Pathways to Zero-Emission Freight:

Infrastructure Needs for Regional and Long-Haul Trucking

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ACEEE

March 2026 | Research Report

About ACEEE

The **American Council for an Energy-Efficient Economy** (ACEEE), a nonprofit research organization, develops policies to reduce energy waste and combat climate change. Its independent analysis advances investments, programs, and behaviors that use energy more effectively and help build an equitable clean energy future.

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Acknowledgments

This report was made possible through the generous support of the Heising–Simons Foundation. The authors gratefully acknowledge external reviewers, internal reviewers, colleagues, and sponsors who supported this report. External expert reviewers included Bill Zobel (Pilot Travel Centers), Jessie Lund and Delaney Dixon (NASEO), and Kristi Villareal (CEC). Internal reviewers included Neal Elliot, Elizabeth Traynor, Mark Rodeffer, and Steve Nadel. Special thanks to Isabelle Winstead.

The authors also gratefully acknowledge the assistance of Michael Joseph (CALSTART); Bart Sowa (GTI Energy); Daniel O'Connor (Cummins); Hamilton Steimer, Anisha Sinha, and Yihao Xie (ICCT); Katie Lee Cox and JT Steenkamp (Prologis); Marshall Miller and Jingyuan Zhao (UC Davis); and Steve Griffith (NEMA). External review and support do not imply affiliation or endorsement. Last, we would like to thank the following members of ACEEE's editorial and communications team: Kate Doughty for assistance with publication and graphic design and Mark Rodeffer and Nick Roper for their help in launching this report.

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Executive summary

Key findings

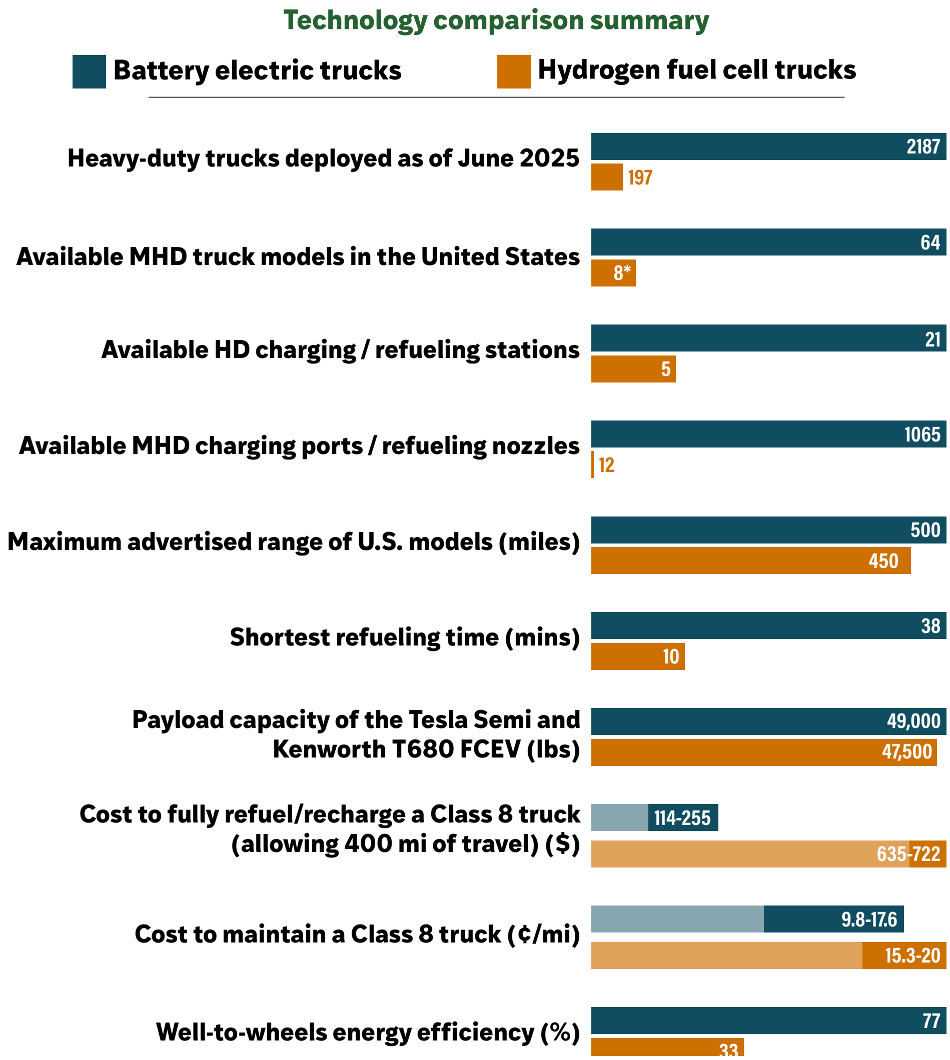
- **States must plan beyond their borders.** Zero-emission freight corridors will only work if neighboring states coordinate siting, timelines, and funding to ensure continuous, usable infrastructure and a cost-effective investment strategy.
- **Prioritizing sites and aligning with utility proactive planning now** will shorten deployment timelines, lower future infrastructure costs, and preserve flexibility as demand grows.
- **Public dollars should prioritize shared, truck-ready charging hubs.** States can maximize impact by focusing funding on shared, high throughput charging hubs that serve multiple fleets and vehicle classes and are designed for real-world freight operations.
- **Charging is the lowest-risk near-term investment; hydrogen requires caution.** Battery electric charging should form the backbone of early corridor investments. Due in part to significantly higher development costs, hydrogen infrastructure should be pursued only through phased, demand-tested approaches to avoid high-cost, underutilized assets.
- **Freight electrification should deliver visible, meaningful community benefits.** Targeting early investments in communities with the highest diesel exposure ensures that corridor development improves air quality and public health while reducing emissions.

Medium- and heavy-duty vehicles (MHDVs) are essential to the U.S. economy, delivering everything from consumer goods to raw materials and agricultural products to ports, stores, factories, and homes. MHDVs produced 23% of transportation greenhouse gas emissions in 2022, and over half of on-road nitrogen oxide and direct particulate matter 2.5 (PM2.5) emissions, despite only representing 4%–6% of the on-road fleet. Growing freight activity in the United States means that greenhouse gas emissions from MHDVs have grown 76% from 1990, more than three times the growth rate of on-road vehicle emissions overall.

In 2024, the Joint Office of Energy and Transportation, the U.S. Department of Energy, Department of Transportation, and the Environmental Protection Agency released the National Zero-Emission Freight Corridor Strategy (NZEFCS or Freight Corridor Strategy) to “catalyze public and private investment; and support utility and regulatory planning and action at local, state, and regional levels.” The Freight Corridor Strategy took a technology-neutral approach by considering both battery electric and hydrogen fuel cell electric MHDVs. Through a four-phased framework, the Freight Corridor Strategy identified priority hubs and corridors of a nationwide zero-emission freight network with consideration for freight volumes, communities disproportionately impacted by poor air quality, supportive state policies, and other factors. The defined network was then used to help inform the investment decisions of key federal funding streams including the Clean Port Program, Charging and Fueling Infrastructure Funds, and Clean Heavy-Duty Vehicles grant program.

The absence of follow-on federal guidance, as well as policy and funding reversals, have shifted responsibility for implementation of zero-emission freight corridors to states willing to take the lead as well as corridor coalitions, utilities, and the private sector. This report builds on the NZEFCS by assessing the future needs of a key subsegment of MHDVs that require greater coordination between states: regional and long-haul trucks operating daily trips of 200 miles or more. Longer distance trips are more likely to be affected by fragmented or patchwork investments across key corridors and require advance planning.

To avoid fragmentation, the key challenge in building out a nationwide zero-emission freight network is to determine how best to sequence investments to balance near-term benefits, cost, and risk. Comparing battery electric trucks and hydrogen fuel cell trucks reflects the current state of commercially available zero-emission trucking options, while acknowledging that technologies will continue to evolve.



*Only two fuel cell truck models are commercially available.

Figure ES1. Market and technology comparison of battery electric and fuel cell trucks. *Sources*: Richard et al. 2026; CALSTART 2025, 2026; Alternative Fuels Data Center n.d.; Tesla n.d.; Hyundai n.d.; Windrose n.d.; Brasher 2024; Daimler Truck 2023; Konstantinou et al. 2025; Basma et al. 2023; Bennett et al. 2022; Hunter et al. 2021; Unterlohner and Earl 2020; Tsakiris 2019.

In addition to providing a summary of the operating conditions and state of technology for battery electric trucks and hydrogen fuel cell trucks, ACEEE also estimates the cost to build out a nationwide public and semi-public refueling network for hydrogen fuel cell and electric trucks along major freight corridors. The six scenarios included in the analysis were developed to examine the cost implications of policy choices around ZEV infrastructure even with some uncertainty about how these technologies will evolve, adoption timelines, and to precisely what extent each technology will depend on public versus private refueling infrastructure. In all examined scenarios, we assume that by 2040, 95% of Classes 4–8 trucks sales are ZEVs. With our applied fleet turnover assumptions, this equates to 35% of on-road trucks in 2040 being ZEVs. For more detail on our approach and methodology, see Appendix A.

Scenario 1: Battery electric vehicle (BEV) (baseline public charging)

Assumes 100% of ZEVs are battery electric trucks across all weight classes with a lower share of charging occurring at public or semi-public stations: 20% of energy demand for Classes 4–6 trucks and 60% for Classes 7–8 trucks.

Scenario 2: BEV, public charging+

Assumes 100% of ZEVs are battery electric trucks, with a higher share of charging occurring at public or semi-public stations: 30% of energy for Classes 4–6 trucks and 80% for Classes 7–8 trucks. This scenario reflects greater reliance on public and semi-public charging infrastructure.

Scenario 3: BEV, public charging++ (test case)

Assumes 100% of ZEVs are battery electric trucks across all classes and 100% of charging occurring at public or semi-public stations. This scenario provides an upper-bound estimate of public infrastructure needs and costs and is used to assess maximum cost exposure.

Scenario 4: Mixed (baseline public charging)

Introduces limited fuel cell adoption in heavy-duty applications, with 20% of Classes 7–8 ZEV trucks using hydrogen fuel cells and all other ZEV trucks battery electric. Public charging shares for electric trucks are the same as in scenario 1, isolating the effect of technology mix.

Scenario 5: Mixed, public charging+

Combines limited fuel cell adoption in Classes 7–8 ZEV trucks (20%) with higher public charging reliance for electric trucks, matching the assumptions in scenario 2.

Scenario 6: Mixed technologies, extended hydrogen station spacing (test case)

Follows the assumptions of scenario 5 but alters the minimum spacing requirement for hydrogen refueling stations so that it is at a constant 200 miles for the entire period of analysis. This scenario provides a lower-bound estimate of infrastructure needs and costs for hydrogen refueling infrastructure.

Building out a public refueling network for battery electric and fuel cell electric trucks requires substantial investment, but the costs of station development associated with each fuel type differ markedly. The costs to build sufficient hydrogen refueling stations are considerably higher than the cost to build sufficient charging stations. As a result, scenarios with both technologies considered in the fleet mix (scenarios 4–6) have the highest overall system costs.

