Energy Data Book, Edition 40*, Oak Ridge National Laboratory, ORNL-5198, June 2022, p. 8-3, https://tedb.ornl.gov/wp-content/uploads/2022/03/TEDB_Ed_40.pdf#page=228. Fleets include 15 or more vehicles in operation or 5 or more vehicles purchased in a year.

[13] Transport Topics, *Top 100 Private Carriers: 2022*, https://pages.ttnews.com/rs/905-BBW-876/images/tt100Private22.pdf.

[14] Davis and Boundy, *Transportation Energy Data Book, Edition 40*, p. 5-4.

[15] Bureau of Transportation Statistics and U.S. Census Bureau, *VIUS PUF Tabulation Tool*, 2023-12, December 23, 2023, https://data.bts.gov/stories/s/VIUS-PUF-Draft/mc6b-y96m/.

[16] An example is the APU on fire engines, which can be a diesel generator that substitutes as a power source in place of the idling main engine. Pierce Manufacturing, "4 Operational Factors for Fire Truck Idle Reduction Technology: Auxiliary Power Unit (APU)," blog post, January 12, 2021, https://www.piercemfg.com/pierce/blog/4-operational-factors-for-fire-truck-idle-reduction-technology.

[17] J. Kast et al., "Designing Hydrogen Fuel Cell Electric Trucks in a Diverse Medium and Heavy Duty Market," *Research in Transportation Economics*, vol. 70 (October 2018), pp. 139-147.

[18] R. Mihelic et al., *Making Sense of Heavy-Duty Hydrogen Fuel Cell Tractors*, North American Council for Freight Efficiency, December 16, 2020, p. 59, https://nacfe.org/wp-content/uploads/2020/12/NACFE-Guidance-on-Hydrogen-Fuel-Cell-Tractors-FINAL-121620.pdf.

[19] See, for example, California Air Resources Board (CARB), *Advanced Clean Fleets Regulation Proposed Draft Regulation Language: Drayage Truck Requirements*, 17 CCR §95691 (draft), September 9, 2021, p. 4, ww2.arb.ca.gov/sites/default/files/2021-08/210909acfdraftdrayage.pdf.

[20] Andrew Krok, "UPS Will Start Using Toyota's Zero-Emission Hydrogen Semi Trucks," CNET, April 23, 2019, https://www.cnet.com/roadshow/news/ups-toyota-project-portal-hydrogen-semi-trucks/.

Corridors

The long-haul and regional-haul vehicles described above can be thought of as participants in transportation corridors. Transportation corridors resist categorization but evolved from the notion of economic corridors providing access to markets for agriculture or natural resource extraction.[21] Examples of present-day corridors include the 275-mile Texas East Central Corridor, which includes I-45 and connects Galveston, Houston, and Dallas. Other corridors can be over 1,000 miles long, such as the multimodal Eastern Seaboard Corridor System (I-85/I-95), which serves passengers and freight. In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA; P.L. 102-240) noted the importance of regional interconnection while designating over 20 transportation corridors for integration into the National Highway System.

Another type, called *alternative fuel corridors* by the Federal Highway Administration (FHWA), consists of charging and fueling infrastructure.[22] Section 11401 of IIJA authorized grants for charging and fueling infrastructure along designated "national alternative fueling corridors" defined in the Fixing America's Surface Transportation Act (FAST Act; P.L. 114-94). The FAST Act required the Secretary of Transportation to designate such corridors to have refueling at "strategic locations along major national highways to support changes in the transportation sector" in support of various goals. Generally speaking, such corridors could be specified so that vehicles traveling along them encounter one refueling station within a few miles of the highway at a given interval (e.g., 150 miles in the case of hydrogen).[23]

Status of Hydrogen and MHDVs

As of June 2024, there were greater than 90,000 hydrogen FCEVs in use globally. Of these, the majority were light-duty vehicles; slightly less than one-quarter—roughly 20,000—were trucks and buses.[24] Globally, trucks lag light-duty vehicles in adopting fuel cell-electric powertrains by more than three to one, according to data from the International Energy Agency (IEA) of the Organisation for Economic Co-operation and Development.[25] One study estimated the introduction of fuel cell-electric heavy-duty trucks to be roughly 10 years behind light-duty vehicles.[26]

When issuing the Phase 2 rule for MHDV fuel consumption and GHG emissions, the National Highway Traffic Safety Administration (NHTSA) and the U.S. Environmental Protection Agency (EPA) noted the tendency for the "heavy-duty sector to significantly lag the light-duty sector in the adoption of advanced technologies" due to greater manufacturing risk at the higher price point, the premium placed on reliability, and the lower sales volumes relative to light-duty

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[21] Transportation Research Board, *Quantifying the Impacts of Corridor Management (2024)* (National Academies Press, 2024), p. 93, http://nap.nationalacademies.org/27477.

[22] Emily Biondi, Associate Administrator, *Request for Nominations—Alternative Fuel Corridors (Round 8/2024)*, Federal Highway Administration, June 14, 2024, p. 2, https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/nominations/2024_request_for_nominations_r8.pdf.

[23] Biondi, *Request for Nominations—AFCs*, p. 3.

[24] The trucks in these data include the MHDV-weight trucks of U.S. statistics and, in addition, include those vehicles weighing at least 3.5 metric tons, or about 7,700 lb., but less than 10,000 lb. GVW. In effect, more vehicles were counted. International Energy Agency (IEA), *Global Hydrogen Review 2024*, October 2024, p. 39, https://www.iea.org/reports/global-hydrogen-review-2024.

[25] IEA, *Global Hydrogen Review 2024*, October 2024, p. 39.

[26] IEA, *Energy Technology Perspectives 2020*, Paris, 2021, p. 156. The study does not define light-duty vehicles, but in the United States these are vehicles with GVWs less than 8,500 lb. See DOE, AFDC, *Vehicle Weight Classes and Categories*, https://afdc.energy.gov/data/10380.

vehicles.[27] A DOE strategy for zero-emission freight corridors observed that the adoption of FCEVs by freight operators was "on a different timeline than EVs [electric vehicles]" but could be "assumed to grow as conditions improve."[28]

Demonstrations and Beyond

DOE anticipates that widespread adoption of medium- and heavy-duty fuel cell-electric vehicles would be preceded by success at demonstration scale.[29] For example, DOE recently funded a 15-vehicle demonstration project of fuel cell-electric hybrid delivery vans, a medium-duty vehicle.[30] Other demonstration projects in the United States have focused on Class 8 combination vehicles, discussed below. Overall, these demonstrations have shown that fuel cell-electric MHDVs could offer a viable alternative to internal combustion engine-vehicles in certain MHDV categories.

The Shore-to-Store project at the Port of Los Angeles completed its initial phase in February 2022 to demonstrate the shoreside movement (i.e., drayage) of off-loaded goods by zero-emission vehicles (ZEVs). Vehicles providing drayage services can experience long idle times while vehicles are waiting in queues, leading to tailpipe emissions; these emissions could be mitigated through use of a noncombustion powertrain.[31] Shell Oil Products US built and operated two hydrogen refueling stations (HRS) as part of the Shore to Store project. Kenworth, a brand of the truck manufacturer group PACCAR, provided 10 prototype vehicles—the hydrogen fuel cell version of its T680, a Class 8 tractor. The vehicles used Toyota's fuel cell-electric system.[32] The cargo capacity was 36,000 lb.[33]

A 2019 on-road demonstration, coordinated by the North American Council on Freight Efficiency, collected on-road data on 10 fuel cell-electric Class 8 vehicles in regional haul operation over a three-week period in October 2019.[34]

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[27] U.S. Environmental Protection Agency (EPA) and U.S. Department of Transportation (DOT), National Highway Traffic Safety Administration (NHTSA), "Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2," 81 *Federal Register* 73498 (October 25, 2016).

[28] Joint Office of Energy and Transportation, *National Zero-Emission Freight Corridor Strategy*, DOE/EE-2816 2024, September 2024, p. 13, https://driveelectric.gov/files/zef-corridor-strategy.pdf.

[29] DOE, *Pathways to Commercial Liftoff: Clean Hydrogen*, March 2023, p. 60, https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf.

[30] DOE, Hydrogen and Fuel Cell Technologies Office, *Hydrogen Fuel Cell Hybrid Electric Delivery Vans in Disadvantaged Communities*, DOE/EE-2742, https://www.energy.gov/eere/fuelcells/articles/hydrogen-fuel-cell-hybrid-electric-delivery-vans-disadvantaged-communities#:~:text=Disadvantaged%20Communities,-The%20Department%20of&text=The%20project%20will%20replace%2015,is%20both%20global%20and%20local.

[31] Andrew J. DeCandis, *Hydrogen Fuel-Cell Electric Hybrid Truck Demonstration: Final Technical Report*, Gas Technology Institute and Houston-Galveston Area Council, DE-EE0005978, https://www.osti.gov/servlets/purl/1496037.

[32] Kenworth, "Port of Los Angeles Rolls Out Hydrogen Fuel Cell Electric Freight Demonstration," press release, June 7, 2021, https://www.kenworth.com/about-us/news/port-of-los-angeles-rolls-out-hydrogen-fuel-cell-electric-freight-demonstration/; and Port of Los Angeles et al., *The Port of Los Angeles Zero- and Near-Zero-Emission Freight Facilities "Shore to Store" Project: Final Project Report*, Grant Number: G17-ZNZE-10, Port of Los Angeles Agreement no. 19-3639, May 10, 2023, p. 9, https://ww2.arb.ca.gov/sites/default/files/2023-05/POLA-Final%20Report.pdf.

[33] C. Hunter et al., *Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks*, National Renewable Energy Laboratory (NREL), NREL/TP-5400-71796, September 2021, p. 82, https://www.osti.gov/biblio/1821615.

[34] Ballard Power Systems and North American Council for Freight Efficiency, *Fuel Cell Electric Trucks: An Analysis of Hybrid Vehicle Specifications for Regional Freight Transport*, June 2020, p. 18, https://nacfe.org/wp-content/uploads/2020/06/Informational_NACFE_BPS_Truck_White_Paper_Download.pdf.

Prizes and Certifications for Technology Development and Deployment

Governments and civil society have competitively awarded prizes for technologies in development and deployment. Prizes often confer both monetary benefits and nonmonetary benefits, such as recognition.[35] Federally awarded prizes are viewed as advantageous by some, as these prizes shift the risk of success or failure to the private entity; the federal government pays only for success.[36]

The federal government has awarded 100 such prizes annually; many of the prizes are focused on applied research and technology development. An analysis by the Office of Science and Technology Policy (OSTP) found that the majority of federally awarded prizes in FY2019 and FY2020 (177 total) were for research and development, proof-of-concept, or prototypes.[37] An example of this is the Lithium-Ion Battery Recycling Prize, awarded by DOE and including three phases: concept, prototype, and demonstration.[38] The OSTP analysis found that, government-wide, roughly one-fourth of prizes awarded were for latter-stage development corresponding to scale-up or commercialization.[39] In FY2019 and FY2020, DOE awarded 12 prizes that were for scale-up or commercialization. Civil society makes prize awards as well.

Prizes can have a measurable, quantifiable goal: the Bright Tomorrow Lighting Prize, or the L-Prize, was specified in Section 655 of the Energy Independence and Security Act of 2007 (P.L. 110-140) to meet a list of specifications related to power consumption (i.e., watts), luminous flux (a measure of brightness), durability, and so forth.[40] The L-Prize, awarded in 2011, was thus defined prospectively.[41] In this respect, the L-Prize was similar to the Ansari XPRIZE, which also established criteria prospectively, for the first privately funded vehicle to reach an altitude of 100 kilometers, coinciding with the Karman line—the demarcation altitude beyond which outer space begins.[42] Some observers note that such prizes can induce technological change, citing the example of the British Longitude Act of 1714, which offered a prize for a method of determining longitude while at sea.[43]

Other prizes can be awarded for fulfilling broad objectives, such as the Green Fleet Award for environmentally responsible fleet operations, made by the National Association of Fleet Administrators—an example of an award made by civil society.[44] The City of Phoenix won the top prize in 2023.[45] Such nonmonetary prizes aim for greater public recognition.[46]

Still another type of award takes the form of certifications for an entity's deployment of commercial technologies. The Leadership in Energy and Environmental Design (LEED) certification is awarded by the U.S. Green Building

[35] CRS Report R45271, *Federal Prize Competitions*, by Marcy E. Gallo.

[36] CRS Report R45271, *Federal Prize Competitions*, by Marcy E. Gallo.

[37] Office of Science and Technology Policy (OSTP), *Implementation of Federal Prize and Citizen Science Authority: Fiscal Years 2019-20*, May 2022, p. A-8, https://bidenwhitehouse.archives.gov/wp-content/uploads/2022/05/05-2022-Implementation-of-Federal-Prize-and-Citizen-Science-Authority.pdf.

[38] OSTP, *Implementation of Federal Prize*, p. B-97; and DOE, EERE, *Lithium-Ion Recycling Prize*, https://www.energy.gov/eere/lithium-ion-recycling-prize.

[39] OSTP, *Implementation of Federal Prize*, p. A-8.

[40] The full criteria are listed at 42 U.S.C. §17243(b). See also Sen. Jeff Bingaman, "The L-Prize: Recognizing Innovations," *The Hill*, September 29, 2009, https://thehill.com/homenews/186862-the-l-prize-recognizing-innovations/.

[41] Light Directory, "DOE Announces Philips as First Winner of the L Prize Competition," August 2, 2011, https://www.lightdirectory.com/news-DOE-Announces-Philips-As-First-Winner-Of-The-L-Prize-Competition.htm.

[42] The prize specified a vessel carrying three passengers and doing so twice within two weeks' time. See XPRIZE Foundation, "Launching a New Space Industry," 2024, https://www.xprize.org/prizes/ansari; Tim Sharp, "SpaceShipOne: The First Private Spacecraft," Space.com, https://www.space.com/16769-spaceshipone-first-private-spacecraft.html, March 15, 2019; and Jonathan C. McDowell, "The Edge of Space: Revisiting the Karman Line," *Acta Astronautica*, vol. 151 (October 2018), pp. 668-677.

[43] National Academies of Sciences, Engineering, and Medicine, *The Role of Inducement Prizes: Proceedings of a Workshop in Brief (2020)* (National Academies Press, 2020), p. 1.

[44] NAFA Fleet Management Association, "Green Fleet Awards," https://www.nafa.org/awards/green-fleet-awards/.

[45] City of Phoenix, "Phoenix Named Top Green Fleet of 2023," September 5, 2023, https://www.phoenix.gov/newsroom/public-works/2855.

[46] Recognition prizes could also include a cash prize.

Council for buildings that satisfy several normative criteria.[47] The certification criteria take account of building systems—such as heating, ventilation, and air conditioning—that are available commercially.

SmartWay is a certification for heavy-duty vehicle fleets that focuses on freight transportation efficiency (i.e., goods movement).[48] SmartWay also maintains a list of verified technologies, which can include aerodynamic fittings for trucks; these technologies are certified by third-party laboratories.[49]

DOE also supported concept vehicles in its SuperTruck program that could be viewed as early demonstrations.[50] Three of the OEM participants—Daimler Truck North America, General Motors, and Ford Motor Co.—are developing Class 4 to Class 6 fuel cell-electric vehicles operating in commercial fleets; one of the participants plans to demonstrate two Class 8 fuel cell-electric vehicles as well.

The numerous demonstrations discussed above are a precursor to the possible advent of production vehicles. In the case of Shore to Store, the demonstration relied on prototypes. Kenworth crafted these in an initial group of five, learned from this first phase, and then made modifications to the vehicle for a second phase of five more vehicles.[51] Building these 10 vehicles was nonetheless different in size and scale from a production run.[52]

The progression from prototype to a marketable production vehicle, and the problems sometimes encountered along the way, is sometimes called the "valley of death"[53] or the market formation stage.[54] At this valley or stage, potential new technologies may struggle to compete with the incumbent technology for a variety of reasons, including the advantage conferred on the incumbent through economies of scale or the incumbent's knowledge gleaned from experience.[55] Reaching commercial success for a vehicle requires lowering the cost, achieving required durability and reliability, satisfying customer attributes (such as noise, vibration, and harshness), complying with regulatory requirements, and so forth.[56] Achieving the desired economies of scale would, in the view of some analysts, require moving to much larger numbers of vehicles than those involved in demonstrations. MHDVs are not produced in large, million-vehicle production runs of LDVs. DOE's May 2024 *Multi-Year Program Plan (MYPP)* notes that the barriers to large-scale adoption make up one of the three categories of challenges that remain after decades of research, development, demonstration, and deployment activities.[57] The federal government

[47] For the current list of these criteria, see U.S. Green Building Council, "LEED Rating System," https://www.usgbc.org/leed.

[48] EPA, "Learn About SmartWay," November 9, 2023, https://www.epa.gov/smartway/learn-about-smartway.