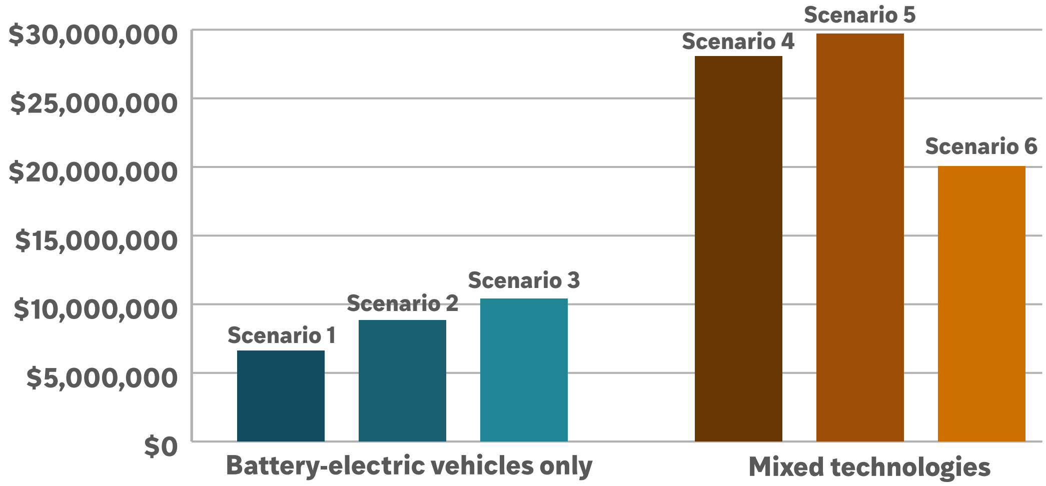


Figure ES2. Total station investment cost, 2025–2040 ($000). ***Source*: ACEEE.**

Zero-emission freight corridors will only succeed if states plan and invest beyond their own borders. Coordinated action on station siting, deployment timelines, and funding strategies is essential to create continuous, usable networks and avoid fragmented, high-cost infrastructure. As battery electric truck technology continues to improve, including the recent introduction of longer-range semi models entering the market, poor coordination and delayed infrastructure deployment risk becoming a binding constraint on adoption. Early preparation of ZEV-ready sites and alignment with utility proactive planning can significantly shorten deployment timelines, reduce future upgrade costs, and preserve flexibility as freight demand grows.

In the near term, battery electric charging represents the lowest-risk and most mature investment pathway and should form the backbone of early corridor development. Charging technology is commercially proven and aligns with existing grid planning processes. In contrast, hydrogen refueling technology remains less developed, significantly more expensive, and dependent on uncertain fuel supply and demand dynamics. It is unclear whether hydrogen infrastructure will advance quickly enough to match the pace and reliability of battery electric systems. As a result, hydrogen investments should proceed cautiously through phased, demand-tested approaches to avoid stranded, underutilized assets.

Introduction and context

Medium- and heavy-duty vehicles (MHDVs), including the trucks used to move products locally, regionally, and across the nation, produced 23% of transportation greenhouse gas (GHG) emissions in 2022—the second largest source behind light-duty vehicles, responsible for 57% of transportation GHG emissions. Between 1990 and 2022, GHG emissions from medium- and heavy-duty vehicles have increased by 76% while emissions from all on-road vehicles increased by 23% (EPA 2024). In addition to the rise in GHG emissions, the concentrated nature of freight activity means that MHDVs also produce air pollution, including nitrogen oxides and fine particles, that harms health in areas of heavy truck traffic.

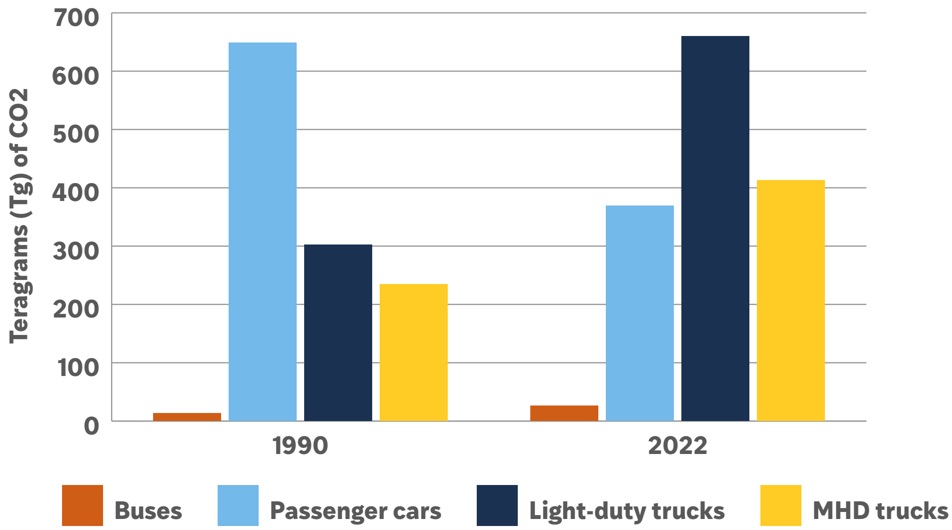


Figure 1. Teragrams (Tg) of CO_2 equivalent in 1990 and 2022 from buses, passenger cars, light-duty trucks, and medium- and heavy-duty trucks. *Source*: EPA 2024.

To support national goals around transportation decarbonization, the Joint Office of Energy and Transportation released the National Zero-Emission Freight Corridor Strategy (NZEFCS) in 2024. The NZEFCS serves to guide the deployment of zero-emission truck infrastructure (particularly electric charging and hydrogen refueling stations) by public entities and private sector stakeholders between 2024 and 2040. The document takes a phased approach, with phase one focused on establishing priority freight hubs around major ports, intermodal facilities, and other areas with high volumes of truck traffic to serve local and regional shipping. Segments of the National Highway Freight Network that lie within these hubs are also established as zero-emission freight corridors. Phase two focuses on establishing corridors to connect the hubs, including key east–west connectors I-10 and I-80, and in phase three, more hubs and more corridors between hubs are established. Finally, phase four covers 94% of the National Highway Freight Network (Chu et al. 2024). In each phase, between 40% and 47% of the benefits derived from prioritizing infrastructure investment in the selected areas are expected to go to disadvantaged communities.

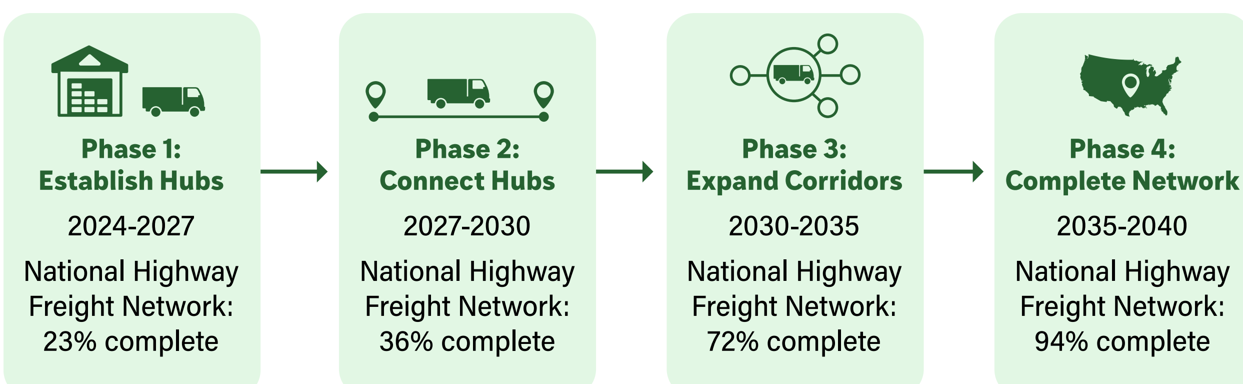


Figure 2. The phases of the NZEFCS. *Source*: Chu et al. 2024.

The NZEFCS took a technology-neutral approach by not assigning a specific type of infrastructure (electric charging or hydrogen refueling) to prioritize for specific freight facilities, hubs, or corridors. Rather, the focus of the document was to consider first the key locations for infrastructure investment and leave technology decisions up to individual states, fleet owners, and facilities. While the NZEFCS intended to catalyze investment and innovation around zero-emission freight vehicles, it was meant to adapt and shift to market needs over time.

Though the implementation schedule of the NZEFCS remains uncertain in the face of rollbacks of federal funding and a lack of planned follow-on documentation, the strategy remains a useful guidance document to help ensure alignment across governments, industry, utilities, and communities as investment into zero-emission freight vehicles is made over time.

This paper seeks to offer guidance to decision makers on the state of technology for both battery electric trucks and hydrogen fuel cell trucks; provide insights into the energy demand, station demand, and associated costs of building out a network for a range of adoption scenarios; and provide recommendations on next steps.

Intended outcomes

The analysis included in this report intends to build off the guidance provided in the NZEFCS to help state and local energy and transportation stakeholders keep long range, coordinated planning of a sustainable, efficient freight system in sight. This report aims to estimate the capital costs of deploying infrastructure to serve both battery electric trucks and fuel cell electric trucks at the corridor, state, and national level; discuss the implications of a technology-neutral approach; and offer recommendations for federal, state, and regional agencies and coalitions.

In particular, the analysis here offers a nationwide assessment of what a technology-neutral approach could cost. At a state or regional level, planning for and investing in both battery electric trucks and fuel cell electric trucks creates several risks around fragmentation, inefficient spending, and operational issues for regional and long-haul truck trips. Without federal guidance and with more decision-making power left to states and key corridors, the lack of a clear path forward could result in a patchwork, underbuilt, and uncoordinated system in which some corridors, warehouses, ports, and other freight facilities in a state invest primarily in electric charging infrastructure, while others invest primarily in hydrogen refueling infrastructure or a combination of the two.

The infrastructure to support a robust and thriving freight network is not built overnight. In the absence of strong federal leadership, the responsibility of deploying and enabling zero-emission freight infrastructure has shifted to states, corridor coalitions, utilities and utility regulations, and private sector partners. Supporting freight decarbonization requires a 10- to 20-year planning horizon. Multimegawatt sites can require extensive distribution upgrades, utilities plan investments in 10–20-year integrated resource and distribution planning cycles, and hydrogen supply chains are nascent and require multiyear planning and permitting. Without a coordinated approach across all stakeholders, we risk delaying infrastructure deployment or overspending public dollars. Failing to transition truck fleets also means delaying the health benefits that come from improved air quality, particularly for those currently exposed to high levels of pollution from MHDVs.

Recent policy framework

Although the freight corridor strategy was a significant federal effort, a shift in federal priorities, legislation, and regulation, including a rescission of the 2009 Greenhouse Gas Endangerment Finding in February 2026, suggest that further guidance on implementation is not forthcoming. Changes in federal policy have led to changes in adoption projections and will likely delay transition timelines. The International Energy Agency (IEA) reduced the projected share of electric MHD truck sales in the United States in 2030 from 20% to 8% (IEA 2025). One major tool for accelerating the adoption of zero-emission trucks at the state level is the Advanced Clean Trucks rule, which requires manufacturers to sell an increasing percentage of zero-emission trucks over time.[1] As of April 2025, 11 states had adopted the Advanced Clean Trucks regulation. However, the federal government passed legislation in May 2025 that effectively denied the ability of these states to implement Advanced Clean Trucks (Kingston 2025). Public Law 119-21, enacted July 2025, also cancelled the Qualified Commercial Clean Vehicle Credit, which provided up to $40,000 in tax credits for battery electric and fuel cell trucks (Dayton 2025).

On the hydrogen side, the Infrastructure Investment and Jobs Act (IIJA), passed in 2021, allocated $8 billion toward the development of regional hydrogen hubs intended to catalyze clean hydrogen production and reduce the cost of clean hydrogen. The U.S. Department of Energy (DOE) also released a report, "Pathways to Commercial Liftoff: Hydrogen," which identified investment in hydrogen hubs as one of the keys to the near-term growth of clean hydrogen, estimating $85 to $215 billion in cumulative investment by 2030 and between $800 to $1,100 billion in cumulative investment by 2050 in addition to the $16 billion in funds for hydrogen hubs earmarked from IIJA (Murdoch et al. 2023). However, in October 2025, two of the seven regional hydrogen hubs had funding revoked: The federal government cancelled $1.2 billion in funding for the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES), a hub in California focused on producing clean hydrogen (ARCHES 2025) and $1 billion was also pulled from the Pacific Northwest Hydrogen Hub, another funder of clean hydrogen projects (Hedreen 2025).

Through federal uncertainty, state-level initiatives to advance zero-emission trucking continue. California is proactively planning and investing in electric charging and hydrogen refueling networks for MHDVs. The SB 671 Clean Freight Corridor Efficiency Assessment, published in December 2023, developed investment strategies for an initial viable network for both battery electric and fuel cell trucks (California Transportation Commission 2023). Two separate strategies are developed and updated to address infrastructure needs highlighted in this assessment. The California Energy Commission's (CEC) Senate Bill 643 Report is focused on hydrogen infrastructure, while CEC's Assembly Bill 2127 Report focuses on charging infrastructure (Villareal 2024; Nicholas et al. 2024). Along the I-95 corridor, the Clean Corridor Coalition, a coalition of the states—Maryland, New Jersey, Delaware, and Connecticut—are collaborating on developing a series of charging hubs along a key corridor (New Jersey Department of Environmental Protection n.d.). Colorado completed a study of MHDV charging infrastructure needs and incentive design strategies in 2023.

[1] Section 177 of the Clean Air Act allows other states to adopt California's vehicle standards such as Advanced Clean Trucks (Slowik 2023).

Initiatives begun during the prior administration continue to bear fruit. The $4.2 billion in funding from the National Electric Vehicle Infrastructure (NEVI) Formula Program continues to be disbursed at the state level, although this is a reduction from the original $5 billion for this five-year program initiated under the IIJA (NACTO 2026). A series of seven corridor studies commissioned by DOE's Vehicle Technology Office includes a look at both sets of technologies. The Northeast Freight Corridor Charging Plan, led by National Grid and focused on charging infrastructure, is among the first of this series to be released (Fagan et al. 2025). For the most part, these corridor studies take different approaches in defining state needs for a select number of corridors for either charging or hydrogen refueling infrastructure instead of assessing needs in tandem, though whether and when the entire set of seven studies will be released remains uncertain.

Trucking operations and state of technology

MHDVs have a large impact on air quality, with heavy-duty vehicles contributing 45% of on-road nitrogen oxide emissions and 57% of on-road, direct PM2.5 emissions (Nadel 2023). Emissions from MHDVs are responsible for approximately 7,700–8,600 deaths in the United States each year (McNeil et al. 2025), and they disproportionately affect communities of color and low-income communities (Demetillo et al. 2021).

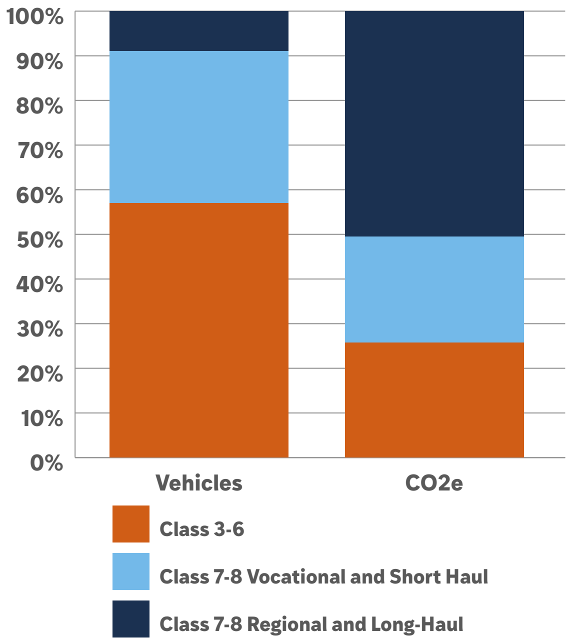


Figure 3. Proportion of MHDVs and greenhouse gas emissions by vehicle class in 2019. *Source*: Ledna et al. 2024.

This report focuses on regional and long-haul trucking, which we define as trips longer than 200 miles. Regional and long-haul trucks constitute only 9% of all MHDVs in the United States, not including buses. However, these trucks account for a disproportionately large share of GHG emissions (51%) from MHDVs (Ledna et al. 2024). Regional and long-haul truck trips represent nearly 16% of all MHDV vehicle miles traveled. These trips are the most likely to rely on en-route charging and refueling along key freight corridors as opposed to overnight charging at depots.

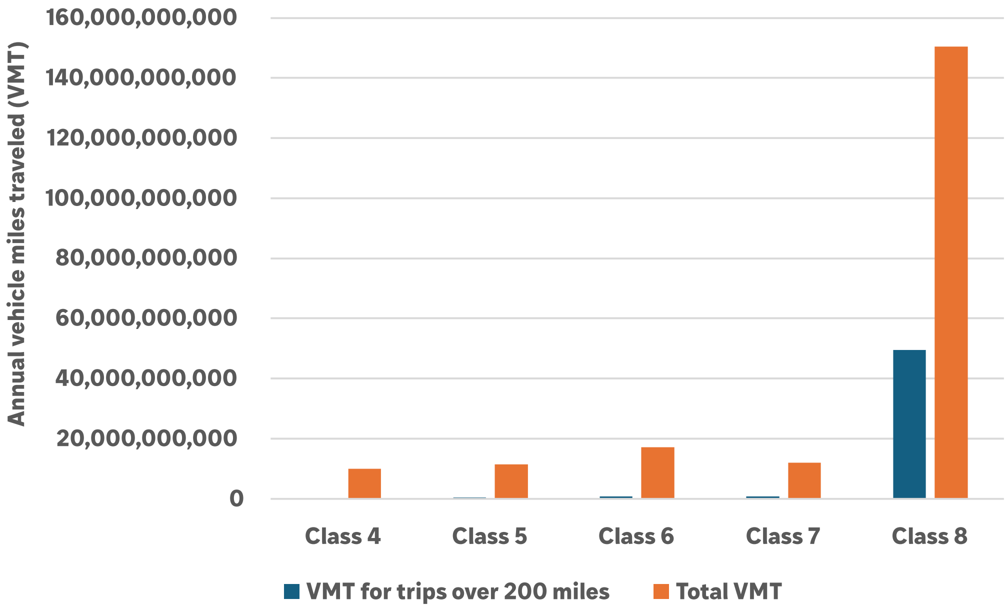


Figure 4. Annual vehicle miles traveled by vehicle class for all trips and for trips over 200 miles.
***Source*: Bureau of Transportation Statistics 2025.**

Technology background

Like battery electric cars, battery electric trucks are recharged using a charger that can range in power from very low (20 kW) to very high (1+ MW) (Yang et al. 2025). Fuel cell trucks also use an electric motor and have batteries. However, rather than pulling electricity primarily from the battery, fuel cell trucks use liquid or gaseous hydrogen fuel to produce electricity that powers the motor and keeps the smaller on-board battery charged. Like diesel and gasoline trucks, fuel cell trucks have storage tanks that get refueled, but refueling typically takes longer (around 12–20 minutes to refill a 70 kg hydrogen storage tank, depending on the hydrogen's form) than it does for diesel trucks (approximately 10 minutes) (Brasher 2024; Nikola 2022; California Fuel Cell Partnership 2019). Trucks with hydrogen internal combustion engines , which operate similarly to gasoline and diesel internal combustion engines but are less efficient than fuel cell trucks, have also recently entered the market in Europe with MAN's hTGX (Fuel Cell Works 2026). According to the U.S. Environmental Protection Agency's (EPA) 2024 Phase 3 GHG Standards for Heavy-Duty Vehicles, fuel cell trucks have a "tank to wheels" efficiency (i.e., only considering energy losses once the fuel is inside the truck) of 50%–55%, compared to 40%–45% for hydrogen internal combustion engines (Wang and Fulton 2024). The latter also produces nitrogen oxides (NOx) tailpipe emissions (DOE n.d.-a); therefore, the scope of this paper focuses on battery electric trucks and fuel cell trucks.

While both battery electric trucks and fuel cell trucks produce zero tailpipe emissions, they do have associated upstream emissions. In the case of battery electric trucks, the extent of upstream emissions depends on the sources of energy production of the utility that provided the electricity. In the United States, roughly 40% of electricity is generated from non-fossil fuel sources, including nuclear, solar, wind, hydropower, and other low- or zero-carbon sources, but this proportion varies by utility and has been increasing over time (EIA 2024). For example, in 2024, 58% of NorthWestern Energy's electricity was generated from non-fossil fuel sources, while only 33% of Southern Company's electricity was generated from non-fossil fuel sources (NorthWestern Energy n.d.; Southern Company 2025). Therefore, trucks recharging at a site powered by NorthWestern Energy will have lower upstream greenhouse gas emissions than those charging at a site powered by Southern Company.

In the case of fuel cell trucks, pure hydrogen can be made through a variety of methods. "Clean" hydrogen, which is defined by DOE as hydrogen in which less than or equal to 4 kg of CO_2 equivalent is produced per kilogram of hydrogen produced on a life-cycle basis, can be made through electrolysis using non-fossil fuel electricity, from fossil fuels (through steam methane reforming, autothermal reforming, or methane pyrolysis) paired with carbon capture and storage, and from biomass and waste feedstocks (DOE 2023). However, 95% of hydrogen produced in the United States today is made through steam methane reforming without carbon capture and storage (DOE n.d.-c). Hydrogen production results in approximately 100 million metric tons of CO_2 equivalent every year (DOE 2023). Additionally, while hydrogen itself is not a GHG, hydrogen leaked into the atmosphere can have an indirect effect on climate change by extending the lifespan of methane, a GHG, in the atmosphere. For hydrogen produced through natural gas reforming, hydrogen leakage rates would need to be less than 4.5% (assuming a 0.5% methane leak rate, as some methane typically escapes during the hydrogen production process), or else the prolonging impact on methane would offset the benefits of switching to hydrogen (Bertagni et al. 2022).