[49] EPA, "Learn About SmartWay Verified Technologies," May 13, 2024, https://www.epa.gov/smartway/learn-about-smartway-verified-technologies.

[50] Sunita Satyapal, "U.S. DOE Hydrogen Program Annual Merit Review (AMR) Plenary Remarks," slide presentation, June 5, 2023, p. 53, https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review23/plenary1_satyapal_2023_o.pdf.

[51] Port of Los Angeles et al., *"Shore to Store" Project*, p. 9.

[52] 81 *Federal Register* 73493 (October 25, 2016), footnote 57.

[53] IHS Markit and Energy Futures Initiative, *Advancing the Landscape of Clean Energy Innovation*, February 2019, p. 37, https://efifoundation.org/reports/advancing-the-landscape-of-clean-energy-innovation/.

[54] A. Grubler et al., "Policies for the Energy Technology Innovation System (ETIS)," in *Global Energy Assessment: Toward a Sustainable Future*, ed. Thomas B. Johansson et al. (Cambridge University Press, 2012), p. 1676.

[55] Grubler et al., "Policies for ETIS," p. 1676.

[56] National Research Council and National Academy of Engineering, *The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs* (National Academies Press, 2004), p. 26.

[57] The other two challenges DOE identified are (1) reducing cost and improving performance and (2) de-risking and scaling up technologies across the value chain. DOE, EERE, *Hydrogen and Fuel Cell Technologies Office Multi-Year* (continued...)

and civil society offer prizes and certifications for development and deployment successes (see **text box** above).

Investment in fuel cell-electric MHDVs is a risk for the public and private sectors because it is unknown if they will ever reach commercial scale. Currently the fueling infrastructure can support limited types of operations such as the relatively self-contained ecosystem of a port, although—as discussed in "Regional Clean Hydrogen Hubs"—some regions have plans to build out refueling infrastructure to support long-haul operations. Fuel cell-electric MHDVs would, as noted, compete on cost and performance with diesel trucks, a mature technology. Unlike diesel trucks, fuel cell-electric vehicles do not have widely deployed technicians and training centers.

Infrastructure

The infrastructure for refueling hydrogen FCEVs is geographically limited and consistent with a demonstration or an early deployment phase. The IEA assesses HRS to be at a high level of technology readiness but acknowledges that the readiness level is short of widespread deployment.[58] As of January 30, 2025, California had 42 public retail HRS in operation for LDVs, with a further 18 not currently in operation.[59] DOE data showed 7 HRS that could service Class 3 through Class 8 vehicles in North America, with 3 of those capable of servicing Class 7 and Class 8.[60] According to DOE, all but 6 of the public HRS for LDVs in the United States are in California.[61] The California Energy Commission envisages at least 13 of the projected 175 light-duty retail HRS by 2027 will also be equipped to serve MHDVs.[62] In 2023, the *Wall Street Journal* reported that truck-maker Nikola was working with partners to develop a fueling network for hydrogen trucks and was anticipating 50 HRS to be in place across the United States within five years.[63] The Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES), one of the Regional Clean Hydrogen Hubs, envisages 60 HRS for MHDVs as part of its hub.[64]

Within the United States, a network of trucks and pipelines currently transports one-third of the 10 million metric tons (Mt) of *on-purpose hydrogen*[65] manufactured annually for large industrial

Program Plan, DOE/GO-102024-6266, May 2024, p. vii, https://www.energy.gov/sites/default/files/2024-05/hfto-mypp-2024.pdf.

[58] IEA, *ETP Clean Energy Technology Guide*, October 22, 2024, https://www.iea.org/articles/etp-clean-energy-technology-guide.

[59] Hydrogen Fuel Cell Partnership, *FCEV Sales, FCEB, and Hydrogen Station Data*, January 30, 2025, https://h2fcp.org/by_the_numbers.

[60] DOE, AFDC, *Hydrogen Fueling Station Locations*, interactive map, https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY.

[61] DOE, AFDC, *Hydrogen Fueling Station Locations*, interactive map, https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY.

[62] J. Berner et al., *Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*, California Energy Commission, CEC-600-2022-064, December 22, 2022, p. 2, https://www.energy.ca.gov/publications/2022/joint-agency-staff-report-assembly-bill-8-2022-annual-assessment-time-and-cost.

[63] Paul Berger, "Hydrogen Fuel Is Gaining Traction with Truckers," *Wall Street Journal*, November 15, 2023, https://www.wsj.com/articles/hydrogen-fuel-is-gaining-traction-with-truckers-20fca3e3.

[64] DOE, OCED, *Regional Clean Hydrogen Hubs Program: California Hydrogen Hub (ARCHES)*, July 2024, p. 2.

[65] Hydrogen is deemed *on-purpose hydrogen* when it is manufactured chiefly for the economic value of the hydrogen. Most on-purpose hydrogen in the United States is produced for chemical and fuels manufacturing. *Byproduct hydrogen* results while producing another chemical deemed to have primary value by a process that produces hydrogen incidentally.

customers.[66] The infrastructure for hydrogen transmission in the United States is nonetheless modest compared with that of natural gas or electricity. U.S. hydrogen pipelines operate mostly in the Gulf of Mexico region and total 1,600 miles,[67] compared with 300,000 miles of natural gas transmission pipelines[68] and nearly 160,000 miles of high-voltage electric transmission power lines across the continental United States.[69] Globally, most hydrogen pipelines are owned by merchant hydrogen producers who sell their hydrogen to industry in bulk.[70]

Government Goals and Pledges

National and supranational strategy documents for hydrogen have asserted that hydrogen FCEVs may be best suited for specific truck missions. A report prepared pursuant to the IIJA, DOE's *U.S. National Clean Hydrogen Strategy and Roadmap*, notes that hydrogen vehicles are useful in applications "requiring long driving ranges, fast fueling, and large or heavy payloads."[71] The *Strategy and Roadmap* envisages MHDVs as a way of decarbonizing an energy application that is otherwise "difficult to electrify" by switching to a technology that delivers the same service with electricity rather than fossil fuel.[72] The *U.S. National Blueprint for Energy and Emissions Innovation in Transportation* finds that long-haul heavy trucks have the most favorable long-term potential for hydrogen in any mode of transportation.[73] A European Union strategy document notes the existence of "different requirements for light- and heavy-duty vehicles" and encourages the use of "heavy-duty road vehicles" for long-haul applications.[74] France lists "heavy-duty mobility" as one of its three priorities in its national hydrogen strategy and observes that "hydrogen meets the needs for high engine power and long range, particularly for captive fleets traveling long distances."[75] The IEA expects that light-commercial vehicles[76] will transition from

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[66] D-Y Lee et al., *Life-Cycle Greenhouse Gas Emissions of By-Product Hydrogen from Chlor-Alkali Plants*, Argonne National Laboratory (ANL), ANL/ESD-17/27, December 2017, p. 1. The estimate of one-third assumes only on-purpose hydrogen is accounted for and that the approximately 3.3 million metric tons (Mt) of byproduct hydrogen from oil refineries is not used in the denominator of the calculation.

[67] Over 90%, by mile of pipeline, is in Texas and Louisiana, with 10 other states having under 35 miles each. DOE, Hydrogen and Fuel Cell Technologies Office, "Hydrogen Pipelines," https://www.energy.gov/eere/fuelcells/hydrogen-pipelines; Hydrogen Tools, *Hydrogen Pipelines*, September 2016, Excel spreadsheet downloadable at https://h2tools.org/hyarc/hydrogen-data/hydrogen-pipelines.

[68] DOT, Pipeline and Hazardous Materials Safety Administration, *Annual Report Mileage for Natural Gas Transmission and Gathering Systems*, May 2, 2022.

[69] Energy Information Administration, "U.S. Electric System Is Made Up of Interconnections and Balancing Authorities," *Today in Energy*, July 20, 2016, https://www.eia.gov/todayinenergy/detail.php?id=27152.

[70] IEA, *Global Hydrogen Review 2021*, October 2021, p. 44, https://www.iea.org/reports/global-hydrogen-review-2021.

[71] DOE, *U.S. National Clean Hydrogen Strategy and Roadmap*, June 2023, p. 32, https://www.hydrogen.energy.gov/library/roadmaps-vision/clean-hydrogen-strategy-roadmap. Prepared pursuant to Section 40314 of the Infrastructure Investment and Jobs Act (IIJA; P.L. 117-58).

[72] DOE, *Hydrogen Strategy and Roadmap*, p. 29.

[73] DOE et al., *The U.S. National Blueprint for Energy and Emissions Innovation in Transportation*, DOE/EE-2674, January 2023, p. 5.

[74] European Commission, *A Hydrogen Strategy for a Climate-Neutral Europe*, COM(2020) 301, July 8, 2020, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0301&from=EN.

[75] Government of the French Republic, *National Strategy for the Development of Decarbonised and Renewable Hydrogen in France*, September 2020, p. 10, https://www.bdi.fr/wp-content/uploads/2020/03/PressKitProvisionalDraft-National-strategy-for-the-development-of-decarbonised-and-renewable-hydrogen-in-France.pdf.

[76] Following the European definition, these include vehicles with mass below 3.5 metric tons (roughly 7,700 lb.), including cargo. IEA, *Energy Technology Perspectives 2020*, 2021, p. 256, https://www.iea.org/reports/energy-technology-perspectives-2020.

battery-electric to fuel cell-electric as the requirements for such vehicles lead to longer ranges and hours of service in the future.[77]

As of September 2022, 17 countries had enacted purchase price subsidies for "heavy-duty fuel cell vehicles."[78] Globally, most policies that affect demand for hydrogen fuel and technology focus on transportation. In many instances, these policies include hydrogen within a basket of fuels as part of zero-emission goals.[79]

Federal Programs on Energy Use and Purchase of MHDVs

Fuel Consumption Regulations

Origin

The Energy Independence and Security Act of 2007 (EISA; P.L. 110-140), Section 102(b) (42 U.S.C. §32902 (b)), requires the Secretary of Transportation to set fuel economy standards for "commercial" MHDVs and work trucks that will achieve the "maximum feasible improvement" in fuel efficiency and that are "appropriate, cost-effective, and technologically feasible."[80] Section 103(b) of EISA defines commercial MHDVs to be on-highway vehicles with a GVW rating of 10,000 lb. or more.

NHTSA's fuel consumption standards for MHDVs are expressed in units of gallons per 1,000 ton-miles, a unit that takes account of the movement of tons of payload, reasoning this was the purpose of some but not all MHDVs.[81] For example, the NHTSA regulations set standards for the Class 8 tractor vehicle family in model years 2024 to 2026 to be in the range of roughly 6.5 to 8 gallons per 1,000 ton-miles, depending on the configuration or subfamily (e.g., low-, mid-, or high-roof cab; day cab or sleeper cab).[82] NHTSA issued the regulations for Phase 1 of the program in 2011 and for Phase 2 in 2016.[83]

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[77] IEA, *Energy Technology Perspectives 2020*, p. 155.

[78] IEA, *Global Hydrogen Review 2022*, September 2022, p. 190, https://www.iea.org/reports/global-hydrogen-review-2022. Heavy-duty trucks in the European scheme are those vehicles having GVW over 15 metric tons. IEA, *Global Hydrogen Review 2022*, p. 43.

[79] IEA, *Global Hydrogen Review 2022*, p. 189.

[80] A work truck is any vehicle between 8,500 and 10,000 lb. GVW rating that is not a medium-duty passenger vehicle (i.e., not designed primarily to carry passengers). An example of a work truck is a pickup truck, meaning a vehicle with a sufficiently long cargo bed in that weight range.

[81] For engines, the unit of fuel consumption is gallons per 100 horsepower-hours, a unit of energy.

[82] See Table 11, "Truck Tractor Fuel Consumption Standards," at 49 C.F.R. §535.5.

[83] EPA and DOT, NHTSA, "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles," 76 *Federal Register* 57106 (September 15, 2011); and EPA and DOT, NHTSA, "Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2," 81 *Federal Register* 73478 (October 25, 2016).

Direct Compliance

NHTSA's regulations do not apply to individual trucks but rather to specific sets of a manufacturer's vehicles in a given model year. Class 8 tractors, for example, comprise a vehicle family (i.e., a *set*) for determining compliance.[84]

Fuel Consumption Credits

A manufacturer may offset deficits in one or more vehicles in a vehicle set with fuel consumption credits. With this compliance flexibility mechanism, the manufacturer generates credits when vehicles in a set outperform the standard. EPA and NHTSA have stated that the credit program "allows manufacturers to certify engines or vehicles that do not perform up to the standard and offset them with engines or vehicles that perform better than the standard."[85]

The mathematical formula for determining credits results in positive credits when a vehicle exceeds the requirements of the standard; the size of the credits is proportional to the difference between the standard and the vehicle performance. These credits may be averaged, banked, or traded (ABT). The vehicle family complies when the sum of all ABT credits equals zero or a positive number.[86] Class 8 or *heavy heavy-duty vehicles* (see 40 C.F.R. §1037.140(5)) comprise a distinct set under the regulations.[87]

Advanced Technology Vehicles and the Impact on Compliance

The NHTSA regulations include various incentives that, when utilized, make the mathematics surrounding compliance more favorable. For example, the Phase 2 standard has provisions for advanced technology vehicles, such as battery-electric and fuel cell-electric Class 8 tractors. Advanced technology vehicles can add to the quantitative outperformance in two ways. First, for calculation purposes, battery-electric and fuel cell-electric Class 8 tractors are deemed as not consuming any fuel, so they substantially outperform the fuel consumption standards and generate positive credits.[88] Second, a fuel cell-electric vehicle would count as 5.5 vehicles for purposes of determining compliance and would increase the credit by the same factor of 5.5.[89] The presence of fuel cell-electric vehicles in a manufacturer's fleet in sufficient numbers could thus substantially aid with compliance. Manufacturers could view this as an incentive to include greater numbers of fuel cell-electric MHDVs in a given model year's production.

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[84] 49 C.F.R. §535.10(c)(2). See also the definition of "vehicle family" and "vehicle subfamily" at 49 C.F.R. §535.4.

[85] EPA, Office of Transportation and Air Quality, *Fact Sheet: EPA and NHTSA Adopt Standards to Reduce Greenhouse Gas Emissions and Improve Fuel Efficiency of Medium- and Heavy-Duty Vehicles for Model Year 2018 and Beyond*, EPA-420-F-16-044, August 2016, https://www.nhtsa.gov/document/fact-sheet-epa-and-nhtsa-propose-standards-reduce-greenhouse-gas-emissions-and-improve.

[86] 49 C.F.R. §535.7(a). The compliance calculation varies according to the vehicle family and, for example, pickup trucks and vans (Classes 2b and 3) utilize a work-factor-based target. 81 *Federal Register* 73740 (October 25, 2016). Engines are also classified into distinct averaging sets.

[87] 81 *Federal Register* 73993 (October 25, 2016).

[88] The fuel consumption standards may be found in Table 11 at 49 C.F.R. §535.5.

[89] 49 C.F.R. §535.7(f)(1)(ii).

Federal Excise Tax

Types of Federal Excise Tax that Apply to Trucks

Federal excise taxes (FETs) apply to specific goods, services, and activities, including purchase and use of trucks. An FET of 12% applies to the sale of trucks with a GVW over 33,000 lb. Trucks with GVW of 55,000 lb. or above also pay an annual use tax.[90] These excise taxes are one source of support for the Highway Trust Fund, though the vast majority of support—85% to 90%—derives from motor fuel taxes.[91]

Exemptions to the Federal Excise Tax on Equipment

Certain idling reduction devices, which reduce fuel consumption while the vehicle is stationary, may be exempted from the FET on truck sales (26 U.S.C. §4053(9)). The Energy Improvement and Extension Act of 2008 (P.L. 110-343, Division B), Section 206, excluded "idling reduction devices" and advanced insulation from the FET.[92] A device must be found eligible by EPA, in consultation with DOE and the Department of Transportation (DOT).[93] APUs, which appear on vehicles needing continuous electric power for refrigeration or other functionality, are generally classified as an idling reduction technology. EPA currently exempts a number of commercially available APUs; exempted APUs are generally reciprocating engines that run off of a propane tank or diesel fuel.[94] Two bills introduced in the 118th Congress—S. 694, the Modern, Clean, and Safe Trucks Act of 2023, and the companion bill, H.R. 1440—would have done away with the truck purchase FET entirely.