Market readiness and performance capabilities

Battery electric trucks and fuel cell trucks are still very new to the U.S. market, accounting for 0.18% of new medium-duty truck registrations and 0.40% of new heavy-duty truck registrations in 2024 (Fadhil and Xie 2025). The battery electric truck market in the United States is significantly more mature than the fuel cell truck market; 2,187 heavy-duty battery electric trucks and 197 fuel cell trucks have been deployed as of June 2025 (Richard et al. 2026). According to data from the Zero-Emission Technology Inventory (ZETI), 64 battery electric MHD truck models are available in the United States for model year 2026, compared to eight hydrogen fuel cell MHD truck models, two of which are broadly commercially available (CALSTART 2025).

Other countries are further ahead in transitioning their truck fleets to zero-emission vehicles. In 2024, roughly 81% of battery electric truck sales occurred in China, and 13% occurred in Europe. Only 2% were sold in the United States (IEA 2025). For fuel cell trucks, 95% of the global stock operates in China as of June 2024, with 1.4% operating in the United States (IEA 2024). In terms of market share, the percentage of medium- and heavy-duty trucks sold in Europe that were electric was 11 times greater (2.2%) than in the United States (0.2%) in 2024. In China, this share was 4.4% (IEA 2025).

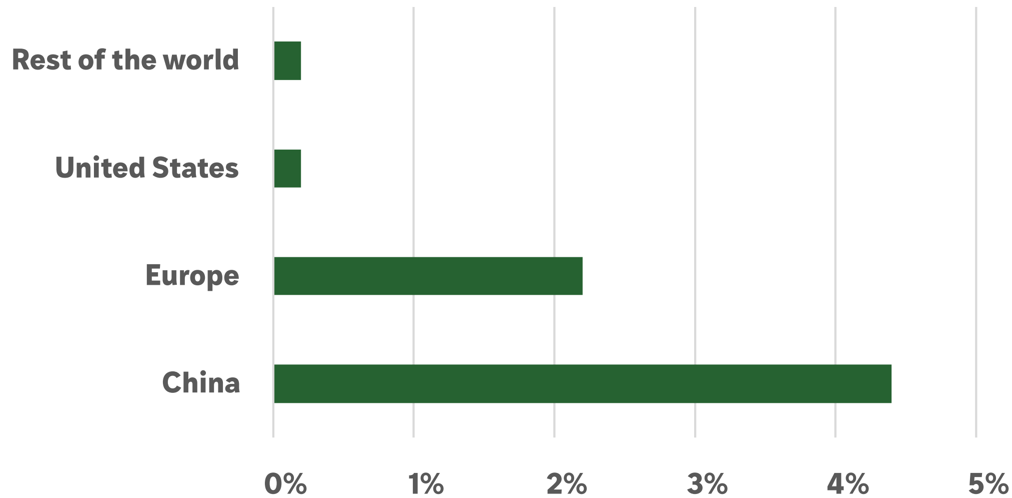


Figure 5. Percentage of electric truck sales by region/country in 2024. *Source:* IEA 2025.

In terms of infrastructure, there are 21 charging stations in the United States that can accommodate heavy-duty trucks. According to CALSTART and DOE's Alternative Fuels Data Center, 167 stations with a combined 1065 charging ports that can provide 150 kW or more of power can accommodate MHDVs (CALSTART 2026, Alternative Fuels Data Center n.d.). An additional 100 stations for heavy-duty trucks are being planned, including 64 Tesla "megacharger" stations (CALSTART 2026; Traugott 2026). For hydrogen refueling infrastructure, there are five hydrogen refueling stations for heavy-duty fuel cell trucks with 12 refueling nozzles. An additional three refueling stations for heavy-duty trucks are being planned (CALSTART 2026, Alternative Fuels Data Center n.d.).

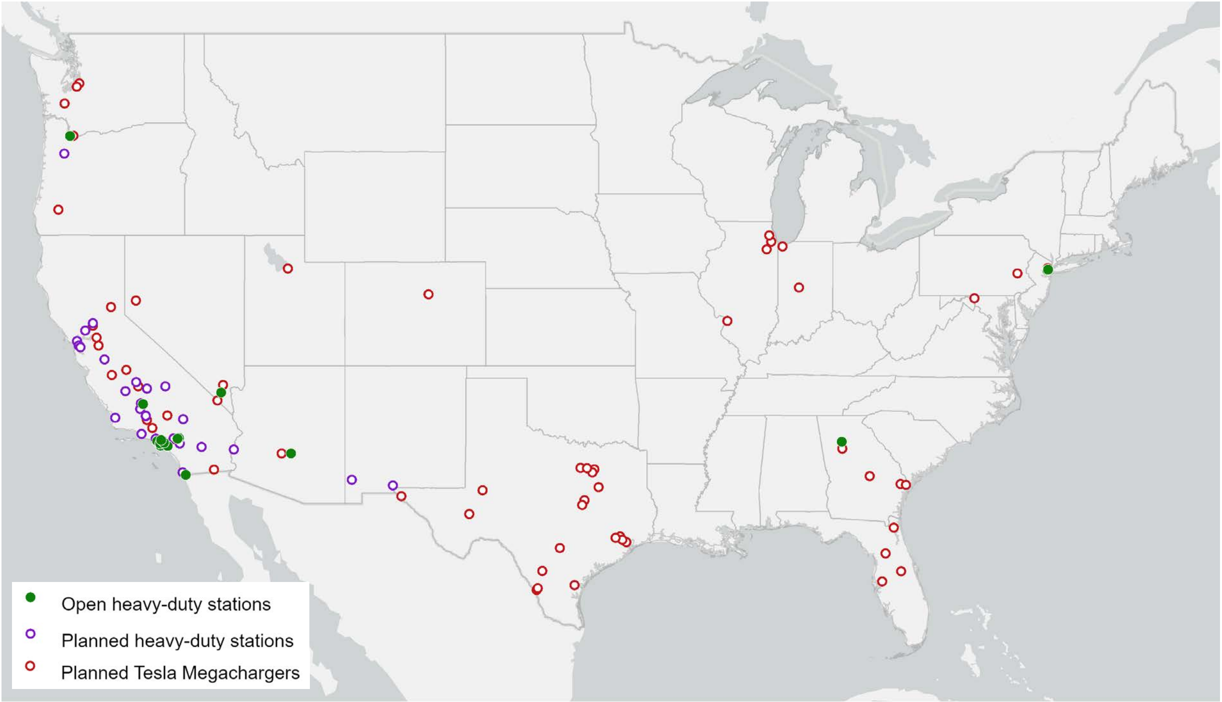


Figure 6. Map of battery electric heavy-duty truck charging stations. ***Sources*****: CALSTART 2026; Alternative Fuels Data Center n.d.; Tesla 2026.**

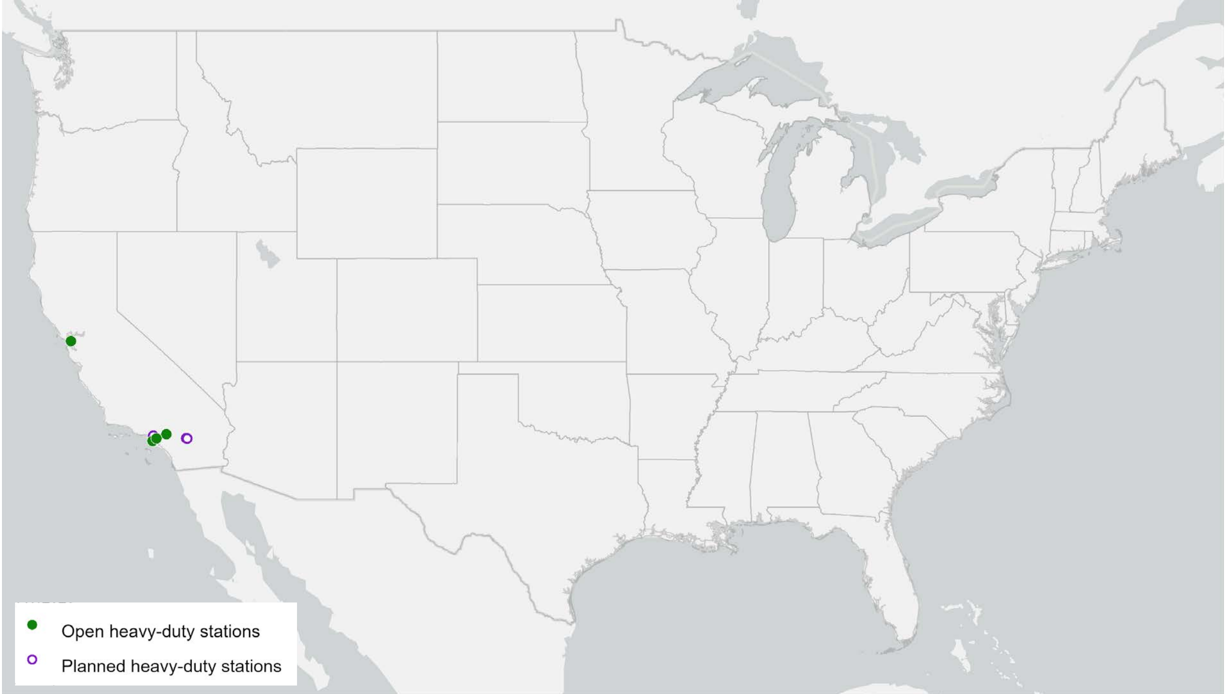


Figure 7. Map of hydrogen fuel cell heavy-duty truck refueling stations. ***Sources*****: CALSTART 2026; Alternative Fuels Data Center n.d.**

Range: Fuel cell trucks typically have longer ranges than battery electric trucks, with the Hyundai XCIENT Fuel Cell Truck advertising a 450-mile range and the IVECO S-eWay fuel cell electric vehicle (FCEV) advertising a nearly 500-mile range (though this model is not available in the United States). Most MHD battery electric trucks have ranges between 100 and 300 miles (CALSTART 2025), though models like the Windrose Long Range Truck and the Tesla Semi advertise ranges of 420 miles and 500 miles, respectively. Results from the North American Council for Freight Efficiency's (NACFE's) 2025 Run on Less, a 2.5-week pilot deployment that collected data on 14 Class 8 trucks, demonstrated an average maximum range (i.e., if the truck travels from 100% state of charge to 0%) for the Windrose Truck of 365 miles and a maximum range for the Tesla Semi of 443 miles. The XCIENT fuel cell truck averaged a maximum range of approximately 496 miles (NACFE 2025). However, the actual range of a vehicle depends on the weight of the payload, changes in elevation, and other factors affecting fuel economy.

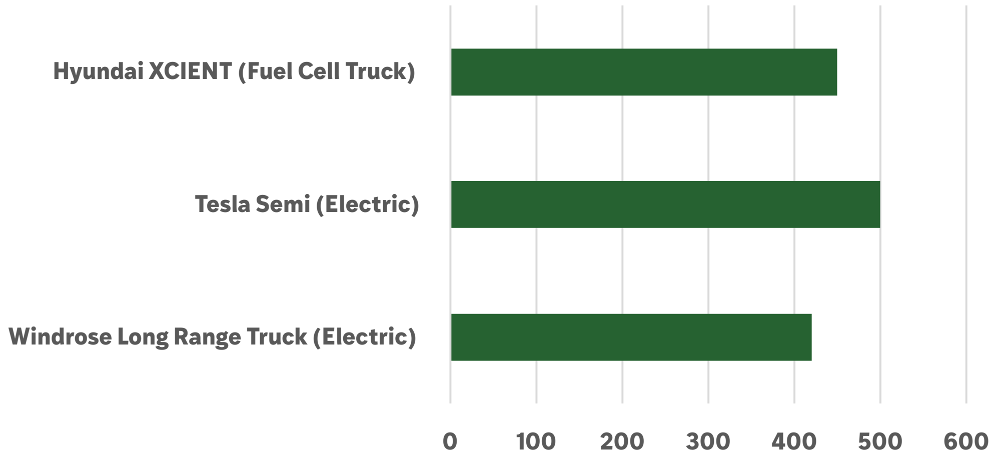


Figure 8. The advertised range of select Class 8 truck models. *Sources*: Hyundai n.d.; Tesla n.d.; Windrose n.d.

Refueling: Refueling times for heavy-duty fuel cell trucks typically range from 20 to 50 minutes, though the usage of liquid hydrogen can offer refueling times closer to 10 minutes (Brasher 2024; Daimler Truck 2023). The time required to refuel depends on the state of the hydrogen (gaseous versus liquid), the size of the storage tank, and the pressure of the dispenser (700 bar or 350 bar). Battery electric truck charging times are longer and often are estimated for recharging up to 80% of the battery's full capacity. This is because the rate of charge slows significantly between 80% and 100%; therefore, charging to 100% typically only occurs overnight when the truck is idle for several hours. The Windrose Long Range Truck advertises a 38-minute recharge time from 20% to 80% at 745 kW (Windrose n.d.). Charging times depend on the battery capacity and the power of the charger. However, even if a charger can provide 350 kW of power, a battery electric truck may not be able to accept a charge rate this high; if a 350-kW charger is plugged into a vehicle that can only accept 250 kW, such as the Volvo VNR Electric, then the communications protocol between the vehicle and the charger will limit the rate such that the vehicle will be charged at 250 kW. Therefore, charging times are also dependent upon the truck's specifications (Roeth et al. 2023). A new technology—Megawatt Charging Systems (MCS)—has the potential to further reduce charging times to 30 minutes. In the United States, WattEV has installed 1.2-megawatt MCS ports at its San Bernadino and Bakersfield truck charging depots, and Tesla shared plans in early 2026 to deploy 64 Tesla Semi megachargers across the United States, each providing at least 1 megawatt of power (WattEV 2026; Traugott 2026). Several stations in Europe have also deployed MCS (Engdahl 2025).

Capacity: With a few exceptions, trucks are prohibited from weighing more than 80,000 lb. on interstate highways (Federal Highway Administration 2003). Subtracting the truck's curb weight and empty trailer weight from this number equates to the truck's payload capacity, or the maximum weight of the cargo that the truck can carry. For Class 8 semi-trucks, the trailer alone can weigh 9,000–14,000 lb. without cargo, depending on the trailer length (Schneider n.d.; Hawley 2021). The battery in battery electric trucks and storage tank in fuel cell trucks also contribute to the vehicle's gross weight. Research based on interviews with suppliers and original equipment manufacturers (OEMs) in 2021 estimates that a Class 8 sleeper cab fuel cell truck with a 70-kg tank can carry approximately 4,121 lb. more than a Class 8 battery electric truck with a battery capacity of 705 kWh (Basma et al. 2023). However, when comparing existing truck models, Class 8 fuel cell truck curb weights are comparable to Class 8 battery electric truck curb weights (see table 1). This weight includes the vehicle's base weight, a full fuel tank, any standard equipment, and necessary fluids, but not cargo or passengers (Beltsis 2025). This means that current battery electric trucks have similar payload capacities to fuel cell trucks.

Table 1. Curb weight of select Class 8 battery electric and fuel cell truck models

Battery electric truck models	Curb weight (lb.)	Approx. payload capacity (lb.)	Fuel cell truck models	Curb weight (lb.)	Approx. payload capacity (lb.)
Tesla Semi	23,000	49,000	Hyundai XCIENT Fuel Cell Truck	28,400	41,600
Windrose Long-Range Truck*	26,235	45,765	Kenworth T680 FCEV	22,500	47,500
Freightliner eCascadia 6x4	21,390	50,610			

***The Windrose Long-Range Truck is a sleeper cab, unlike the other truck models displayed, which are day cabs.**

Note: Payload capacity varies based on trailer weight; payload capacity estimates assume, and do not include, a 10,000-lb. trailer and assume that battery electric trucks receive the federal 2,000-lb. exemption on maximum gross vehicle weight.

***Sources*: Schultz et al. 2025; Konstantinou et al. 2025; Tesla n.d.; Windrose n.d.**

The weight of an electric truck battery depends on the battery's capacity, which is related to the truck's range. Typically, batteries weigh roughly 6.7–7.7 kg (or 14.7–17 lb.) per kWh of capacity (Ricardo 2021; Magnino et al. 2024). Therefore, models like the eCascadia, which has a range of 230 miles and a capacity of 438 kWh, likely has a battery weight of 6,439–7,446 lb. Some models with higher battery capacities, such as the Windrose, likely have batteries weighing over 10,000 lb. Meanwhile, the heaviest component specific to a fuel cell truck, the storage tank, weighs approximately 21.6 kg (47.6 lb.) per kg of hydrogen fuel. The gaseous hydrogen fuel itself makes up roughly 4.5% of the total weight of the tank (Ricardo 2021; DOE Hydrogen and Fuel Cell Technologies Office n.d.). Many Class 8 fuel cell trucks models, such as the Hyundai XCIENT, have 70-kg tanks, which means these tanks likely weigh approximately 3,384 lb. However, new liquid hydrogen tanks are 20%–30% lighter and more energy dense (Pizzutilo et al. 2024).

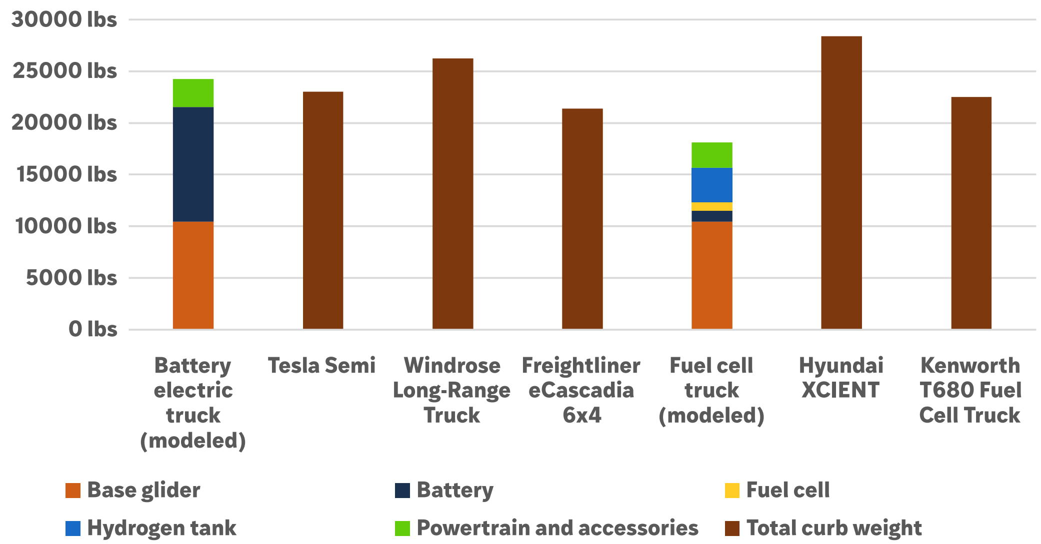


Figure 9. The weight of each component in a Class 8 battery electric truck and fuel cell truck, based on a bottom-up analysis informed by interviews with suppliers and OEMs in 2021, and the reported curb weights of recent models. Assumes a 705-kWh battery capacity for the battery electric truck and a 70-kg fuel tank for the fuel cell truck. *Sources*: Basma et al. 2023; Schultz et al. 2025; Konstantinou et al. 2025; Tesla n.d.; Windrose n.d.

Lifespan: Once the maintenance costs exceed the cost of purchasing a new or used vehicle, or after the vehicle age or mileage reaches a certain threshold, fleets sell their trucks for scrap or usage in off-road applications. Large fleets tend to use new trucks for 3–5 years before selling them to another firm *(*DOT 2021). The average useful life of a Class 8 internal combustion engine long-haul truck is around 7–9 years (Kurani et al. 2023; DOT 2021). Regional haul and medium-duty trucks tend to have longer lifespans, averaging between 11 and over 20 years due to their lower annual mileage (Mihelic et al. 2018).

For battery electric trucks, the total cost of ownership over the life of the vehicle depends partially on whether or not the vehicle's battery will need to be replaced. The rate of battery degradation depends on how the vehicle is operated and charged and the conditions in which it operates, and comprehensive data on battery lifespans in MHDVs are limited due to the lack of long-haul and regional battery electric trucks that have been operating for several years. However, some manufacturers claim that lithium iron phosphate batteries, which are often used in battery electric trucks, can last for 5,000–6,000 cycles (SpiderWay 2025; A&S Power 2025). If a truck recharges twice per day, six days per week, 50 weeks per year for eight years, it will have completed 4,800 cycles. Given the shorter lifespan of long-haul trucks, it is therefore possible that a long-haul truck may not need to replace its battery. Additionally, in the light-duty market, improvements in battery technology have lengthened the average lifespan of EV batteries. According to Geotab data on approximately 10,000 light-duty electric vehicles, the average annual rate of degradation fell from 2.3% in 2019 to 1.8% in 2024 (Argue 2025). Batteries are typically replaced after they have degraded to holding 80% of their original capacity.

For fuel cell trucks, some hydrogen fuel tank manufacturers advertise a 30-year lifespan for their tanks (Syré et al. 2024). In this case, the tank would not need to be replaced over the lifespan of the vehicle. However, there are limited data on the lifespan of fuel cell stacks in MHDVs. One manufacturer, Ballard, claims that its fuel cell stacks can last for over 25,000 hours (Ballard 2024). This means that if a fuel cell truck operates for 11 hours per day, six days per week, 50 weeks per year, then it would last for approximately 7.5 years before needing to be replaced or repaired.