Vehicle Requirements: Range and Cargo Capacity

Overview

The discussion in this section applies to Class 8 tractor-trailer combination vehicles—a powered tractor connected to a non-powered multi-axle trailer—and smaller straight trucks (typically Class 4) that deliver goods. See **Figure 1**. The Class 8 vehicles are expected to deliver those goods to a destination that could be several hundred miles distant. The advent of battery-electric, fuel cell-electric, and other alternative powertrains has caused analysts to consider whether these vehicles can replace the incumbent technology, the internal combustion engine powertrain. Though there is no one factor that determines the success of a new vehicle powertrain, for this specific application analysts have attempted to isolate a set of factors that could lead to success. Almost all of the vehicles considered in the simulations described below were able to haul typical cargo loads and perform adequately according to several performance indicators. The empty

[90] DOT, FHWA, Office of Highway Policy Information, "Heavy Vehicle Use Tax," June 23, 2020, https://www.fhwa.dot.gov/policyinformation/hvut/mod1/whatishvut.cfm.

[91] CRS Report R46938, *Federal Excise Taxes: Background and General Analysis*, by Anthony A. Cilluffo; and CRS Report R47022, *Federal Highway Programs: In Brief*, by Robert S. Kirk.

[92] 26 U.S.C. §4053(9).

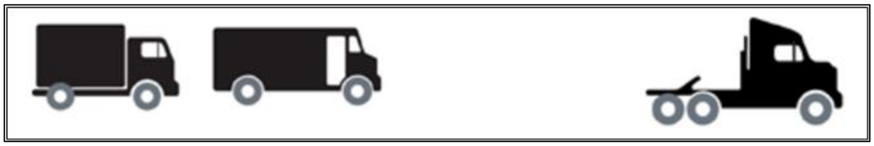
[93] EPA, "Learn About Federal Excise Tax Exemption," May 18, 2024, https://www.epa.gov/verified-diesel-tech/learn-about-federal-excise-tax-exemption#:~:text=The%20truck%20excise%20tax%2C%20which,and%20remitted%20by%20the%20seller.

[94] EPA, "List of Idling Reduction Technologies (IRTs) That Are Eligible for the Federal Excise Tax Exemption," May 17, 2024, https://www.epa.gov/verified-diesel-tech/list-idling-reduction-technologies-irts-are-eligible-federal-excise-tax.

weights of the vehicles vary, mostly due to differences in powertrains and energy storage, and the following discussion illuminates how cargo weight and driving range involve trade-offs.

The analyses described in this section consider the powertrain performance and the cargo capacity of simulated vehicles, including fuel cell-electric MHDVs. The results of these simulations suggest that the performance of the fuel cell powertrain could support the operating range and cargo requirements of truck operators. Similar to the demonstrations discussed above in "Status of Hydrogen and MHDVs," the simulations support a finding that fuel cell-electric MHDVs in certain weight classes could perform sufficiently well and offer a viable alternative to internal combustion engine-vehicles.

Figure 1. Examples of Class 4 and Class 8 Vehicles



Source: U.S. Department of Energy, Alternative Fuels Data Center, *Types of Vehicles by Weight Class*, June 2012, https://afdc.energy.gov/data/10381.

Notes: Class 4 trucks (left) include a city delivery truck and a walk-in truck. The Class 8 truck (right) is a tractor capable of pulling a 53-foot semi-trailer.

Performance Requirements

Comparing vehicles with different types of powertrains that fulfill the same mission requires the analyst or product development team to specify the performance requirements and other vehicle attributes. Generally speaking, the engine will need to provide sufficient torque over a range of engine speeds to move the vehicle through its duty cycle. Diesel, fuel cell-electric, and battery-electric trucks will not perform identically and, for example, at the same engine speed may not be able to summon as much torque or may consume fuel at a faster or slower rate.[95]

The performance requirements are selective and stylized and do not challenge the powertrain to run at all operating points that might be encountered during real-world conditions.[96] Performance requirements can include sufficient cruise speed, minimum acceleration times from 0 mph to 30 mph and 0 mph to 60 mph, and maximum continuous speeds in both flat topographies and on grade (i.e., the speed a vehicle maintains at a given slope, typically 6% rise-over-run).[97] Such performance characteristics may be expressed in maps or graphic plots of the key performance attributes of the powertrain as they vary over the duty cycle of the vehicle.[98] These maps or plots offer insight into the overall performance and fuel consumption rate of an engine or vehicle.[99]

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[95] The measure of engine speed is the angular velocity of the crankshaft, similar to revolutions per minute (RPMs) but greater by a factor of 2π. *Power* is the mathematical product of engine speed and torque.

[96] The operating points would, in one conception, be a plot of *fuel-speed-load*, that is, a graphic representation of the engine fuel consumption, engine speed, and torque at a set of operating points.

[97] For an illustration of how the performance requirements might relate to the operation and performance of the engine, see Figure 5 in J. Marcinkoski et al., "Driving an Industry: Medium and Heavy Duty Fuel Cell Electric Truck Component Sizing," *World Electric Vehicle Journal*, vol. 8, no. 1 (March 25, 2016), pp. 78-89, https://doi.org/10.3390/wevj8010078.

[98] See, for example, Figure 5 in J. Marcinkoski et al., "Driving an Industry: Medium and Heavy Duty Fuel Cell Electric Truck Component Sizing," *World Electric Vehicle Journal*, vol. 8, no. 1 (March 25, 2016), pp. 78-89, https://doi.org/10.3390/wevj8010078.

[99] Strictly speaking, the fuel component of the *fuel-speed-load* characteristics applies only to diesel or gasoline engines. (continued...)

Crucially, the fuel consumption rate, in concert with the tank size, will determine the vehicle range.

The performance requirements, in addition to characterizing the kinetics of the vehicle, provide a goal or target to be met during the component design and sizing exercise.[100] Designers could choose one particular motor size and continuous power rating for the simulation run and observe whether the performance requirements are satisfied. If not, the simulation would be iterated at a higher power rating and so on until the requirements are met and a solution achieved.[101]

The powertrain must respond to the torque request the driver makes when pressing the accelerator pedal and must satisfy the demand for mechanical power.[102] This demand, generally speaking, is influenced by the types of activities the vehicle performs. Small trucks for parcel delivery, often Class 4, will have frequent start-stop movements and overall urban driving characteristics. Long-haul Class 8 tractor-trailer combination vehicles might travel at cruise conditions (e.g., a constant speed of 55 mph or 65 mph) for several hundred miles per day. When accelerating, the torque requirement will be higher than at constant speeds, defining a further performance requirement.[103]

Cargo Requirements

Today's long-haul vehicles can support payloads at the legal maximum for on-highway movements with sufficient fuel and satisfactory engine performance to support daily operating ranges and duty cycles. The ability to haul the same payload as today's vehicles is one of the key requirements any MHDV based on alternative powertrains would need to satisfy.

Class 8 combination vehicles are rated at up to 80,000 lb. GVW (combined) and, if fully laden, could have payloads as high as 50,000 lb. or greater depending on the weight of the tractor plus empty trailer.[104] Often, in practice, the available cargo volume in the trailer will fill up, or "cube out," before the maximum weight can be reached. One estimate based on the operations of a large fleet found that this occurs 80% of the time.[105] The payloads discussed below reflect this, and the GVW of the test vehicles simulated in the analyses are mostly below 80,000 lb.

The 80,000 lb. de facto limit derives from federal law, which, with certain exceptions, restricts GVW on the Interstate Highway System to no more than 80,000 lb. or the maximum weight allowable under prevailing state law or regulation in effect as of July 1, 1956, whichever is greater (23 U.S.C. §127(a)(2)). Federal law sets a maximum single axle weight of 20,000 lb. and a maximum tandem (double) axle weight of 34,000 lb. and requires that maximum axle weights be calculated using the bridge gross weight formula (23 U.S.C. §127(a)(2); 23 C.F.R. §658.5). (The Class 8 vehicles discussed in this section have five single axles: one single axle and two tandem axles.) States must allow "reasonable access" to the Interstate Highway System, meaning

For a study that developed comparable maps across the three types of powertrains, see A. Burke and H. Zhao, "Fuel Economy Analysis of Medium/Heavy-Duty Trucks – 2015-2050," paper presented at the EVS30 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Stuttgart, Germany, October 2017, https://steps.ucdavis.edu/wp-content/uploads/2017/05/BURKE-ZHAO-EVS30-MDHD-Fuel-Economy-Analysis_ver1.pdf.

[100] The operating parameters would need to be suitably chosen as well.

[101] See, for example, J. Marcinkoski et al., "Driving an Industry," p. 4 et seq.

[102] L. Guzzella and C. H. Onder, *Introduction to Modeling and Control of Internal Combustion Engine Systems*, 2nd ed. (Springer-Verlag, 2010), p. 192.

[103] L. Guzzella and C. H. Onder, *Introduction to Modeling and Control of Internal Combustion Engine Systems*, 2nd ed. (Springer-Verlag, 2010).

[104] DOE, Vehicle Technologies Office, *Fact #621: Gross Vehicle Weight vs. Empty Vehicle Weight*, May 3, 2010, https://www.energy.gov/eere/vehicles/fact-621-may-3-2010-gross-vehicle-weight-vs-empty-vehicle-weight.

[105] R. Mihelic et al., *Hydrogen Fuel Cell Tractors*, p. 103.

that roads where states set weight limits generally conform to the federal limits just noted. (See Section 412 of the Surface Transportation Assistance Act of 1982 [STAA; P.L. 97-424].)

Three Studies of Class 8 Combination Vehicles

This section discusses three simulations of Class 8 tractor-trailers. CRS selected the studies in the following discussion because they make a comparison across three powertrains—diesel, battery-electric, and fuel cell-electric—and apply a consistent analytical framework within each study. Two of the studies consider the performance requirements of the vehicle, devise a virtual set of components to satisfy those requirements, and assemble a virtual vehicle. The results of the simulations illuminate how vehicles have different weights, and thus different cargo-carrying abilities and fuel economies, and how these attributes vary with choice of powertrain. The third study also employs a commercial modeling platform to quantify the vehicle hydrogen consumption and compares this with diesel and battery-electric vehicle energy use.

A number of factors cause the results of the three studies to be not completely comparable. The performance requirements placed on each simulated vehicle were fairly consistent among studies, but were not identical. The method for determining the optimal component size and the models used to conduct the simulations varied. Further, each study embodies different judgments about how much improvement in technology might occur in the future. Readers interested in the details of the individual powertrains may consult the respective studies.

Argonne National Laboratory

A modeling exercise by Argonne National Laboratory (ANL) uses a vehicle simulation computational platform, Autonomie, and considers over 20 types of MHDVs.[106] Holding the range constant at 500 miles, the study simulates two types of combination Class 8 vehicles—long-haul and regional-haul—using three different powertrains: diesel, battery-electric, and fuel cell-electric.[107] The results of the long-haul simulation are shown in **Figure 2**. The study includes vehicles with performance requirements (discussed above in "Overview") and vehicle attributes comparable to today's vehicles and customer expectations. The ranges are somewhat idealized as they lead to fuel exhaustion. The study includes two technology cases—high and low—assuming different levels of technological progress over time. For example, both the peak efficiency and the power density of the fuel cell are superior in the high-technology case.

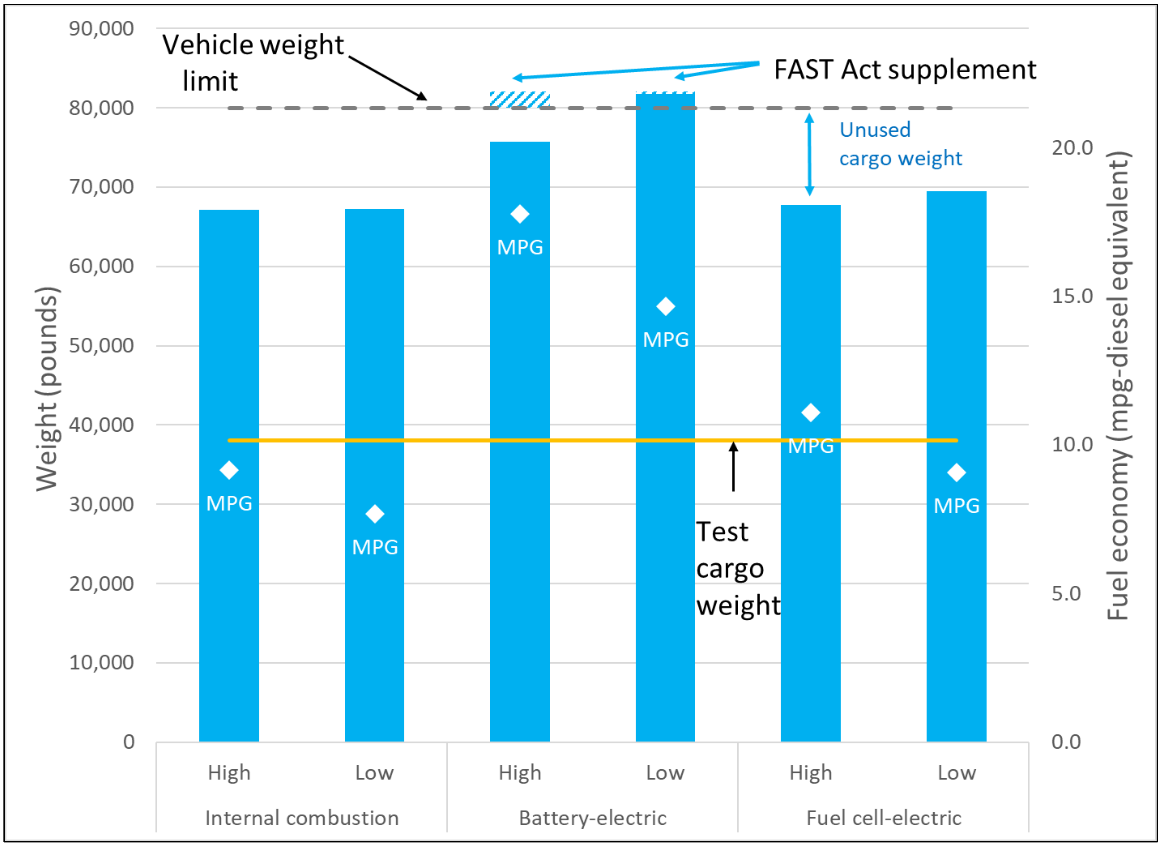
The study finds that, for a test cargo weighing 38,000 lb., all vehicles with all three powertrains perform according to the performance requirements. As shown in **Figure 2**, the combined GVW is less than the maximum of 80,000 lb., in all except the low-technology battery-electric vehicles, implying that the vehicles could carry some additional cargo weight, labeled "unused cargo weight." The unused cargo weight is 10,000 lb. less for the battery-electric vehicle versus the diesel. This lesser cargo capacity for alternative powertrains versus conventional (i.e., diesel) is sometimes known as *lost payload*. The results of the ANL study further show that the fuel cell-

[106] ANL, "Quantify the Impact of U.S. Department of Energy R&D on Vehicle Energy Consumption and Cost from Light- to Heavy-Duty Classes," October 2023, https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.

[107] Ehsan Sabri Islam et al., *A Comprehensive Simulation Study to Evaluate Future Vehicle Energy and Cost Reduction Potential*, ANL, ANL/ESD-22/6, October 2022, p. 68, https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/ (scroll down to locate "previous reports and analysis"). Performance and cargo requirements (p. 53) include 0-30 mph acceleration time; 0-60 mph acceleration time; sustainable maximum speed at 6% grade; driving range between refueling/recharging; cargo mass; maximum cruising speed; start/launch capability on grade; and maximum sustainable grade at highway cruising speed.

electric truck is closer in curb weight to diesel and thus the lost payload is substantially smaller than for a battery-electric.

Figure 2. Argonne National Laboratory Simulation of Three Powertrains in a Class 8 Long-Haul Tractor-Trailer Vehicle in High- and Low-Technology Cases



Source: Argonne National Laboratory, "Quantify the Impact of U.S. Department of Energy R&D on Vehicle Energy Consumption and Cost from Light- to Heavy-Duty Classes," analysis for medium- and heavy-duty vehicles, October 2023, https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/; dataset for medium- and heavy-duty vehicles (MHDVs) available at https://anl.app.box.com/s/oy04bje3ltc21rz5py4bq1ed4s4bn0vo.

Notes: Vehicles are year 2025. The high- and low-technology cases should be interpreted as ranges. Validation of the vehicle mpg and cargo capacity may take a few years of on-road testing. Vehicle weight (blue bars) includes cargo weight; mpg = miles per gallon. The empty curb weight of the combined vehicle is the portion of the blue bar above the amber "test cargo weight" line. All three vehicle powertrain types have the same cargo weight in the simulation, but in some instances could take on a greater amount of additional cargo without exceeding the combined vehicle weight rating; this leftover capacity is denoted in the figure as "unused cargo weight." The FAST Act increased the allowable weight by 2,000 pounds for battery-electric MHDVs; the "FAST Act supplement." The supplement is partly obscured by the vehicle weight in the case of the low-technology battery-electric vehicle.

The study does not explicitly consider the FAST Act (P.L. 114-94), which added 2,000 lb. to the limit on the GVW for battery-electric or compressed natural gas-combustion powertrains and reduces lost payload, if any, by the same amount. Such vehicles could, in principle, have a maximum gross combined vehicle weight (GCVW) of no more than 82,000 lb. on the Interstate Highway System, or reasonable access thereto. **Figure 2** illustrates the allowance for the battery-electric powertrain by adding a cross-hatched rectangle, labeled as "FAST Act supplement." For the low-technology battery vehicle, the 2,000 lb. allowance is necessary to accommodate the full test payload: the weight of the empty vehicle plus test payload exceeds 80,000 lb.

Figure 2 also plots fuel economy, in miles per gallon (mpg) diesel equivalent, as diamonds to be read off along the right-hand vertical axis. The battery-electric powertrain is the most fuel efficient of the three, when considering only the energy use of the vehicle, owing to the convenience of electricity being both (1) the fuel that is stored on board the vehicle and (2) the fuel required by the inherently more efficient electric motor.[108] In contrast, a fuel cell would first need to convert the hydrogen stored on board the vehicle, at an efficiency of 45% to 60%, into the electricity needed to turn the motor.[109] The two powertrains (fuel cell-electric and battery-electric vehicles) thereafter convert electricity to mechanical power at 90%.[110] Other powertrains convert between different forms of energy with lesser efficiencies. Diesel engines, for example, convert the onboard diesel fuel into the shaft work performed by the engine and do so with 25% to 45% *brake thermal efficiencies*—the efficiency measuring the mechanical energy at the crankshaft compared with the fuel energy. None of these metrics consider the energy and emissions associated with extracting and refining the primary resource and—in the case of battery-electric vehicles—converting the primary resource to another form of energy. For the battery-electric vehicle, energy emissions could be substantially undercounted, as the primary energy resource must be converted to electricity. For further discussion, see CRS Report R46420, *Environmental Effects of Battery Electric and Internal Combustion Engine Vehicles*, by Richard K. Lattanzio and Corrie E. Clark.

National Renewable Energy Laboratory (NREL)

A modeling exercise by the National Renewable Energy Laboratory (NREL) uses a vehicle simulation computational platform, the Future Automotive Systems Technology Simulator (FASTSim) model.[111] The outputs are vehicle performance and cost. NREL uses FASTSim to build vehicle models "to translate component- and vehicle-level goals into vehicle performance (miles per gallon [mpg]) and cost" for Class 8 long-haul vehicle applications and for other types of vehicles. FASTSim uses input data on powertrain performance, such as peak engine efficiencies and component power densities, and calculates onboard fuel and energy storage requirements. The study takes account of key performance requirements, such as time to accelerate from 0 mph to 60 mph and range (miles) on one tank, as discussed above in the "Overview" section. The study runs simulations at a cargo weight of 36,000 lb.[112]

The NREL study finds, as does the ANL study (above), that battery-electric combined vehicles weigh the most but nonetheless satisfy the performance requirements and carry the test cargo

[108] The calculation of the fuel economy of the battery-electric vehicle does not include the energy needed to generate the electricity in the first place, or the fuel economy would be lower. The same is true to a lesser degree of the fuel economy of diesel and gasoline engines in the ANL study, which also does not include the energy to extract and refine the petroleum before the fuel is on board the vehicle.

[109] A. Ferrara et al., "Energy Management of Heavy-Duty Fuel Cell Electric Vehicles: Model Predictive Control for Fuel Consumption and Lifetime Optimization," paper presented at the 21st IFAC Conference, Berlin, July 2020, pp. 14205-14210, https://www.sciencedirect.com/science/article/pii/S2405896320314233.

[110] Renault Group, "The Energy Efficiency of an Electric Car Motor," *Energy and Motorization*, March 9, 2021, https://www.renaultgroup.com/en/news-on-air/news/the-energy-efficiency-of-an-electric-car-motor/.

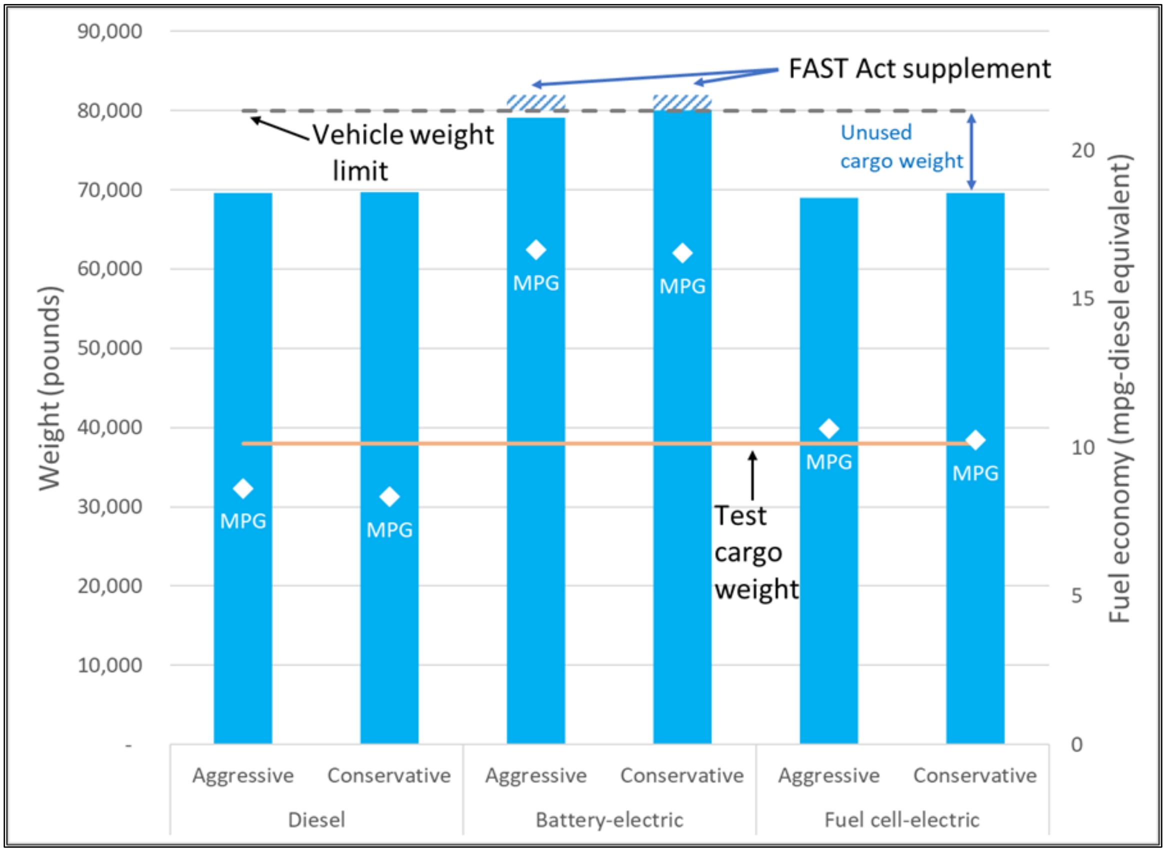
[111] E. Brooker et al., *FASTSim: A Model to Estimate Vehicle Efficiency, Cost and Performance*, NREL, NREL/CP-5400-63623/SAE Technical Paper 2015-01-0973, April 14, 2015, https://www.nrel.gov/docs/fy15osti/63623.pdf.

[112] A. Brooker et al., *Vehicle Technologies and Hydrogen and Fuel Cell Technologies Research and Development Programs Benefits Assessment Report for 2020*, NREL, NREL/TP-5400-79617, August 2021, https://www.nrel.gov/docs/fy21osti/79617.pdf.

weight. **Figure 3** includes plots of loaded vehicle mass, cargo mass, and regulatory limits and allowances.

The NREL study considers two different technology cases: "conservative," which NREL describes as "business as usual," and "aggressive," which NREL describes as a high rate of technology progress.[113] The fuel economy was slightly higher and the empty vehicle weight slightly lower in the aggressive case.

Figure 3. NREL Vehicle Simulation of Three Powertrains in a Class 8 Long-Haul Tractor-Trailer Vehicle in Aggressive and Conservative Technology Cases



Source: National Renewable Energy Laboratory (NREL), using data from A. Brooker et al., *Vehicle Technologies and Hydrogen and Fuel Cell Technologies Research and Development Programs Benefits Assessment Report for 2020*, NREL/TP-5400-79617, 2021, https://www.nrel.gov/docs/fy21osti/79617.pdf; dataset available via automatic download at https://www.nrel.gov/transportation/assets/docs/tda-mdhd-attributes-2022-09-03-v5.xlsx.

Notes: Vehicles are year 2025; range is 800 kilometers (~500 miles); mpg = miles per gallon. NREL sizes the components for full legal weight and runs its simulations at the test cargo weight shown. Vehicle weight (blue bars) includes cargo weight. The empty curb weight of the combined vehicle is the portion of the blue bar above the amber "test cargo weight" line. All three vehicle powertrain types have the same cargo weight in the simulation, but two of them—the diesel and fuel cell-electric vehicles—could take on still more capacity without exceeding the combined vehicle weight rating; this leftover capacity is denoted as "unused cargo weight" in the right-most bar, and it also applies to the others with underutilized capacity. The FAST Act supplement increased the allowable weight by 2,000 pounds for battery-electric medium- and heavy-duty vehicles (MHDVs).

113 From "Overview" tab of dataset that downloads automatically from https://www.nrel.gov/transportation/assets/docs/tda-mdhd-attributes-2022-09-03-v5.xlsx.

International Council on Clean Transportation

The International Council on Clean Transportation (ICCT) analyzes how overall vehicle weight can vary, again across three vehicle powertrain types. The analysis holds cargo weight constant, except where doing so would exceed applicable limits. The analysis is part of a study of options for regulating MHDVs in the EU.[114] As a consequence of the study's focus on the EU, the test payload and maximum vehicle mass reflect EU limits, which are each roughly 10% higher than in the United States. Generally, large trucks in the EU cannot exceed 40 metric tons (~88,000 lb.).

The study considers multiple ranges. **Figure 4** shows the results at 800 kilometers (~500 miles), for comparability with the other studies discussed above, and includes plots of loaded vehicle mass, cargo mass, and regulatory limits and allowances. (For comparison, CALSTART maintains a database with the range of currently available fuel cell-electric MHDVs.[115]) Two of the three powertrains are able to haul the test payload in the current case, while the battery-electric vehicle is not able to.

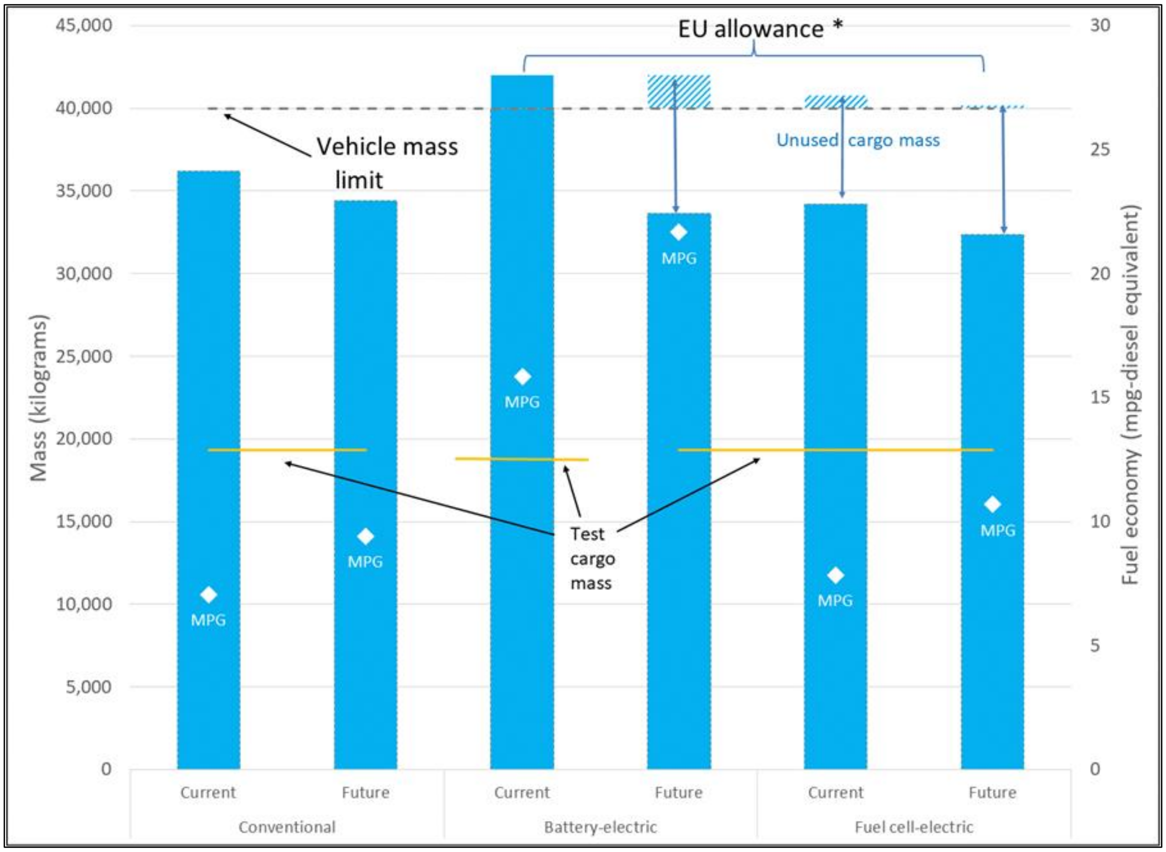
ICCT applies the applicable EU allowance for the ZEVs. Regulations in the EU allow up to an additional 2,000 kg for zero-emission vehicles, which are defined in the EU as vehicles that do not have an internal combustion engine or that emit less than 1 gram of carbon dioxide per kilowatt-hour (kWh).[116] For comparison, the FAST Act supplement in the United States is roughly half as large, or roughly 900 kg. The allowance reflects how much heavier the zero-emission componentry would be relative to that of a diesel; the allowance does not automatically step up to 2,000 kg. For the fuel cell-electric vehicle configured by ICCT, this extra mass is 782 kg in the current case and 178 kg in the future case. The ICCT future case includes increased peak fuel cell efficiency, decreased aerodynamic drag and vehicle weight, lighter battery packs, and other improvements; the future case represents the study authors' judgments about improvements possible by 2030.

[114] H. Basma and F. Rodríguez, *Fuel Cell Electric Tractor-Trailers: Technology Overview and Fuel Economy*, International Council on Clean Transportation, Working Paper 2022-23, July 18, 2022, pp. 24, 32, https://theicct.org/wp-content/uploads/2022/07/fuel-cell-tractor-trailer-tech-fuel-1-jul22.pdf.

[115] CALSTART, *Drive to Zero's Zero-Emission Technology Inventory (ZETI) Tool Version 9.0*, https://globaldrivetozero.org/tools/zero-emission-technology-inventory/.

[116] European Commission, "Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019 Setting CO_2 Emission Performance Standards for New Heavy-Duty Vehicles and Amending Regulations (EC) No 595/2009 and (EU) 2018/956 of the European Parliament and of the Council and Council Directive 96/53/EC," *Official Journal of the European Union*, vol. 62, July 25, 2019, pp. L 198/202-240, https://eur-lex.europa.eu/eli/reg/2019/1242/oj#d1e1921-202-1.

Figure 4. ICCT Simulation of Three Powertrains in a Class 8 Long-Haul Combination Tractor-Trailer in Current and Future Cases



Source: H. Basma and F. Rodríguez, *Fuel Cell-Electric Tractor-Trailers: Technology Overview and Fuel Economy*, International Council on Clean Transportation, Working Paper 2022-23, July 18, 2022, pp. 29, 32, https://theicct.org/publication/fuel-cell-tractor-trailer-tech-fuel-jul22/.

Notes: "Current" year, while not given, is presumably the year of publication (2022). "Future" year is 2030; range is 800 kilometers (~500 miles). Vehicle mass (blue bars) includes cargo mass. White diamonds indicate fuel consumption rate (right axis); mpg = miles per gallon.
(*) The European Union (EU) allows up to an additional 2 metric tons (2,000 kilograms, or roughly 4,400 lb.) for zero-emission vehicles. For the battery-electric vehicle in current technology, the modeled vehicle uses the EU allowance but is not able to pull the entire test mass of 19,300 kilograms (~42,500 lb.). The future battery-electric case and the current and future fuel cell-electric cases can use the EU allowance, depicted in blue with hatched pattern.