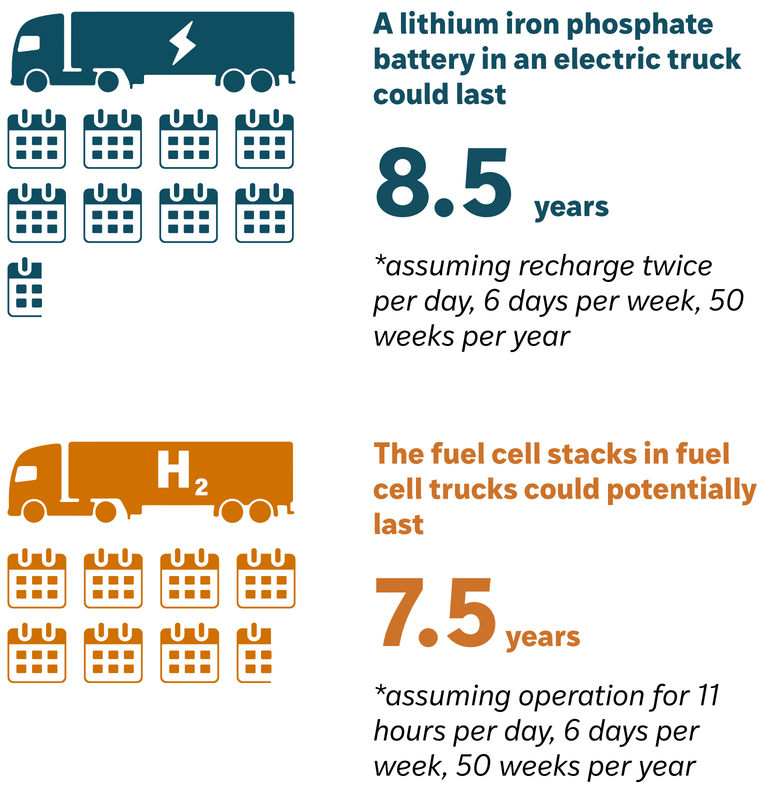


Figure 10. The estimated lifespan of batteries in electric trucks and fuel cell stacks in fuel cell trucks. ***Sources*****: SpiderWay 2025; A&S Power 2025; Ballard 2024.**

Total cost of ownership (TCO): Research from the International Council on Clean Transportation (ICCT) and the University of California-Davis (UC Davis) estimate the total cost of ownership of Class 8 battery electric trucks to be lower than the cost of ownership of fuel cell trucks, with estimates for battery electric trucks ranging from $1.45/mi. to $2.50/mi. and estimates for fuel cell trucks ranging from $1.76/mi. to $3.53/mi. (Basma et al. 2023; Burke et al. 2022). Basma et al. assessed TCO for model year 2022 trucks over a five-year period assuming an average daily mileage of 500 miles, while Burke et al. compares model year 2020 battery electric and fuel cell trucks with ranges of 500 miles over a five-year period. The lower cost for battery electric trucks is largely attributed to lower operating costs, as electricity and its associated infrastructure is significantly cheaper than green hydrogen, which is made via electrolysis using renewable energy, and hydrogen infrastructure. Studies suggest that the cost to recharge a Class 8 truck ranges from $0.17/kWh to $0.38/kWh (Bennett et al. 2022; Basma et al. 2023). This means that a 705-kWh capacity electric truck such as the Windrose Long Range Truck would cost $120–268 to recharge from 0%, or $114–255 to charge it sufficiently to travel 400 miles based on its advertised range. Estimated green hydrogen costs range from $10.20/kg to $11.60/kg. Although this cost is expected to decline as production grows over time, research estimates that it will cost $8.70/kg to $9.60/kg in 2040, which is not low enough to reach cost parity with the electricity needed to recharge battery electric trucks (Basma et al. 2023). At the current rate, a 70-kg tank in a fuel cell truck like the Hyundai XCIENT would cost $714–812 to fully refill, or $635–722 to refuel it sufficiently to travel 400 miles. Both estimates are lower than the cost to refuel a 250-gallon Class 8 diesel truck, which would cost approximately $862–967 to refill at $3.45/gal. to $3.87/gal. (EIA 2026). However, a diesel truck can travel for over 1,700 miles on a single fill (Park et al. 2024). Research also estimates that battery electric trucks cost less to maintain ($0.098/mi. to $0.176/mi.) than fuel cell trucks ($0.153/mi. to $0.20/mi.) (Basma et al. 2023; Hunter et al. 2021).

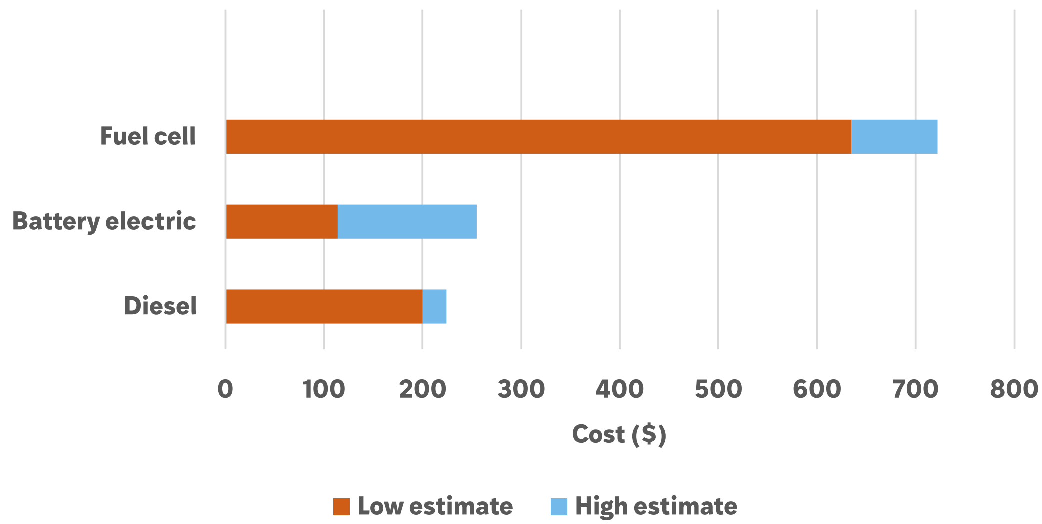


Figure 11. The cost to refuel a Class 8 diesel, battery electric, and fuel cell truck with enough charge/fuel to cover 400 miles. ***Sources*****: Bennett et al. 2022; Basma et al. 2023; EIA 2026; Park et al. 2024.**

Vehicle efficiency: Assuming both fuel cell trucks and battery electric trucks are powered by renewable energy, fuel cell trucks are associated with a higher rate of energy loss throughout the full life cycle primarily due to energy loss occurring during electrolysis (as energy input is required to produce the hydrogen), transportation, storage, and distribution of the hydrogen, and conversion of hydrogen to electricity in the fuel cell. During electrolysis, approximately 18%–24% of the energy used to produce the hydrogen is lost, and 11%–23% is lost during transport, storage, and distribution. Finally, 46%–53% is lost during the conversion of hydrogen to electricity. After accounting for smaller losses due to converting direct current (DC) to alternating current (AC) and energy loss from the engine, only 23%–33% of the "starting" energy is used to move a fuel cell trucks. Meanwhile, 76%–77% of the starting energy is used to move an electric truck (with losses largely occurring during conversion between AC and DC power and drivetrain system-related losses), as the "state" of the fuel is relatively unchanged from the start and little energy is lost in electricity transmission (Unterlohner and Earl 2020; Tsakiris 2019).

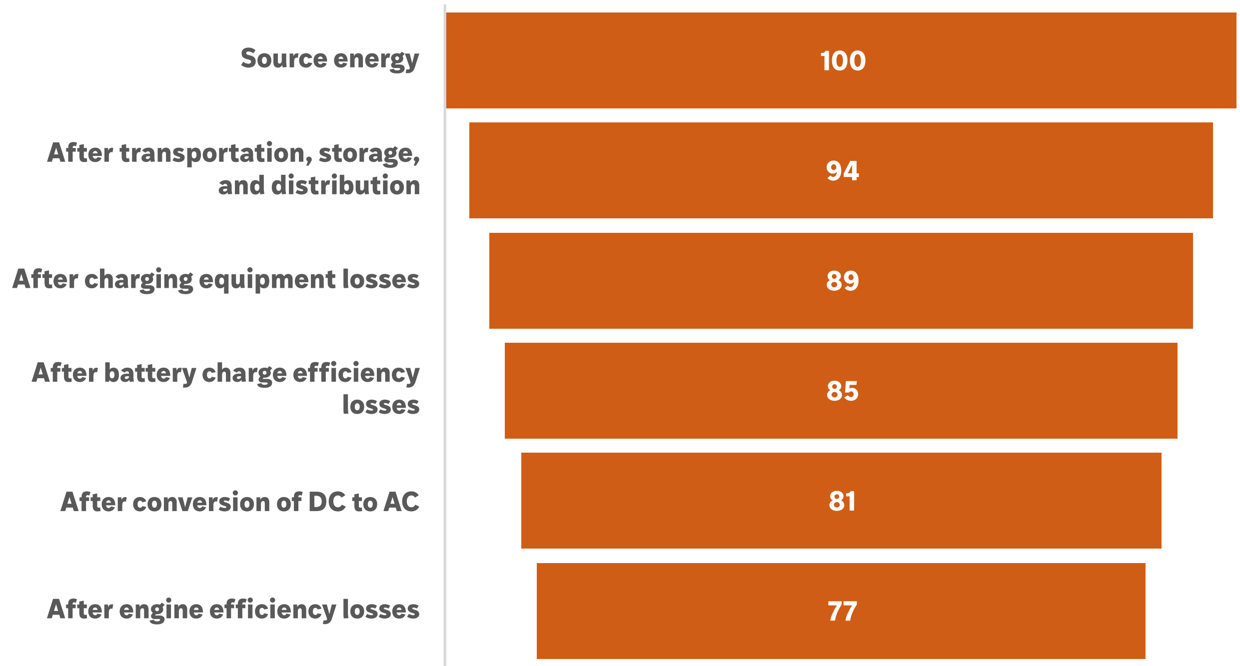


Figure 12. The percentage of energy retained to propel a battery electric truck from the point of energy production. *Sources*: Unterlohner and Earl 2020; Tsakiris 2019.

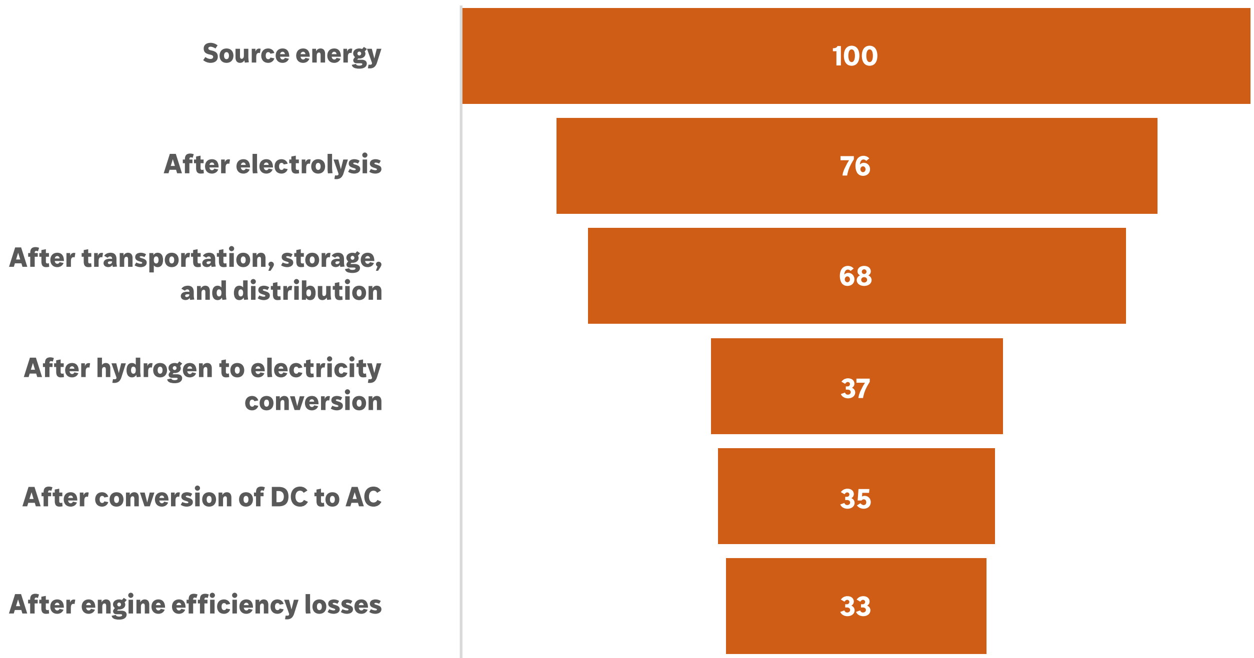


Figure 13. The percentage of energy retained to propel a fuel cell truck from the point of energy production. *Sources*: Unterlohner and Earl 2020; Tsakiris 2019.