The test payload is 19,300 kg (~42,500 lb.); in all except current technology battery-electric vehicles, the vehicle has capacity for additional payload. At 1,000 kilometers (~620 miles; not shown in the figure), ICCT notes that battery-electric combination vehicles experience 40% lost payload due to the large battery required (1,884 kWh). This lost payload, however, decreases to 9% in a future case with improvements in truck chassis, trailer, and powertrain.[117]

For comparison, CRS looked at additional studies that considered the relationship between cargo weight and vehicle weight. A study by Oak Ridge National Laboratory in 2019, on battery-electric trucks, considers various cargo masses and finds that for ranges above 200 miles, the size of the battery would lead to lost payload, similar to **Figure 4** for the "current" battery-electric

[117] Basma and Rodríguez, *Fuel Cell Electric Tractor-Trailers*, p. 24.

case.[118] A field study by Ballard Power Systems, a fuel cell manufacturer, and the North American Council on Freight Efficiency collects on-road data on 10 fuel cell-electric Class 8 vehicles in regional-haul operation and finds the average consumption is 9.14 mpg-diesel equivalent, again similar to the ICCT study's results, falling in between the current and future cases in **Figure 4** for fuel cell-electric trucks.[119]

Industry Benchmark on Vehicle Range: The Experience of Nikola

Nikola, a maker of battery-electric and fuel cell-electric trucks, has made available its comparison of hauling capacity of the three powertrains considered in the studies discussed immediately above. In a March 2020 shareholder presentation, Nikola Motor Corporation, as it was then styled, offered a "general technology comparison" focused on the vehicle attributes of range and weight.[120] Nikola Motor Corporation conceived of two platforms—a shorter-haul battery-electric Class 8 tractor and a longer-haul fuel cell-electric Class 8 tractor—as complementary, with battery-electric trucks better suited to shorter hauls and the so-called last mile of delivery. Details are in **Table 1**. In July 2023, Nikola announced production of its Class 8 tractor with fuel cell powertrain and 500-mile range and produced 42 Class 8 tractors in 2023.[121] Nikola announced it had sold 200 Class 8 tractors in the third quarter of 2024.[122] In the first quarter of 2025, Nikola announced it had voluntarily filed for Chapter 11 bankruptcy.[123] Kenworth, Volvo, and Hyundai Motor have announced plans for production of hydrogen MHDVs.[124]

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[118] DOE, EERE, *Medium- and Heavy-Duty Vehicle Electrification: An Assessment of Technology and Knowledge Gaps*, ORNL/SPR-2020/7, December 2019, p. 29, https://info.ornl.gov/sites/publications/Files/Pub136575.pdf.

[119] The study reports 7.8 kg hydrogen consumed per 100 kilometers. CRS converts this to mpg-diesel equivalent using the lower heating value of hydrogen of 33.3 kWh, and 37.99 kWh per diesel gallon equivalent. The notion of fuel equivalencies considers the respective quantities of two different fuels with the same energy content, with the latter defined within the specific calculation. Ballard Power Systems and North American Council for Freight Efficiency, *Fuel Cell Electric Trucks: An Analysis of Hybrid Vehicle Specifications for Regional Freight Transport*, June 2020, p. 18, https://nacfe.org/wp-content/uploads/2020/06/Informational_NACFE_BPS_Truck_White_Paper_Download.pdf.

[120] Nikola Motor Corporation, "Investing in a Cleaner Future," presentation, March 2020, https://www.sec.gov/Archives/edgar/data/1731289/000110465920033164/tm2012695d1_ex99-1.htm.

[121] Keiron Greenhalgh, "Nikola Begins Production of Hydrogen Fuel Cell Class 8 Truck," *Transport Topics*, August 2, 2023, https://www.ttnews.com/articles/nikola-hydrogen-truck; and Jennifer Gangi, "Hydrogen Driving Trucking and Transit on Path to Zero Emissions," *ACT News*, April 17, 2024, https://www.act-news.com/news/hydrogen-driving-trucking-and-transit-on-path-to-zero-emissions/.

[122] Nikola, "Nikola Records Sales of 88 Hydrogen-Powered Class 8 Trucks for North American Customers in Q3 2024; 200 Total Sold This Year," press release, October 2, 2024, https://www.nikolamotor.com/nikola-records-sales-of-88-hydrogen-powered-class-8-trucks-for-north-american-customers-in-q3-2024-200-total-sold-this-year.

[123] Nikola, "Nikola Initiates Comprehensive Voluntary Chapter 11 Sale Process," press release, February 19, 2025, https://www.nikolamotor.com/nikola-initiates-comprehensive-voluntary-chapter-11-sale-process.

[124] Volvo Truck, "Fuel Cell Trucks—When and Why Do We Need Them?," press release, January 10, 2023, https://www.volvotrucks.com/en-en/news-stories/stories/2022/nov/when-and-why-fuel-cell-truck.html; Hyundai Motor Company, "Hyundai Motor Drives Sustainable Clean Logistics in U.S. with Vision for Hydrogen Society," press release, May 22, 2024, https://ecv.hyundai.com/global/en/newsroom/press-releases/hyundai-motor-drives-sustainable-clean-logistics-in-us-with-vision-for-hydrogen-society-BL00200522; and Kenworth, "Kenworth Announces T680 Hydrogen Fuel Cell Commercialization Plans," press release, May 2, 2023, https://www.kenworth.com/about-us/news/kenworth-announces-t680-hydrogen-fuel-cell-commercialization-plans/.

Table 1. Nikola Motor Corporation's Estimated Ranges and Weights for Class 8 Tractor-Trailers

(estimates of hauling capacity include weights of trailer plus cargo)

Power Source	Range	Estimated Hauling Capacity[a]
Diesel	500-750 mi.	~61,000-63,000 lb.
Battery-electric	100-300 mi.	~53,000-55,000 lb.
Fuel cell-electric	500-750 mi.	~56,000-58,000 lb.

Source: Nikola Motor Corporation, "Investing in a Cleaner Future," presentation, March 2020, https://www.sec.gov/Archives/edgar/data/1731289/000110465920033164/tm2012695d1_ex99-1.htm.

Notes: In the Nikola presentation, vehicle weight plus "hauling capacity" (i.e., cargo weight) sum to 80,000 lb.; lb. = pounds; mi. = miles. The firm is now styled as Nikola or Nikola Corporation.

a. Includes weight of trailer. The empty weight of a semi-trailer varies but different sources notionally fix the weight at 10,000 lb. and 13,500 lb., for example. Dustin Hawley, "How Much Does a Semi Truck Weigh?," J.D. Power, February 4, 2021, https://www.jdpower.com/cars/shopping-guides/how-much-does-a-semi-truck-weigh; C. Hunter et al., *Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks*, National Renewable Energy Laboratory, NREL/TP-5400-71796, September 2021, p. 82, https://www.osti.gov/biblio/1821615.

Trade-Offs Involving Parcel Delivery Vehicles (Class 4)

Lighter vehicles, such as Class 4, make deliveries to homes and businesses and, generally speaking, handle the *last mile* of the supply chain. A 2024 model result of MHDVs by ANL considers conventional, battery-electric, and fuel cell-electric (including hybrid) powertrains in Class 4 delivery vehicles. The results show that the Class 4 vehicle in all three powertrains could meet the performance requirements (discussed above in "Overview") while transporting a load of 1,650 kg (~3,640 lb.) a distance of 150 miles. The fuel economy (miles per gallon or miles per gallon diesel equivalent) of the vehicles varies across powertrains, with the alternative powertrains (battery-electric and fuel cell-electric) being more efficient at converting the chemical energy into miles traveled.

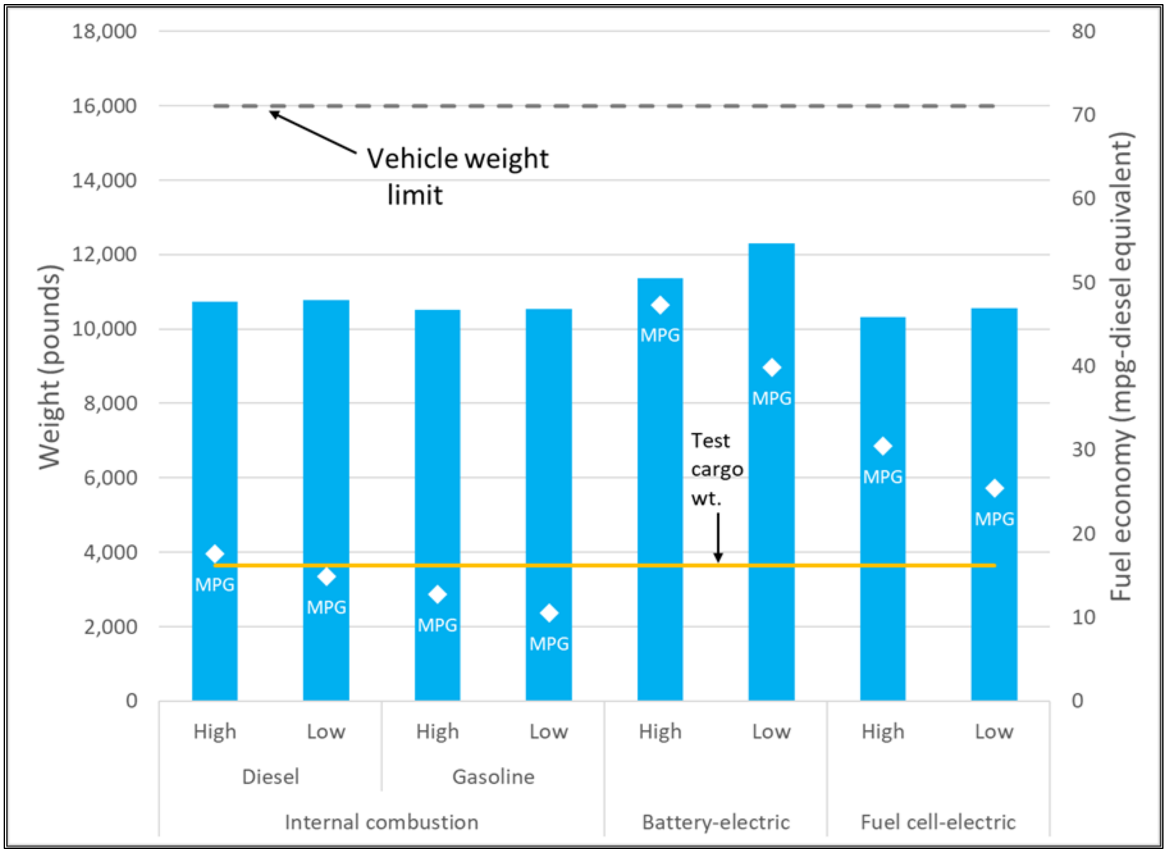
The ANL analysis considers two technology cases: a low-technology case, in which there is no DOE-sponsored research program, and a high-technology, "program success" case, in which DOE programs reach technical targets. For the program success case (high-technology), the study assumes the vehicle will achieve DOE's year-2050 goals across a number of vehicle characteristics (e.g., drag coefficient, or C_dA) and powertrain components (e.g., fuel cell peak efficiency). ANL uses these goals and a set of performance requirements to develop technical specifications for the completed vehicle.[125] Calibrated to these specifications, ANL uses Autonomie, the vehicle simulation computational platform, and determines the size (e.g., power rating) of the powertrain components and the vehicle's energy use.[126] **Figure 5** plots the weight and the fuel economy of the loaded vehicle in the simulation. Among conventional powertrains, the study considers both diesel engines and gasoline engines (i.e., spark-ignited, Otto cycle

[125] In the companion report, ANL notes that manufacturers do not typically make the performance requirements available, so ANL uses the advertised power ratios, gear ratios, etc. to derive a compatible set of such requirements for use in the study. Ehsan Sabri Islam et al., *Detailed Simulation Study to Evaluate Future Transportation Decarbonization Potential*, ANL, Contract ANL/TAPS-23/3, October 2023, p. 43, https://vms.taps.anl.gov/research-highlights/vehicle-technologies/u-s-doe-vto-hfto-r-d-benefits/.

[126] The study calculates the requirements at the maximum GVW rating for Class 4 vehicles, or 16,000 lb.

engines). In **Figure 5**, fuel economy is plotted as diamonds and the values read off along the right-hand vertical axis.

Figure 5. Simulation of Three Powertrains in a Class 4 Delivery Vehicle



Source: Argonne National Laboratory, *U.S. DOE VTO/HFTO R&D Benefits*, January 2024, https://vms.taps.anl.gov/research-highlights/vehicle-technologies/u-s-doe-vto-hfto-r-d-benefits/. Dataset for medium- and heavy-duty vehicles downloadable at https://anl.box.com/s/oy04bje3ltc21rz5py4bq1ed4s4bn0vo.

Notes: Vehicles are year 2025. The high- and low-technology cases should be interpreted as ranges. Validation of the vehicle mpg and cargo capacity may take a few years of on-road testing. Vehicle weight (blue bars) includes cargo weight; mpg = miles per gallon. The empty curb weight of the combined vehicle is the portion of the blue bar above the amber "test cargo weight" line.

Vehicle Cost

Various studies have compared the purchase cost of the Class 8 vehicle across the different types of powertrains including diesel, battery-electric, and fuel cell-electric. Generally speaking, battery-electric trucks and fuel cell-electric trucks still cost more to purchase than comparable diesel trucks. A 2022 analysis by ICCT estimates that a battery-electric Class 8 day cab vehicle, which has no sleeping compartment, costs two to three times as much as a comparable diesel vehicle, and a comparable fuel cell-electric vehicle costs three to four times as much as a diesel, prior to financial incentives.[127] By 2030, the costs of battery-electric and fuel cell-electric trucks

[127] Claire Buysse, "How Much Does an Electric Semi Really Cost?" International Council on Clean Transportation (ICCT) blog, February 24, 2022, https://theicct.org/cost-electric-semi-feb22/. See especially figure, "Purchase Price of a Class 8 Day Cab by Powertrain."

(Class 8 day cabs) are projected to converge, with both vehicles costing 150% to 170% the cost of a comparable diesel, prior to financial incentives. For comparability, the studies of Class 8 vehicles discussed below will also be for day cabs.

The modeling exercise by ANL[128] cited in **Figure 2**, which also considers vehicle cost, finds that for a 2025 Class 8 day cab in regional-haul operation, the battery-electric truck costs 150% to 230% the cost of a diesel, while the fuel cell-electric truck costs 140% to 190% the cost of a diesel. By 2030, the costs of battery-electric and fuel cell-electric trucks (Class 8 day cabs) are projected to converge, with both vehicles costing roughly 120% to 170% the cost of a diesel, prior to any financial incentives.[129]

A study by NREL finds that, for Class 8 long-haul combination vehicles with day cab, the battery-electric version has an estimated manufacturer's suggested retail price (MSRP) that is roughly twice the diesel's MSRP, while the fuel cell-electric has an MSRP that is roughly 1.5 times higher—both in 2025, the first year for which results for all three powertrains were presented—prior to any financial incentives. For the 2030 scenario, involving technical progress, the battery-electric vehicle MSRP reduces to roughly the same, 1.3 to 1.5 times the diesel MSRP, and the fuel cell-electric MSRP reduces to 1.2 to 1.4 times the diesel MSRP.[130] The study notes the possibility of the 45W tax credit but does not apply it.[131] The tax credit is discussed further in "Commercial Clean Vehicles: *Internal Revenue Code* Section 45W," below.

For Class 4 parcel delivery vehicles, the NREL study finds that the MSRP is higher for fuel cell-electric Class 4 trucks versus diesel by roughly a factor of two in the 2018 scenario; by the 2025 scenario, the fuel cell-electric MSRP is 1.33 times that of the diesel. The battery-electric truck MSRP is 1.84 times the diesel MSRP in the 2018 scenario and in the 2025 scenario has improved to being slightly less than diesel, or 0.91 times diesel.[132] The study by ANL finds that the MSRP of the fuel cell-electric vehicle would be 1.20 to 1.29 times that of the diesel and 1.12 to 1.23 times that of the gasoline engine, depending on the technology case (low or high). For the battery-electric vehicle, the study finds that the MSRP would be 1.27 to 1.79 times that of the diesel and 1.19 to 1.27 times that of the gasoline engine, depending on the technology case (low or high).

Recent Developments

Financial Assistance Programs on Deployment of Hydrogen Trucks

Legislation enacted in the last several years has greatly increased the amount of funding and other financial incentives available toward deployment of FCEVs. Deployment support can focus on demonstration or early commercial phases and include activities such as transporting and dispensing hydrogen fuel; vehicle manufacturing; vehicle purchase, such as by fleets; and final

[128] ANL, "Quantify the Impact of U.S. Department of Energy R&D on Vehicle Energy Consumption and Cost from Light- to Heavy-Duty Classes," October 2023, https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.

[129] ANL, "Quantify the Impact of U.S. Department of Energy R&D on Vehicle Energy Consumption and Cost from Light- to Heavy-Duty Classes," dataset for medium- and heavy-duty vehicles downloadable at "vehicle results" link at https://vms.taps.anl.gov/research-highlights/vehicle-technologies/u-s-doe-vto-hfto-r-d-benefits/ or at https://anl.box.com/s/oy04bje3ltc21rz5py4bq1ed4s4bn0vo.