Applications in regional and long-haul trucking

A large proportion of truck charging stations will likely exist in private depots, warehouses, and other facilities. Some of these stations may be accessible to the public, or to a group of fleets with which the facility owner has a contract. For a truck traveling 250 miles to a warehouse, unloading/loading, and driving 250 miles back to base, this trip would be possible with some battery electric trucks assuming the truck can recharge during dwell time at the warehouse. Dwell time, or the time spent by a driver at a facility to load or unload cargo, can provide ample opportunity for drivers to recharge. Analysis of over 48,000 loads across four U.S. facilities showed that the median dwell time for full truckload trips was 2.6 hours, and for less-than-truckload trips (in which the truck is carrying cargo from multiple different shippers) was 2.1 hours (Trading Partner Alliance 2019). At 350 kW, this would allow for sufficient time for many Class 8 battery electric trucks to recharge from 10% or 20% to 80%.

However, if charging/refueling at the warehouse, port, or other facility is not possible, or if a truck is traveling over 400 miles between facilities, then one or more stops along the route to recharge/refuel would be necessary. Truck drivers in the United States are subject to hours-of-service (HOS) regulations, which require a 30-minute break after eight hours of driving. They must also limit their total driving in a single shift to 11 hours, and may not drive after 14 hours have passed since coming on duty (for example, a driver cannot come on duty at 8 a.m. and still be driving after 10 p.m., even if they had several hours of downtime while cargo was being unloaded at a warehouse) (FMCSA 2022). A 30-minute break would allow enough time for a fuel cell trucks to refuel and, with MCS and trucks able to accept 1+ MW of power, this may provide sufficient time to recharge an electric truck to 80%. However, a truck may need to stop sooner than the eight-hour maximum driving time, given that a truck traveling at 65 mph for eight hours would travel 520 miles—longer than the real-world range of most battery electric trucks and fuel cell trucks.

Public charging and refueling station considerations

Because long-distance freight relies on en-route charging and refueling (i.e., fast, short-duration charging/refueling at a public or semi-public station along a major corridors), station spacing is a critical design consideration. If stations are spaced too far apart, the network may not be robust enough to complete certain trips. The California Transportation Commission's SB 671 Clean Freight Corridor Efficiency Assessment recommends siting MHDV charging stations every 50 miles or less to create a minimum viable network. The same report also recommends siting MHDV hydrogen refueling stations every 270 miles or closer (California Transportation Commission 2023).

Beyond spacing, station siting is constrained by available grid capacity. Interviews with charging hub companies indicate that most plan to develop hubs with initial capacities between 3 and 7 MW, with the ability to scale to 15–30 MW in the future (Ghosh 2025). Insufficient grid capacity could delay or prevent station construction and thus, the deployment of battery electric trucks. Similarly, the availability of hydrogen fuel could limit the development of hydrogen fuel stations.

Charging stations must be developed in advance of significant electric truck adoption rates in order to support these trucks. A single station could require up to 40 MW, and by 2030, the demand from battery electric MHDVs could add 1,000 MW to peak load in Texas and 500 MW to peak load in California. This increase could require upgrading or constructing new substations—a process that can take several years. Therefore, utilities must begin planning now to support future demand on the grid (Nadel 2024a).

Hydrogen refueling infrastructure presents different challenges. Because of its high cost and the complexity of hydrogen storage, refueling stations for fuel cell trucks must be developed and refueled in close synchronization with fuel cell trucks deployment. Liquid hydrogen is more efficient to transport than gaseous hydrogen if the distance between the production plant and the refueling station is greater than 200 miles, since liquid hydrogen is denser than gaseous hydrogen and therefore more of it can be transported at a time; however, liquefaction is an energy-intensive process, and if it is not used quickly enough, it will evaporate ("boil off"), resulting in energy and monetary loss DOE n.d.-b). Boil-off can result in losses of less than 1% to 5% per day, depending on the size and design of the tank and how the tank is cooled (Yang et al. 2023).

Assuming fuel prices incorporate infrastructure costs, hydrogen stations require high utilization to remain cost effective. The infrastructure required for truck charging stations is less expensive, and these stations can be built and scaled more gradually (IEA 2025). Early deployment of charging stations is therefore associated with a lower risk of energy loss; if the station is underutilized, the electricity that would have gone to recharging trucks will be used elsewhere.

Key takeaways for infrastructure planning

Though origins and destinations may vary, regional and long-haul trucks travel along predictable trunkline corridors and hubs. Infrastructure decisions for these trucks have an outsized influence on both climate outcomes and community health. The question for states and regions is therefore not whether to invest in zero-emission freight infrastructure, but how to sequence those investments to deliver near-term benefits while managing cost and risk.

The technology and operational evidence in this section points to battery electric trucks as the most infrastructure-ready option for regional and long-haul operations in the near term. Battery electric trucks dominate global zero-emission truck sales, account for the vast majority of U.S. deployments to date, and offer lower total cost of ownership than fuel cell trucks due to cheaper energy and maintenance. From an infrastructure perspective, this matters because electric charging infrastructure can be built incrementally, scaled as demand grows, and, if underutilized, does not result in stranded fuel or lost energy.

Operational patterns reinforce this conclusion. Many regional and some long-haul duty cycles can already be served by battery electric trucks when charging is available during dwell time at warehouses, ports, and distribution centers. Therefore, while battery electric trucks may require longer to recharge, strategic planning can create overlap between dwell time and recharging time, minimizing disruption to freight operations. The maximum range of battery electric trucks and fuel cell trucks currently on the market is also comparable.

Finally, the higher energy efficiency of battery electric trucks highlights the value of prioritizing battery electric trucks in an economy that is expected to see growing freight travel. Green hydrogen fuel is energy intensive to produce and the conversion of electricity to hydrogen, and back to electricity results in significant losses. Battery electric trucks require less energy to operate, freeing up more resources for other energy demand sources.

Table 2. Market and technology comparison of battery electric and fuel cell trucks

Metric	Battery electric trucks	Hydrogen fuel cell trucks
Heavy-duty trucks deployed as of June 2025	2,187	197
Available MHD truck models in the United States	64	8*
Maximum advertised range of U.S. models (miles)	500	450
Shortest refueling time (min.)	38	10
Payload capacity of the Tesla Semi and Kenworth T680 FCEV (lb.)	49,000	47,500
Cost to fully refuel/recharge a Class 8 truck (allowing 400 mi of travel) ($)	114-255	635-722
Cost to maintain a Class 8 truck (¢/mi.)	9.8-17.6	15.3-20
Well-to-wheels energy efficiency (%)	77	33

*Only two fuel cell truck models are commercially available.

Sources: Richard et al. 2026; CALSTART 2025; Tesla n.d.; Hyundai n.d.; Windrose n.d.; Brasher 2024; Daimler Truck 2023; Konstantinou et al. 2025; Basma et al. 2023; Bennett et al. 2022; Hunter et al. 2021; Unterlohner and Earl 2020; Tsakiris 2019

Methodology and scope of analysis

To help state and corridor decision makers in long-term planning for charging and refueling networks, ACEEE estimates the cost to build out a nationwide public and semi-public refueling network for hydrogen fuel cell and electric trucks along major freight corridors. For the purposes of our analysis, public and semi-public stations are defined as stations either fully public and available to any fleet or requiring a reservation or subscription to access and shared between fleets. Supported by the latest research and real-world cost information on zero-emissions trucks and refueling stations, as well as consultations with academic, industry, and public sector experts, the analysis assesses the needs of Cass 4–8 trucks making trips of 200 miles or more.

The six scenarios considered were developed to allow an examination of the cost implications of policy choices around zero-emission vehicle (ZEV) infrastructure even with some uncertainty about how these technologies will evolve, adoption timelines, and to precisely what extent each technology will depend on public versus private refueling infrastructure. The scenarios assessed consider the costs to build recharging stations for electric trucks, namely DC fast charging (DCFC) stations, and hydrogen refueling stations with offsite hydrogen production for fuel cell trucks. For more detail on our approach and methodology, see Appendix A.

Scenario design and modeling assumptions

Results are assessed across six scenarios that vary in two aspects: (1) the mix between electric and hydrogen fuel cell trucks, collectively referred to as ZEVs, as well as (2) the balance between public or semi-public and private refueling. All other variables, including the projection of ZEV adoption between 2025 and 2040, are fixed between the scenarios and are detailed below and in Appendix A.

How to read the scenarios: All scenarios apply only to trucks that travel 200 miles or more per day, which are more likely to rely on corridor-based refueling and higher-power charging. The scenarios generally vary along two dimensions:

(1) the share of battery electric versus hydrogen fuel cell trucks by vehicle class, and

(2) the extent to which electric trucks rely on public/semi-public versus private depot charging.

Hydrogen fuel cell trucks are assumed to rely exclusively on public refueling in all scenarios.

Together, these scenarios illustrate how infrastructure requirements and costs change the share of energy delivered through public charging increases and as technology pathways evolve, while holding overall ZEV adoption constant.

Scenario 1: Batter electric vehicle (BEV) (baseline public charging)

Assumes 100% of ZEVs are battery electric trucks across all weight classes with a lower share of charging occurring at public or semi-public stations: 20% of energy demand for Classes 4–6 trucks and 60% for Classes 7–8 trucks.

Scenario 2: BEV, public charging+

Assumes 100% of ZEVs are battery electric trucks, with a higher share of charging occurring at public or semi-public stations: 30% of energy for Classes 4–6 trucks and 80% for Classes 7–8 trucks. This scenario reflects greater reliance on public and semi-public charging infrastructure.

Scenario 3: BEV, public charging++ (test case)

Assumes 100% of ZEVs are battery electric trucks across all classes and 100% of charging occurring at public or semi-public stations. This scenario provides an upper-bound estimate of public infrastructure needs and costs and is used to assess maximum cost exposure.

Scenario 4: Mixed (baseline public charging)

Introduces limited fuel cell adoption in heavy-duty applications, with 20% of Classes 7–8 ZEV trucks using hydrogen fuel cells and all other trucks battery electric. Public charging shares for electric trucks are the same as in scenario 1, isolating the effect of technology mix.

Scenario 5: Mixed, public charging+

Combines limited fuel cell adoption in Classes 7–8 ZEV trucks (20%) with higher public charging reliance for electric trucks, matching the assumptions in scenario 2.