[130] Hunter et al., *Spatial and Temporal Analysis,* p. 34.

[131] ANL, "Quantify the Impact of U.S. Department of Energy R&D on Vehicle Energy Consumption and Cost from Light- to Heavy-Duty Classes," October 2023, https://vms.taps.anl.gov/research-highlights/u-s-doe-vto-hfto-r-d-benefits/.

[132] Hunter et al., *Spatial and Temporal Analysis,* p. 36.

use of hydrogen for energy services by truck fleets (e.g., port operations, goods movement). The conceptual boundary between research and development (R&D) versus deployment is not always certain and, for example, activities based on developing new manufacturing lines or concept vehicles such as SuperTruck, discussed below, may be difficult to classify definitively as one or the other.[133]

The IIJA and P.L. 117-169, known as the Inflation Reduction Act of 2022 (IRA), are two supplemental appropriations bills that include support for deployment of FCEVs in very large projects, such as Regional Clean Hydrogen Hubs, but also smaller awards made to specific hydrogen MHDV projects. Annual appropriations continue to focus principally on R&D and precompetitive activities.[134] This section focuses primarily on deployment activities that are funded from the supplemental appropriations bills owing to their size, scope, and scale.

Recent developments carry or have carried implications for spending on the programs discussed in this section. These include, but are not limited to, the issuance of the executive order "Unleashing American Energy,"[135] DOE's reported plans to review all post-election awards (which would include four of the seven Regional Clean Hydrogen Hubs),[136] and an Office of Management and Budget (OMB) memorandum[137] (later rescinded)[138] pausing obligation and disbursement of federal financial assistance. According to news report in March 2025, DOE was considering whether to discontinue funding for some of the hydrogen hubs.[139]

Charging and Fueling Infrastructure (CFI): Grants and Tax Credits

Section 11401 of the IIJA authorized grants for charging and fueling infrastructure along "designated alternative fuel corridors," as the latter are defined in the FAST Act (P.L. 114-94); corridors are discussed above in "Status and Characteristics of MHDVs." Grantees may use the funds for a variety of alternative fuel infrastructure, including battery recharging or hydrogen fueling. The IIJA (§11101(b)(1)(C)) provided a total of approximately $2.5 billion for FY2022 to FY2026 from the Highway Trust Fund[140] for this program.[141] Two bills in the 119th Congress, S. 651 and H.R. 1513, would end the program.

The program is being implemented by FHWA. Of the $623 million awarded in the first round of funding, over 80% went toward electric vehicle charging, with the remaining $98 million going

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[133] See, for example, DOE's recent announcement of an award of $4.5 million to Boston Materials: DOE, "DOE Awards over $11 Million Through MAKE IT Prize to Boost Domestic Clean Energy Manufacturing Development and Opens New $32 Million Round of the Prize," press release, December 12, 2024, https://www.energy.gov/technologytransitions/articles/doe-awards-over-11-million-through-make-it-prize-boost-domestic.

[134] DOE, Office of the Chief Financial Officer, *FY 2025 Congressional Justification: Volume 2*, DOE/CF-0203, March 2024, p. 304, https://www.energy.gov/sites/default/files/2024-03/doe-fy-2025-budget-vol-2-v4.pdf.

[135] Executive Order 14154, "Unleashing American Energy," 90 *Federal Register* 8353 (January 29, 2025).

[136] Peter Behr, "DOE Project Funding Needs Trump Lieutenants' Blessing," *E&E News*, February 12, 2025, https://www.eenews.net/articles/doe-project-funding-needs-trump-lieutenants-blessing/.

[137] Office of Management and Budget (OMB), "Temporary Pause of Agency Grant, Loan, and Other Financial Assistance," Memorandum for Heads of Executive Departments and Agencies, M-25-13, January 27, 2025.

[138] OMB, "Rescission of M-25-13," Memorandum for Heads of Executive Departments and Agencies, M-25-14, January 29, 2025, https://www.cfo.gov/assets/files/M-25-14%20Final.pdf.

[139] "US Weighs Funding Cuts to Four of Seven Hydrogen Hubs," *Reuters*, March 26, 2025.

[140] For a description of the Highway Trust Fund, see CRS Report R47022, *Federal Highway Programs: In Brief*, by Robert S. Kirk.

[141] CRS Report R47034, *Energy and Minerals Provisions in the Infrastructure Investment and Jobs Act (P.L. 117-58)*, coordinated by Brent D. Yacobucci. See "Division A—Surface Transportation," prepared by Melissa N. Diaz.

toward hydrogen or combination hydrogen and electric vehicle refueling projects.[142] FHWA announced awards totaling $521.2 million on August 27, 2024, as a continuation of the first round of funding. Of these, one project on hydrogen refueling for MHDVs was to receive $102.4 million.[143] For the second round of funding, FHWA announced $635.7 million in awards on January 8, 2025, including $80.63 million for projects on hydrogen or hydrogen and electric vehicle charging.[144] H.R. 1052 in the 119th Congress would rescind certain unobligated balances.

Alternative Fuel Refueling Property Credit: *Internal Revenue Code* Section 30C

Section 13404 of the IRA amends Section 30C of the *Internal Revenue Code* (IRC) to provide an Alternative Fuel Refueling Property Credit. IRC 30C provides a tax credit up to 30% of the cost of alternative fuel refueling property, up to $100,000.

Clean Heavy-Duty Vehicles Program

Section 60101 of the IRA, "Clean Heavy-Duty Vehicles," amends the Clean Air Act (42 U.S.C. §§7401-7671) and provides $1 billion to be used for replacement of non-zero-emission vehicles with zero-emission vehicles (ZEVs). Section 60101 defines a ZEV as a vehicle that does not create emissions of criteria pollutants or greenhouse gases from its exhaust.[145] As such, the definition includes fuel cell-electric vehicles. Monies from the Clean Heavy-Duty Vehicles Program, in the form of grants and/or rebates, may be used to cover the incremental cost of replacing the current stock of vehicles with ZEVs.

The IRA also authorizes the use of funds for refueling and maintenance infrastructure, workforce development and training, and other activities supporting adoption of ZEVs. EPA is the implementing agency and opened the notice of funding opportunity (NOFO) on April 24, 2024, with applications due July 25, 2024.[146] EPA had not announced funding awards from this NOFO as of February 28, 2025.

Reduction of Truck Emissions at Port Facilities Grant Program

Section 11101(b)(1)(F) of the IIJA authorizes a program "to carry out the reduction of truck emissions at port facilities" and provides $50 million per year, FY2022 to FY2025, from the Highway Trust Fund. In addition, Division J of the IIJA appropriates $30 million annually over the period FY2022 to FY2026.[147] On April 24, 2024, the Biden Administration announced $148 million in grants for 16 projects, much of it aimed at refueling infrastructure and reducing

[142] FHWA, "CFI Round 1B Grant Award Recipients," press release, August 26, 2024, https://www.fhwa.dot.gov/environment/cfi/grant_recipients/round_1b/.

[143] FHWA, "Investing in America: Number of Publicly Available Electric Vehicle Chargers Has Doubled Since Start of Biden-Harris Administration," press release, August 27, 2024, https://highways.dot.gov/newsroom/investing-america-number-publicly-available-electric-vehicle-chargers-has-doubled-start.

[144] FHWA, "CFI Round 2 Grant Award Recipients," press release, January 8, 2025, https://www.fhwa.dot.gov/environment/cfi/grant_recipients/round_2/.

[145] Criteria air pollutants are regulated under Section 108(a) of the Clean Air Act and include some of the air emissions commonly associated with power plants and vehicles such as oxides of nitrogen (NO_x) and particulate matter (PM).

[146] EPA, "Clean Heavy-Duty Vehicles Program," July 20, 2023, https://www.epa.gov/inflation-reduction-act/clean-heavy-duty-vehicle-program.

[147] FHWA, "Infrastructure Investment and Jobs Act Fact Sheets: Reduction of Truck Emissions at Port Facilities," January 31, 2025, https://www.fhwa.dot.gov/bipartisan-infrastructure-law/rtep.cfm.

pollution from idling.[148] One project grant, $25.1 million awarded to the Port Authority of Houston, included funding for a portable hydrogen fueling station.[149] Many of the awards were not related to hydrogen but were made for projects on electric charging infrastructure and replacement of diesel vehicles with battery-electric vehicles.

Clean Ports Program

EPA's Clean Ports Program is funded through IRA Section 60102, with the goal of reducing air pollution at ports through grants.[150] EPA issued a NOFO of up to $2.8 billion for the Zero-Emission Technology Deployment Competition grants for zero-emission port equipment and infrastructure.[151] Eligible entities include, but are not limited to, owners and operators of cargo-handling equipment and drayage trucks who apply in partnership with air pollution control agencies or port authorities or other agencies with authority at ports.[152] On October 29, 2024, EPA announced the selection of 30 grants totaling $2.8 billion.[153] Of these, three projects worth a total of $471 million support charging and refueling infrastructure, material handling equipment, drayage trucks, and locomotives for either hydrogen-fueled vehicles or both hydrogen-fueled and electric vehicles.[154]

Port Infrastructure Development Program

Division J of the IIJA funded the Port Infrastructure Development Program (46 U.S.C. §54301), which is authorized to improve the safety, efficiency, and reliability of ports in four areas. In one area, environmental and emissions mitigation measures, the authorizing statute calls for "electric vehicle charging or hydrogen refueling infrastructure for drayage and medium or heavy-duty trucks and locomotives that service the port and related grid upgrades" (46 U.S.C. §54301(a)(3)(A)(ii)(IV)(hh)). The awards announced by DOT following the FY2022, FY2023, and FY2024 solicitations do not, however, explicitly include hydrogen.[155] The IIJA appropriated a total of $2.25 billion from FY2022 through FY2026. The program received additional money from annual appropriations: $234.31 million in FY2022, $212.20 million in FY2023, and $120.46 million in FY2024; $50 million of FY2024 monies may be used for discretionary grants.[156]

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[148] FHWA, "Biden-Harris Administration Announces Nearly $150 Million in Grants to Help Reduce Truck Air Pollution Near America's Ports," press release, April 24, 2024, https://highways.dot.gov/newsroom/grants-help-reduce-truck-air-pollution-ports.

[149] Port Houston, "Port Houston Awarded $25 Million Grant," January 17, 2025, https://porthouston.com/wp-content/uploads/2025/01/Port-Houston-Receives-25-Million-Grant_-Final-Jan-17-2025-1.pdf.

[150] EPA, "Request for Information – Transportation Programs," November 4, 2022, https://www.regulations.gov/document/EPA-HQ-OAR-2022-0874-0002.

[151] EPA, "Clean Ports Program: Notices of Funding Opportunities," May 23, 2024, https://www.epa.gov/ports-initiative/cleanports#notices.

[152] EPA, *Clean Ports Program 'Fast Facts'*, April 2024, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P101A2VI.pdf.

[153] EPA, "Biden-Harris Administration Announces Selections for Nearly $3 Billion of Investments in Clean Ports as Part of Investing in America Agenda," press release, October 29, 2024, https://www.epa.gov/newsreleases/biden-harris-administration-announces-selections-nearly-3-billion-investments-clean.

[154] EPA, "Clean Ports Program Selections," December 10, 2024, https://www.epa.gov/ports-initiative/clean-ports-program-selections.

[155] DOT, Maritime Administration, "Port Infrastructure Development Program," November 15, 2024, https://www.maritime.dot.gov/PIDPgrants.

[156] See P.L. 117-103, P.L. 117-328, P.L. 118-42, and *Notice of Funding Opportunity for the Maritime Administration's Port Infrastructure Development Program (PIDP) Under the Infrastructure Investment and Jobs Act ("Bipartisan Infrastructure Law") and Consolidated Appropriations Act, 2024*, March 8, 2024, https://www.maritime.dot.gov/sites/marad.dot.gov/files/2024-05/Final%20FY24%20PIDP%20Amended%20NOFO%2004252024.pdf.

Regional Clean Hydrogen Hubs

The IIJA authorized and funded an $8 billion program on Regional Clean Hydrogen Hubs (Section 40315 and Division J, Title III, of IIJA)—networks of hydrogen producers, consumers, and infrastructure in a common geography. DOE has committed up to $7 billion to seven consortiums ("selectees") and obligated a small portion of that amount.[157] DOE selected a consortium for a Demand-Side Support Initiative valued at up to $1 billion as part of the program.[158]

Two of the hubs—the California Hydrogen Hub (ARCHES) and the Pacific Northwest Hydrogen Association (PNWH2)—plan to link their activities on fuel cell trucks to develop a West Coast freight network.[159] ARCHES envisages 5,000 or more fuel cell-electric trucks, Class 6 through Class 8, and 60 HRS for MHDVs as part of the project.[160] PNWH2 envisages up to 10 HRS to be built in a node in Ferndale, WA, and additional HRS along the I-5, I-90, and I-84 corridors and in a node in Durkee, OR.[161]

Advanced Technology Vehicle Manufacturing (ATVM) Loan Program

The IIJA (§40401(b)) enlarged the scope of the Advanced Technology Vehicle Manufacturing (ATVM) Loan Program (42 U.S.C. §17013) so that the proceeds of direct loans could be used for manufacturing facilities for qualifying MHDVs.[162] The Consolidated Appropriations Act, 2023 (P.L. 117-328), Division D, Section 308, repealed the restrictions that would have otherwise prevented the use of prior appropriations for MHDVs.[163] The program assists OEs in meeting fuel economy standards and encourages domestic production of more fuel-efficient vehicles.

Domestic Manufacturing Conversion Grants

Section 50143 of the IRA created the Domestic Manufacturing Conversion Grants and appropriated $2 billion to provide grants for domestic production of FCEVs and other types of electric- and hybrid-electric-drive vehicles. DOE issued a Funding Opportunity Announcement on August 31, 2023.[164] DOE announced the awards on July 11, 2024.[165] Of the facilities that

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[157] The White House, "Biden-Harris Administration Announces $7 Billion for America's First Clean Hydrogen Hubs, Driving Clean Manufacturing and Delivering New Economic Opportunities Nationwide," press release, October 13, 2023, https://bidenwhitehouse.archives.gov/briefing-room/statements-releases/2023/10/13/biden-harris-administration-announces-regional-clean-hydrogen-hubs-to-drive-clean-manufacturing-and-jobs/. Amount of obligations was determined by CRS using data pulled from USASPENDING.gov as of March 5, 2025.

[158] DOE, OCED, "DOE Selects Consortium to Bridge Early Demand for Clean Hydrogen, Providing Market Certainty and Unlocking Private Sector Investment," press release, January 17, 2024, https://www.energy.gov/oced/articles/doe-selects-consortium-bridge-early-demand-clean-hydrogen-providing-market-certainty.

[159] DOE, OCED, *Regional Clean Hydrogen Hubs Program: California Hydrogen Hub (ARCHES)*, July 2024, p. 3.

[160] DOE, OCED, *Regional Clean Hydrogen Hubs Program: California Hydrogen Hub (ARCHES)*, July 2024, p. 2.

[161] DOE, OCED, *Regional Clean Hydrogen Hubs Program: Pacific Northwest Hydrogen Hub (PNWH2)*, pp. 4-5.

[162] Until then, the program had focused on the production of efficient passenger vehicles.

[163] The restrictions had been put in place by IIJA §40401(a)(2).

[164] DOE, Office of Manufacturing Energy and Supply Chains, *Domestic Manufacturing Conversion Grants*, https://www.energy.gov/mesc/domestic-manufacturing-conversion-grants. For due dates and requirements, see DOE, *Inflation Reduction Act (IRA) Domestic Manufacturing Conversion Grants*, DE-FOA-0003106, August 31, 2023, https://infrastructure-exchange.energy.gov/Default.aspx#FoaIdf9eb1c8a-9922-46b6-993e-78972d823cb2.

[165] DOE, "Biden-Harris Administration Announces Nearly $2 Billion to Support American Auto Workers, Convert Facilities for Electric Vehicles," press release, July 11, 2024, https://www.energy.gov/mesc/domestic-manufacturing-conversion-grant-program.

received the grants, those owned by Volvo Technology of America, LLC, plan to do work on fuel cell-electric vehicles.[166]

Commercial Clean Vehicles: *Internal Revenue Code* Section 45W[167]

Section 13403 of the IRA creates a new tax credit at Section 45W of the *Internal Revenue Code* (IRC 45W) for qualified commercial clean vehicles placed in service by the taxpayer during the year. The credit is the lesser of (1) 30% of the purchase price[168] or (2) the incremental cost of the vehicle relative to a comparable conventional vehicle. Credit amounts cannot exceed $40,000 for vehicles not less than 14,000 lb., which, generally speaking, corresponds to Class 4 through Class 8 vehicles.[169] Eligible vehicles would need to operate on a fuel cell and be certified to meet or exceed certain emissions standards, be made by a qualified manufacturer (IRC §30D(d)(1)(C)),[170] and meet other requirements.

On November 2, 2022, the Department of the Treasury opened a one-month comment period on the implementation of the IRC 45W credit.[171] The IRS has since issued Notice 2023-09 that provides a safe harbor determination for the incremental costs relative to the $7,500 cap for calendar year 2023.[172] The Congressional Budget Office estimates that IRC 45W would reduce federal revenues by $3.583 billion from FY2023 through FY2031.[173]

Not included in this discussion is IRC 30D, which applies to vehicles having GVW ratings less than 14,000 lb. and has other restrictions.

Summary and Framework

This section summarizes the programs discussed above and, in **Table 2**, presents a framework for considering the impact on deployment of truck FCEVs. The table lists the programs and summarizes them according to the form of financial assistance each provides and the focus of the program. For each program, **Table 2** indicates which aspect of deployment would be affected. Generally speaking, the assignment to the categories indicates the type of business that would be the direct beneficiary of the financial assistance, but other categories might benefit indirectly. Thus, the categories are not mutually exclusive. The table shows that fleet operations may be the target of few of the studied programs.

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[166] DOE, "Biden-Harris Administration Announces Nearly $2 Billion to Support American Auto Workers, Convert Facilities for Electric Vehicles."

[167] See also CRS Report R47202, *Tax Provisions in the Inflation Reduction Act of 2022 (H.R. 5376)*, coordinated by Molly F. Sherlock.

[168] This arm of the tax credit would be 15% of the vehicle's cost if gasoline or diesel.

[169] For vehicles with GVW ratings less than 14,000 lb., the cap is $7,500.

[170] The IRS elaborated an index of qualified manufacturers. See IRS, "Qualified Manufacturers for Clean Vehicle Credits," March 21, 2025, https://www.irs.gov/credits-deductions/manufacturers-for-qualified-commercial-clean-vehicle-credit.

[171] Department of the Treasury and IRS, *Request for Comments on Section 45W Credit for Qualified Commercial Clean Vehicles*, Notice 2022-56, November 2, 2022, https://www.irs.gov/pub/irs-drop/n-22-56.pdf; Department of the Treasury and IRS, "IRS Seeks Comments on Upcoming Energy Guidance," news release, November 3, 2022, https://www.irs.gov/newsroom/irs-seeks-comments-on-upcoming-energy-guidance.

[172] IRS, "Treasury, IRS Issue Guidance on the Incremental Cost for the Commercial Clean Vehicle Credit," news release, December 5, 2023, https://www.irs.gov/newsroom/treasury-irs-issue-guidance-on-the-incremental-cost-for-the-commercial-clean-vehicle-credit.

[173] Congressional Budget Office, *Estimated Budgetary Effects of H.R. 5376, the Inflation Reduction Act of 2022*, August 5, 2022, p. 11, https://www.cbo.gov/publication/58366.

Table 2. Framework for Analysis of Programs That Could Apply to Hydrogen Truck Deployment

(covers the types of deployment activities discussed in the report)

Name and Authorization	Form of Assistance	Purpose and Activities	Fueling Infrastructure	Vehicle Mfg.	Vehicle Purchase	Operations: Ports	Operations: Fleets[a]
Charging and Fueling Infrastructure; IIJA §11401; FAST Act	Grants[b]	CFI along alternative fuel corridors[c]	X				X
Alt. Fuel Refueling Property Credit; IRA §13404	Tax credit (IRC §30C)	30% cost of CFI up to $100K	X				
Clean Heavy-Duty Vehicles; IRA §60101	Grants	Buy down incremental cost of ZEVs; CFI	X		X		
Truck Emissions at Port Facilities; IIJA §11402	Grants[d]	Truck emissions at port facilities	X			X	
Clean Ports Program; IRA §60102	Grants	CFI; cargo handling and drayage	X			X	
Port Infrastructure Development; NDAA 2010[e]	Grants	Cargo handling and drayage vehicles			X	X	
Regional Clean Hydrogen Hubs; IIJA §40314	Cooperative agreements	Regional Clean Hydrogen Hubs	X		X	X	X
ATVM Loan Program; IIJA §40401(b); EISA	Direct loans	For facilities to manufacture MHDVs		X			
Domestic Mfg. Conversion Grants; IRA §50143	Grants	For conversion of facilities to make ZEVs		X			
Commercial Clean Vehicles; IRA §13403	Tax credit (IRC §45W)	Vehicle purchase credit up to $40K if ≥14,000 lb. GVW rating[f]			X		

Source: CRS analysis.

Notes: Alt. = alternative; ATVM = Advanced Technology Vehicle Manufacturing (42 U.S.C. §17013); CFI = charging and fueling infrastructure; grant programs can include both electric vehicle and hydrogen infrastructure; EISA = Energy Independence and Security Act of 2007, P.L. 110-140; FAST Act = Fixing America's Surface Transportation Act, P.L. 114-94; GVW = gross vehicle weight; IIJA = Infrastructure Investment and Jobs Act, P.L. 117-58; IRA = P.L. 117-169, known as the Inflation Reduction Act of 2022; IRC = *Internal Revenue Code*, Title 26 U.S.C.; Mfg. = manufacturing; MHDV = medium- and heavy-duty vehicles (≥10,000 lb. GVW rating); NDAA 2010 = National Defense Authorization Act for Fiscal Year 2010, P.L. 111-84; ZEVs = zero-emission vehicles, that is, vehicles that do not directly create criteria pollutants or greenhouse gases.

a. Includes regional- and long-haul fleets. See description in the section "Operations."

b. Authorized to be appropriated from the Highway Trust Fund per IIJA §11101(b)(1)(C). For further information on spending from the Highway Trust Fund, see CRS Report R47022, *Federal Highway Programs: In Brief*, by Robert S. Kirk, and CRS Report R46938, *Federal Excise Taxes: Background and General Analysis*, by Anthony A. Cilluffo.

c. The FAST Act authorized "national alternative fueling corridors" (23 U.S.C. §151). The Federal Highway Administration refers to these as "alternative fuel corridors."

d. Authorized to be appropriated from the Highway Trust Fund per IIJA §11101(b)(1)(F).

e. Port Infrastructure Development Program, 46 U.S.C. §54301, first authorized in P.L. 111-84. Appropriation per Division J of the IIJA and in annual appropriations: P.L. 117-103, P.L. 117-328, and P.L. 118-42.

f. IRC §45W also applies to vehicles <14,000 lb. GVW rating, which are not within the scope of this report and which have a lower cap.

California Programs on Truck Portfolios and Fleets

As noted above, in the section "Status of Hydrogen and MHDVs," almost all public-facing hydrogen refueling infrastructure is located in California. California has issued regulations that apply to ZEVs generally and would affect fuel cell-electric MHDVs and also battery-electric MHDVs.

Advanced Clean Fleets Regulation

In April 2023, the California Air Resources Board (CARB) adopted the Advanced Clean Fleets Regulation to require certain fleet owners to purchase ZEVs.[174] CARB applied for a waiver of the Clean Air Act's prohibition against states setting vehicle and engine emissions standards on July 12, 2024.[175] CARB withdrew the request on January 13, 2025.[176] If it had been granted a waiver, the regulation would have applied to vehicles with GVW ratings from 8,501 lb. up to 80,000 lb.[177] Any new acquisitions by fleets of such vehicles would have been required to follow a portfolio standard that gradually phased out conventional powertrains.[178]

Advanced Clean Trucks Regulation

California's Advanced Clean Trucks Regulation moved forward after April 2023, when EPA issued a waiver of the Clean Air Act's prohibition against states setting vehicle and engine emissions standards.[179] The Advanced Clean Trucks Regulation requires manufacturers of vehicles that are based on combustion engines to sell a percentage of zero-emission MHDVs and Class 2b vehicles (i.e., vehicles with GVW ratings just below that of MHDVs).[180] This requirement applies to manufacturers who certify they are compliant with regulations on tailpipe emissions from chassis cab[181] or complete MHDVs. The percentage of California sales required of these manufacturers will increase over time depending on the type and class of truck.

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[174] Eric Miller, "California OKs Advanced Clean Fleets Regulation: Truckers Criticize Rule as Unworkable," *Transport Topics*, April 28, 2023, https://www.ttnews.com/articles/california-clean-fleets-rule.

[175] 89 *Federal Register* 57151 (July 12, 2024).

[176] Letter from Steven S. Cliff, Executive Officer, CARB, to Jane Nishida, Acting Administrator, U.S. EPA, January 13, 2025, https://www.epa.gov/system/files/documents/2025-01/ca-acf-carb-withdrawal-ltr-2025-1-13.pdf.

[177] CARB, *Advanced Clean Fleets Regulation Summary*, May 17, 2023, https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-overview.

[178] CARB, *Advanced Clean Fleets Regulation Summary*.

[179] EPA, "California State Motor Vehicle and Engine Pollution Control Standards; Heavy-Duty Vehicle and Engine Emission Warranty and Maintenance Provisions; Advanced Clean Trucks; Zero Emission Airport Shuttle; Zero-Emission Power Train Certification; Waiver of Preemption; Notice of Decision," 88 *Federal Register* 20688 (April 6, 2023). Generally speaking, states are prohibited from adopting or enforcing standards for emissions from new motor vehicles and vehicle engines (42 U.S.C. §7534(a)). Certain states may, subject to a waiver by the Administrator of EPA, set their own standards if the state determines such standards to be at least as protective of public health and welfare as federal standards (42 U.S.C. §7543(b)). The Administrator may waive the prohibition only if the states had issued standards prior to March 30, 1966. Other states may nonetheless issue standards identical to California's (42 U.S.C. §7507).

[180] CARB, *Advanced Clean Trucks Fact Sheet: Accelerating Zero-Emission Truck Markets*, August 20, 2021, https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet.

[181] A chassis cab is a truck without a complete body that may be upfit to a variety of commercial configurations. See, for example, Ford Motor Company, "2022 Ford Super Duty® Chassis Cab," 2023, https://www.ford.com/commercial-trucks/chassis-cab/, accessed January 10, 2023.

Legislation Introduced in the 118th Congress

A number of bills introduced in the 118th Congress would have addressed the use of fuel cell-electric MHDVs.

The Hydrogen for Ports Act of 2023, S. 647, would have authorized a grant program for, among other purposes, "the purchase, installation, planning, design, or construction of, as appropriate ... fuel cell drayage or long-haul trucks that—(i) use an eligible fuel; and (ii) are for use at ports." S. 647 was referred to the Committee on Commerce, Science, and Transportation. In the House, H.R. 6872 had a similar provision as in S. 647 to provide grants for "fuel cell trucks." H.R. 6872 was referred to the Committee on Energy and Commerce and the Committee on Transportation and Infrastructure.

The Hydrogen for Trucks Act of 2023, S. 648, would have established a demonstration program that included elements aimed toward parallel market adoption of refueling infrastructure and the vehicles themselves. S. 648 was referred to the Committee on Commerce, Science, and Transportation. In the House, H.R. 6871, the Hydrogen for Trucks Act, was referred to the House Committee on Science, Space, and Technology. Both S. 648 and H.R. 6871 had a provision for grants to assist "in funding capital projects to purchase heavy-duty fuel cell vehicles and related equipment, including hydrogen fueling stations."

H.R. 3447 would have authorized "a hydrogen powered vehicle to exceed certain weight limits on the Interstate Highway System." The bill was reported by the Committee on Transportation and Infrastructure (H.Rept. 118-217) on September 26, 2023. The bill would have modified 27 U.S.C. §127, "Vehicle weight limitations-Interstate System," to raise the maximum allowable weight of fuel cell-electric trucks to be 82,000 lb., on a par with vehicles using natural gas-fueled combustion engines and battery-electric powertrain.

The Vehicle Innovation Act of 2023, H.R. 4542, would have, among other purposes, authorized a program on materials and manufacturing processes of advanced vehicle technologies. The bill included research, development, and demonstration on advanced energy technologies for MHDVs in commercial, vocational, and transit applications, specifically on fuel cells, hydrogen fueling infrastructure, and refueling equipment design and concepts. The bill further required DOE to provide financial assistance for integration of numerous vehicle technologies on medium- and heavy-duty platforms and trailers. The bill was referred to the House Committee on Science, Space, and Technology and to the House Committee on Energy and Commerce and to the latter's Subcommittee on Energy, Climate, and Grid Security. An identical bill in the Senate, S. 1099, was referred to the Committee on Energy and Natural Resources.

The Hydrogen Infrastructure Finance and Innovation Act, H.R. 7200, would have established a pilot program and provided grants or loans for a range of hydrogen transportation, storage, and delivery activities, including refueling. The act would have also expanded the scope of the Title XVII loan guarantees authorized by the Energy Policy Act of 2005 so that the eligible categories included not just hydrogen fuel but also hydrogen technologies in the transportation sector.[182] The bill was referred to the Committee on Energy and Commerce, the Committee on Transportation and Infrastructure, and the Committee on Science, Space, and Technology.[183] An identical bill in the Senate, S. 649, was referred to the Committee on Energy and Natural Resources.

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[182] For further information on the loan program, see CRS Insight IN11432, *Department of Energy Loan Programs: Title XVII Innovative Technology Loan Guarantees*, by Phillip Brown et al.

[183] The bill was subsequently referred to the Subcommittee on Railroads, Pipelines, and Hazardous Materials and the (continued...)

Summary and Framework for Consideration

This section summarizes the bills discussed above and, in **Table 3**, presents a framework for considering their impact on deployment. The table lists the bills and summarizes them according to the form of financial or other assistance each would have provided and the focus of the program. For each program, **Table 3** indicates which aspect of deployment would have been affected. Generally speaking, the assignment to the categories indicates the type of business that would have been the direct beneficiary of the financial assistance, but other categories might benefit indirectly. Thus, the categories are not mutually exclusive.

Subcommittee on Highways and Transit of the Committee on Transportation and Infrastructure and to the Subcommittee on Energy, Climate, and Grid Security of the Committee on Energy and Commerce.

Table 3. Bills in the 118th Congress That Addressed Deployment of Hydrogen MHDVs

Bill	Form of Assistance	Purpose and Activities	Fueling Infrastructure	Vehicle Mfg.	Vehicle Purchase	Operations: Ports	Operations: Fleets
Hydrogen for Ports Act of 2023, S. 647; and Hydrogen for Ports Act, H.R. 6872	Grants	Purchase of fuel cell-powered equipment and hydrogen refueling equipment			X	X	
Hydrogen for Trucks Act of 2023, S. 648; and Hydrogen for Trucks Act, H.R. 6871	Grants	Purchase of fuel cell-electric heavy trucks and related equipment, including refueling equipment	X		X		
H.R. 3447 [untitled]	Regulatory change	Add 2,000 lb. to weight limit					X
Vehicle Innovation Act of 2023, H.R. 4542; and Vehicle Innovation Act, S. 1099	Grants	Development of vehicle technologies; participants from multiple sectors; off-road equipment		X[a]			
Hydrogen Infrastructure Finance and Innovation Act, H.R. 7200; and S. 649 [identical title]	Grants and loans	Loans for purchase of hydrogen transportation and delivery infrastructure	X		X		

Source: CRS analysis of bills.

Notes: MHDVs = medium- and heavy-duty vehicles; mfg. = manufacturing; lb. = pounds.

a. The bill emphasizes research and development (i.e., predeployment).

Considerations for Congress

This section describes a number of potential issues for consideration by Congress. First is a series of options for consideration by Congress if it decides that support for the deployment of fuel cell-electric MHDVs is warranted. Principally, the policy options for Congress given below would address the infrastructure for transporting and dispensing hydrogen, vehicle manufacturing, vehicle purchase by fleets, and the final use of hydrogen for energy services in truck fleets (e.g., port operations, goods movement). Then this section describes possible oversight activities related to current hydrogen and fuel cell-electric MHDV programs.

Risks of Government Support for Hydrogen-Fueled Trucks

In providing financial assistance, government assumes the risk that it might support a failed enterprise—the failure of fuel cell-electric trucks to achieve market share. Further, even if technologically successful, the government-supported technology may be overtaken or obviated by other developments or changes in market conditions, as was the case with synthetic fuels in the 1970s and 1980s.[184] Small owner-operators who buy trucks secondhand at lower prices will likely not purchase new fuel cell-electric MHDVs at full price and thus not be a beneficiary of the government support. Critics of hydrogen also point to the availability of electric vehicles, and these two alternative powertrains (fuel cell-electric and battery-electric) will be competing for the same market in a zero-sum fashion: the more one powertrain captures the benefits, the less the other will.

Streamlining Federal Programs

In S.Rept. 118-72, which the joint explanatory statement to the Consolidated Appropriations Act, 2024 (P.L. 118-42) incorporated by reference, the Senate Appropriations Committee took note of the number of coordination mechanisms—including crosscuts and "Earthshots," such as the Hydrogen Shot program—and directed DOE to simplify and consolidate these into one function. Such consolidation could result in a harmonization of goals between hydrogen hubs and hydrogen corridors, for example. One option for congressional oversight could be to require a management study of consolidating these coordination mechanisms, either by DOE, an outside organization such as the National Academy of Public Administration following the Federal Advisory Committee Act, Section 15 (P.L. 105-153), or a similar external entity.[185]

Addressing Deployment of Fuel Cell-Electric Trucks

Fleet Operations

Prizes

Congress could offer a monetary prize to makers of medium- and heavy-duty fuel cell-electric vehicles structured around criteria on the movement of freight. Such criteria could include the range and cargo size (mass). For example, the prize might be awarded for a vehicle made in a

[184] National Research Council, *The Government Role in Civilian Technology: Building a New Alliance* (National Academy Press, 1992), p. 59.

[185] Congress gave a similar direction on p. 212 of H.Rept. 115-929, which accompanied P.L. 115-244, the Energy and Water, Legislative Branch, and Military Construction and Veterans Affairs Appropriations Act, 2019.

production run of at least 10 substantially equivalent vehicles or tractors that could haul a cargo of 30,000 lb. a certain distance without refueling.

Another possibility would be to apply the prize to a fleet of trucks; for example, the prize could be awarded to a fleet that, in the aggregate, moved a certain number of ton-miles of cargo in revenue operations using fuel cell-electric vehicles. To increase recognition, Congress could host the award of the prize as was done in 2011 for the Bright Tomorrow Lighting Prize (L-Prize).[186]

Corridors

Congress could authorize and fund a program drawn on the Highway Trust Fund for hydrogen truck corridors and require that this program harmonize with the Regional Clean Hydrogen Hubs. This program could be an extension of the Charging and Fueling Infrastructure Grant Program authorized by the IIJA (23 U.S.C. §151(f)). Through the Alternative Fuel Corridor Grants ("corridor grants"), Congress could integrate hydrogen corridors with the Regional Clean Hydrogen Hubs. In establishing program requirements, Congress could, for example, direct FHWA to require that the corridor have at least one terminus in a Regional Clean Hydrogen Hub. Congress could direct FHWA to make awards according to some of the following criteria:

- geographic diversity;
- vehicle diversity (Class 4, Class 8, and other);
- mission diversity (drayage, regional haul, long haul);
- anticipated heavy-duty vehicle traffic, commensurate with the number of refueling stations; and
- employment and service workforce (training, access).

Weight Limits

Currently, fuel cell MHDVs must comply with the same weight limits as conventional vehicles. Although Section 1410 of the FAST Act (P.L. 114-94) provided an additional 2,000 lb. of allowable weight for two types of vehicles with alternative fuels and powertrains—battery-electric and compressed natural gas-combustion vehicles—there is no current federal allowance for fuel cell-electric vehicles.[187] Congress could consider adding an additional weight allowance for fuel cell-electric MHDVs, as in H.R. 3447 (where they are termed "hydrogen fuel cell vehicles") in the 118th Congress.

The benefits for fuel cell adoption include making fuel cell-electric trucks more competitive with conventional vehicles. Especially in applications in which trucks move goods, any reduction in cargo capacity can make a vehicle less competitive. The additional 2,000 lb. would compensate for the higher tractor weight of a fuel cell-electric truck relative to a diesel. Some analysts argue that greater weight would improve fuel consumption and safety by reducing the number of overall

[186] Sen. Jeff Bingaman and Sen. Lisa Murkowski hosted the announcement of the winner of the L-Prize in 2011. Light Directory, "DOE Announces Philips as First Winner of the L Prize Competition," press release, August 2, 2011, https://m.lightdirectory.com/news-DOE-Announces-Philips-As-First-Winner-Of-The-L-Prize-Competition.htm.

[187] 23 U.S.C. §127(s).

trips.[188] Potential drawbacks include incremental damage to road surfaces incurred at higher weights.[189]

Fuel Consumption Standards

The presence of fuel cell-electric vehicles in a manufacturer's sales allows for favorable treatment in the NHTSA fuel consumption regulations. Were a manufacturer to produce sufficient numbers of such vehicles, they would have an easier time achieving compliance with NHTSA fuel consumption regulations. This creates an incentive to sell such vehicles. In the regulations, fuel cell-electric vehicles benefit from an advanced vehicle technology credit that makes each such vehicle, already highly advantageous to compliance, have the effect of 5.5 vehicles in a feature known as multipliers.[190] In effect, the advanced vehicle technology credits offset any underperforming combustion powertrain vehicles. Congress could enact the current system of credit multipliers, due to expire after model year 2027.[191]

Advantages and Disadvantages

An advantage of having the credits resulting from the credit multiplier past model year 2027 is that it would provide a continued incentive for market uptake of fuel cell-electric trucks, and it has since combined with other incentives for deployment of hydrogen trucks discussed above in "Financial Assistance Programs on Deployment of Hydrogen Trucks." At the time this system of credits was last proposed, in 2016, EPA said that "adoption rates for these advanced technologies in heavy-duty vehicles are essentially nonexistent today and seem unlikely to grow significantly within the next decade without additional incentives."[192] NHTSA deemed this a method to encourage manufacturers to "generate a viable business case" for such vehicles.[193] The CARB, commenting on NHTSA's proposed rule for MHDVs, stated that credits would help in accelerating the deployment of "zero-emission trucks."[194] More generally, stable incentives send a consistent policy signal about government expectations for innovation. The effect of incentives can include retaining knowledge essential to technology innovation and reducing the uncertainty faced by private-sector investors.[195]

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[188] J. Woodrooffe, "Opportunity Cost for Society Related to U.S. Truck Size and Weight Regulation," *Journal of the Transportation Research Board*, vol. 2547 (January 1, 2016), pp. 25-31.

[189] A 2016 report by FHWA estimates that raising the weight limit to 88,000 lb. might incur an additional 0.4% to 0.7% in pavement lifecycle costs and a one-time investment in bridges of $0.4 billion. FHWA, *Comprehensive Truck Size: Report to Congress*, April 2016, https://ops.fhwa.dot.gov/freight/sw/map21tswstudy/ctsw/CTSLWS Report to Congress FINAL.pdf.

[190] One fuel cell vehicle counts as 5.5 vehicles in the current program (49 C.F.R. 535.7(f)(1)(ii)), but the value of the multiplier effectively decreases to one after model year 2027. 81 *Federal Register* 73498 (October 25, 2016); and DOT, NHTSA, "Corporate Average Fuel Economy Standards for Passenger Cars and Light Trucks for Model Years 2027 and Beyond and Fuel Efficiency Standards for Heavy-Duty Pickup Trucks and Vans for Model Years 2030 and Beyond," 89 *Federal Register* 52924 (June 24, 2024).

[191] After 2027, the multipliers effectively revert to unity (i.e., become equal to one). 81 *Federal Register* 73498 (October 25, 2016); and EPA, "Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles—Phase 3," 88 *Federal Register* 26013 (April 27, 2023).

[192] 81 *Federal Register* 73498 (October 25, 2016).

[193] 81 *Federal Register* 73498 (October 25, 2016).

[194] Letter from Mary D. Nichols, Chair, Air Resources Board (California), to Gina McCarthy, EPA Administrator, and Mark R. Rosekind, NHTSA Administrator, October 1, 2015, p. 71, https://ww2.arb.ca.gov/sites/default/files/classic//msprog/onroad/caphase2ghg/comments/carb_phase_2_comments.pdf.

[195] M. Jaccard et al., "Policies for Energy System Transformations: Objectives and Instruments," in *Global Energy* (continued...)

A disadvantage is that increasing the number of fuel cell vehicles would allow a manufacturer's conventional vehicles to have higher fuel consumption. CARB estimated that a 3% uptake of the advanced vehicle technology credits (with multiplier) for model year 2027 and later would reduce the benefits of the regulations overall by 3% in 2050.[196]

Federal Excise Tax

Currently there is a 12% federal excise tax (FET) on the sale of trucks. Additionally, certain trucks with GVW ratings of 55,000 lb. pay an annual use tax.[197] These excise taxes are one source of support for the Highway Trust Fund, though the vast majority of support—85% to 90%—derives from motor fuel taxes.[198]

Congress could add technologies to the list of exemptions from the FET. For example, Congress could exempt the purchase of an APU operating on hydrogen from the FET. The APU appears on vehicles needing continuous refrigeration, such as on long-haul Class 8 vehicles. Congress has already exempted certain idling technologies, sometimes called "start-stop" technologies, from the FET.[199] Generally speaking, only aftermarket devices are eligible.

Another approach to modifying the excise tax might be to exclude the incremental cost of the powertrain. The incremental cost of the fuel cell powertrain would be determined relative to a vehicle with a conventional powertrain. Carrying out such an exemption would necessitate a method to calculate the incremental cost that would be exempted. As discussed above in the section "Commercial Clean Vehicles: *Internal Revenue Code* Section 45W," the IRS has such a method for calculating the incremental cost already in place.

An advantage of excluding the purchase price of the truck and aftermarket equipment from the FET is to increase adoption of fuel cell-electric MHDVs versus trucks sold with conventional powertrains.[200] A disadvantage of an exemption is that it would reduce the amount of money paid into the Highway Trust Fund, which is the source of funds used to construct highways and to build out charging and refueling infrastructure for battery-electric vehicles and fuel cell-electric vehicles.

Loan Programs

Congress could evaluate whether the scope of eligible projects under the Title XVII loan programs, authorized by Section 1703 of the Energy Policy Act of 2005 (42 U.S.C. §16513), could be expanded to include hydrogen vehicles as a category eligible to receive loan guarantees.

Assessment: Toward a Sustainable Future, ed. Thomas B. Johansson et al. (Cambridge University Press, 2012), p. 1580.

[196] Nic Lutsey, *Integrating Electric Vehicles Within U.S. and European Efficiency Regulations*, International Council on Clean Transportation, Working Paper 2017-07, June 22, 2017, p. 4, https://theicct.org/sites/default/files/publications/Integrating-EVs-US-EU_ICCT_Working-Paper_22062017_vF.pdf; and Letter from Mary D. Nichols, Chair, Air Resources Board (California), to Gina McCarthy, EPA Administrator, and Mark R. Rosekind, NHTSA Administrator, October 1, 2015, p. 71, https://ww2.arb.ca.gov/sites/default/files/classic//msprog/onroad/caphase2ghg/comments/carb_phase_2_comments.pdf.

[197] DOT, FHWA, Office of Highway Policy Information, "Heavy Vehicle Use Tax," June 23, 2020, https://www.fhwa.dot.gov/policyinformation/hvut/mod1/whatishvut.cfm.

[198] CRS Report R46938, *Federal Excise Taxes: Background and General Analysis*, by Anthony A. Cilluffo; and CRS Report R47022, *Federal Highway Programs: In Brief*, by Robert S. Kirk.

[199] The Energy Improvement and Extension Act of 2008 (P.L. 110-343, Division B), Section 206, excluded "idling reduction devices" and advanced insulation from the FET.

[200] Kevin Jones, "Can EV Enthusiasm Spark FET Repeal?" *FleetOwner*, March 10, 2023.

Currently, Title XVII applies to hydrogen fuel. In the 118th Congress, the Hydrogen Infrastructure Finance and Innovation Act, H.R. 7200 and S. 649, would have expanded the scope of the Title XVII loan guarantees to include hydrogen technologies in the transportation sector, among other end uses.[201]

Summary of Options and Framework

This section summarizes options for consideration by Congress and applies the framework given in the section "Recent Developments," above. **Table 4** summarizes the program options, including the form of assistance and a brief description. For each program, **Table 4** also indicates which aspect of deployment would be addressed.

[201] For further information on the loan program, see CRS Insight IN11432, *Department of Energy Loan Programs: Title XVII Innovative Technology Loan Guarantees*, by Phillip Brown et al.

Table 4. Options Congress Could Consider for Deployment of Fuel Cell-Electric MHDVs

(options may require new authorizing statute or amendment to existing statute)

Possible Authorization[a]	Form of Assistance	Purpose and Activities	Fueling Infrastructure	Vehicle Mfg.	Vehicle Purchase	Operations: Ports	Operations: Fleets[b]
None at present	Prize	Award to first fleet to move a specified quantity (ton-miles) of goods					X
23 U.S.C. §151	Highway Trust Fund grants	Fund operations along alternative fuel corridors					X
23 U.S.C. §127(s)	Regulatory relief	Add 2,000 lb. to weight limit (H.R. 3447, 118th Congress)					X
42 U.S.C. §32902(b)	Regulatory credits	Maintain vehicle technology credit toward fuel consumption compliance			X		
26 U.S.C. §4053	Excise tax relief	Exempt fuel cell APUs from federal excise tax			X		
Title XVII,[c] 42 U.S.C. §16513	Loan guarantees	Make FCEVs eligible (H.R. 7200, 118th Congress)			X		

Source: CRS analysis.

Notes: MHDV = medium- and heavy-duty vehicle; lb. = pounds; mfg. = manufacturing; APU = auxiliary power unit; FCEV = fuel cell-electric vehicle; ton-miles = the mathematical product of the cargo weight and the distance moved.

a. Where given, citations are broad indicators of where there is an existing authorization in a similar or adjacent program that could be amended.

b. Includes regional- and long-haul fleets. See description in the section "Operations."

c. Title XVII of the Energy Policy Act of 2005 (P.L. 109-58), 42 U.S.C. §§16511-16517.

Oversight

Congress may conduct hearings or fact-finding activities on the effectiveness and efficiency of several programs.

Success of Early Deployment

Congress may monitor the build-out of refueling infrastructure and consider whether federal financial incentives would correct any shortfalls or, conversely, if the number of FCEVs is commensurate with the number of HRS. In 2022, the California Energy Commission estimated it had built almost four times as much dispensing capacity as it needed for light-duty FCEVs in the state.[202] Congress could further consider whether the IRC 45W tax incentive is driving the purchase of too few or too many hydrogen-fueled MHDVs relative to the number of HRS. Congress could also consider the role of IRC 30C, the Alternative Fuel Refueling Property Credit, in achieving the appropriate balance between the number of vehicles and refueling capacity. Congress could also consider the number and size of hydrogen refueling infrastructure projects selected in IIJA Section 11401 grants. For example, of the $613 million of awards announced January 17, 2024, $89 million was for projects for hydrogen refueling or a combination of hydrogen refueling and electric charging for MHDVs.[203]

The Role of MHDVs in Regional Clean Hydrogen Hubs

In the IIJA, Section 40314, Congress gave several criteria for the selection of the hydrogen hubs. The end-use diversity criterion specifies at least one hub be based on the transportation sector.[204] Congressional oversight activities could examine how and to what extent DOE has awarded grant monies to any hubs that have a transportation focus or have been identified by DOE as having a transportation focus, and Congress could examine the extent to which the grant recipients are including fuel cell-electric MHDVs. The California Hydrogen Hub, being developed by ARCHES, envisages 5,000 or more fuel cell-electric trucks, Classes 6 through 8, and 60 HRS stations for MHDVs.[205]

Grants and Contracts

The agencies are implementing a number of additional spending programs related to hydrogen trucks; many of these programs have several hundred million dollars appropriated to them. Agencies have set goals for when they will open solicitations and make the awards. These include, but are not limited to, the Clean Heavy-Duty Vehicles Program ($1 billion, IRA); the Reduction of Truck Emissions at Port Facilities Grant Program ($400 million, IIJA); and the Port Infrastructure Development Program ($2.25 billion, IIJA, and over $500 million from annual

[202] J. Berner et al., *Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*, California Energy Commission, CEC-600-2022-064, December 22, 2022, p. 39, https://www.energy.ca.gov/publications/2022/joint-agency-staff-report-assembly-bill-8-2022-annual-assessment-time-and-cost.

[203] FHWA, "Biden-Harris Administration Announces $623 Million in Grants to Continue Building Out Electric Vehicle Charging Network," press release, January 11, 2024, https://highways.dot.gov/newsroom/biden-harris-administration-announces-623-million-grants-continue-building-out-electric.

[204] The end-use diversity criterion also required at least one hub to be based on each of the following: electric power generation; industrial sector; and commercial and residential heating.

[205] DOE, OCED, *Regional Clean Hydrogen Hubs Program: California Hydrogen Hub (ARCHES)*, July 2024.

appropriations from FY2022 through FY2024).[206] Congress may monitor awards, obligations, and outlays.

Author Information

Martin C. Offutt
Analyst in Energy Policy

Disclaimer

[206] Includes $234.31 million in FY2022, $212.20 million in FY2023, and $120.46 million in FY2024; $50 million of FY2024 monies may be used for discretionary grants.