Scenario 6: Mixed technologies, extended hydrogen station spacing (test case)

Follows the assumptions of scenario 5 but alters the minimum spacing requirement for hydrogen refueling stations so that it is at a constant 200 miles for the entire period of analysis. This scenario provides a lower-bound estimate of infrastructure needs and costs for hydrogen refueling infrastructure.

Overview of key assumptions

To estimate infrastructure needs, we follow the phased buildout of NZEFCS and apply assumptions about station spacing to determine the number of refueling and recharging sites (Chu et al. 2024). Total costs are calculated based on building a sufficient capacity to meet the fuel demand of both truck types, using construction cost estimates drawn from existing literature and ACEEE data collection of real-world construction costs. Costs include equipment, labor, permitting, materials, and other costs to construct stations. Costs not included are land costs or costs for utility upgrades and service extension costs or to support offsite hydrogen production or transportation. All costs are in constant 2025 dollars. Additional detail on infrastructure phasing and cost assumptions is provided in Appendix A.

We do not model a scenario in which 100% of ZEVs are FCEVs, given the state of technology, the limited supporting infrastructure for hydrogen refueling and fuel generation, and industry consensus around EVs meeting the need of medium-duty vehicles. In contrast, we do assume it is possible that electric trucks will be the sole ZEV technology used in part because electric trucks can take advantage of a preexisting electrical grid and advances in battery and vehicle technology.

We also assume electric trucks will be more likely to rely on private depot charging than FCEVs, reflected in scenarios 4–6. Because our cost model focuses exclusively on public and semi-public refueling infrastructure, this structure would otherwise understate the total infrastructure costs associated with electric trucks relative to FCEVs. Scenario 3 addresses this limitation by assuming all electric truck energy demand is met through public charging, providing a more comparable estimate of total refueling infrastructure costs across technologies. This scenario likely overestimates real-world costs, since depot charging would typically use lower-power and lower-cost equipment than assumed for public charging stations. An additional scenario, scenario 6, also varies the spacing assumption for hydrogen refueling stations and provides a lower bound for hydrogen refueling station investment. These scenarios are designed to reflect possible technology pathways and infrastructure deployment models.

In all examined scenarios, we assume that by 2040, 95% of Classes 4–8 trucks sales are ZEVs. This equates to 35% of on-road trucks in 2040 being ZEVs, the final year of our modeling analysis, but 55% of vehicle miles traveled (VMT) from Classes 4–8 trucks are from ZEVs in that year. The higher percentage for VMT is due to the fact that newer vehicles are driven more on average than older vehicles. The model varies the efficiency of each class and fuel type and all efficiency levels grow over time as the technology and vehicle designs are expected to improve. The ZEV sales projection represents an illustrative high-adoption scenario designed to demonstrate potential infrastructure needs, though actual adoption rates may differ based on evolving market conditions and policy support.

Infrastructure density and cost requirements

To understand how much charging and refueling infrastructure is needed, and the associated costs, we modeled six future scenarios using the same assumptions about truck travel, vehicle efficiency, and overall zero-emission truck adoption. Between the scenarios, the varying factors focused on the mix between which technologies the trucks use (battery electric or fuel cell) as well as how much fueling happens at public or semi-public stations versus private depots.

Fuel demand and infrastructure requirements by scenario in 2040

The more trucks rely on public or semi-public charging, the more total energy public and semi-public stations must deliver. Total refueling capacity in 2040 increases between scenarios in line with increases in fuel demand. Electric capacity reflects the total rated capacity of all stations or the collective peak potential demand of all stations. Hydrogen refueling capacity reflects the maximum daily throughput of all stations or the peak potential throughput of all stations.

Table 3. Fuel demand by scenario

<table>
<tr><th rowspan="2">Scenario number</th><th colspan="2">Total fuel demand in 2040</th><th colspan="2">Total refueling capacity in 2040</th></tr>
<tr><th>Electric</th><th>Hydrogen</th><th>Electric</th><th>Hydrogen</th></tr>
<tr><td>1: BEV</td><td>35,584 GWh</td><td rowspan="3">N/A</td><td>16,139-MW capacity</td><td rowspan="3">N/A</td></tr>
<tr><td>2: BEV, public charging+</td><td>47,464 GWh</td><td>22,221-MW capacity</td></tr>
<tr><td>3: BEV, public charging only (test case)</td><td>59,680 GWh</td><td>26,682-MW capacity</td></tr>
<tr><td>4: Mixed technologies</td><td>28,490 GWh</td><td rowspan="3">753,872 MT H_2/day</td><td>13,868-MW capacity</td><td rowspan="2">9,162 MT H_2/day</td></tr>
<tr><td>5: Mixed technologies, public charging+</td><td>38,005 GWh</td><td>18,329-MW capacity</td></tr>
<tr><td>6: Mixed technologies, extended hydrogen station spacing (test case)</td><td>38,005 GWh</td><td>18,329-MW capacity</td><td>5,269 MT H_2/day</td></tr>
</table>

Charging and hydrogen station investment costs by scenario in 2040

Building out a public refueling network for battery electric trucks and FCEVs requires substantial investment, but the costs of station development associated with each fuel type differ markedly. The costs to build sufficient hydrogen refueling stations are considerably higher than the cost to build sufficient charging stations. As a result, scenarios with both technologies considered in the fleet mix (scenarios 4–6) have the highest overall system costs.

In scenarios 4 and 5, which include FCEVs, the estimated cost of the hydrogen refueling network in the two scenarios with FCEVs is over $22 billion, which does not vary between the two because the hydrogen assumptions are the same. The costs to build charging stations are considerably less, ranging from almost $6 billion to $10 billion when all ZEVs are electric and charged at public/semi-public stations. For charging stations, costs increased for scenarios where all ZEVs were electric and when there was a greater share of charging done at public/semi-public stations. In comparison, in 2021, total state spending on highways and roads was about $121 billion, with slightly more than half of that going to capital expenditure (Urban Institute n.d.).

Table 4. Station costs by fuel type and scenario

Scenario number	Charging station investment cost, 2025–2040 ($000)	Hydrogen station investment cost, 2025–2040 ($000)	Total investment cost, 2025–2040 ($000)
1: **BEV**	$6,607,691	n/a	$6,607,691
2: **BEV, public charging+**	$8,833,539	n/a	$8,833,539
3: **BEV, public charging only (test case)**	$10,413,598	n/a	$10,413,598
4: **Mixed technologies**	$5,784,838	$22,280,264	$28,065,102
5: **Mixed technologies, public charging+**	$7,419,994	$22,280,264	$29,700,257
6: **Mixed technologies, extended hydrogen station spacing (test case)**	$7,419,994	$12,620,770	$20,040,764

The cost risks of a technology-neutral approach to infrastructure investment are clear when comparing scenarios 2 and 5, which share the same characteristics other than the inclusion of FCEVs in scenario 5. In scenario 5 the total costs are over three times greater than in scenario 2, entirely attributable to the need to build out a hydrogen refueling system. While there are savings because the total charging capacity is smaller (about 18.3 MW versus 22.2 MW in scenario 2), these cost savings are dwarfed by the additional $22.3 billion needed for the hydrogen refueling system in scenarios 4 and 5. The costs for the charging system are more evenly distributed over time, evident in the values for scenarios 1–3. The addition of hydrogen refueling station costs adds significant costs in the later years when spacing requirements increase, evident in scenarios 4 and 5.

Table 5. Total costs ($000) for scenarios

Scenario number	2025–2030	2031–2035	2036–2040	Total
1: **BEV**	$1,943,924	$2,252,530	$2,411,236	$6,607,691
2: **BEV, public charging+**	$2,461,663	$3,178,017	$3,193,859	$8,833,539
3: **BEV, public charging only (test case)**	$2,953,407	$3,702,834	$3,757,356	$10,413,598
4: **Mixed technologies**	$4,114,855	$7,565,185	$16,385,061	$28,065,102
5: **Mixed technologies, public charging+**	$4,556,138	$8,178,492	$16,965,628	$29,700,257
6: **Mixed technologies, extended hydrogen station spacing (test case)**	$4,522,154	$6,997,226	$8,521,383	$20,040,764

The number of charging stations is consistent across the scenarios because it is based on the minimum spacing requirement, which does not vary. While all scenarios have 1,622 electric charging stations in 2040, the total built capacity and capacity per station varies as the number of electric trucks and the demand on the public charging network varies.

Per station costs

Per station costs for both fuel types are based on station capacity and decline over time, even as average capacity increases slightly for both station types across scenarios. Even though by 2040 in scenario 5 there are almost two times as many charging stations as hydrogen refueling stations, the cost per hydrogen station is over 6.5 times higher than the cost per charging station.

Table 6. Capacity and costs per new station in scenario 5

	2030		2035		2040	
Fuel Type	Capacity (MT/ day or MW)	Cost ($000)	Capacity (MT/ day or MW)	Cost ($000)	Capacity (MT/ day or MW)	Cost ($000)
Hydrogen	8.7	$22,417	9.4	$23,124	9.4	$22,050
Electric	10.0	$4,652	11.3	$4,273	11.3	$3,544

The costs presented here reflect onsite station equipment and construction and do not include offsite grid infrastructure upgrades or hydrogen transport, transmission, and distribution costs. Grid upgrades required to supply power to charging stations are estimated to account for roughly 20% to 40% of overall project costs on average, although this share varies depending on station size and local grid conditions (Xie 2025; Wood et al. 2024; Alexander et al. 2024; Basma et al. 2023). For hydrogen refueling stations, infrastructure beyond the station represents a substantial portion of overall system costs. The station development costs may account for between 15% and 40% of overall costs, with the remainder associated with upstream hydrogen production, transport, and distribution infrastructure. These estimates are subject to greater uncertainty given the limited scale of hydrogen production, transport and refueling networks today (Burke et al. 2024).

Site-specific factors can significantly affect grid upgrade costs for en-route charging hubs. These include the capacity of existing substations, available feeder capacity, and regional load conditions. An assessment of 39 prioritized charging hubs for battery electric trucks across nine northeastern states conducted by National Grid found that near-term grid upgrade costs based on actual grid conditions averaged to about $2 million per MW for larger stations. In contrast, an analysis of potential sites for large charging hubs in less populated areas of Wyoming, Colorado, and New Mexico estimated total grid upgrade costs ranging from $5 million to $11 million for stations sized between 8 MW and 35 MW, corresponding to per-megawatt costs below $500,000 in some cases (Alexander et al. 2024). These findings illustrate how local grid conditions and station size strongly influence grid upgrade costs. Limited grid capacity or the need to construct a new substation can substantially increase costs while on-site generation, battery storage, or managed charging strategies that reduce peak demand can help lower them. As a result, grid upgrade costs are often more location-specific and variable than station construction costs.

Hydrogen infrastructure requires broader investments across the fuel production and delivery supply chain. Unlike battery electric charging, which can build on the existing electric grid, hydrogen refueling depends on the availability of production facilities, transportation infrastructure, and storage systems. An assessment examining hydrogen delivery via both pipeline and trucking found that station development costs accounted for between 15% and 40% of total system costs when including hydrogen production and distribution costs. The analysis found the lowest levelized hydrogen costs per kilogram of H_2 when hydrogen was delivered by pipeline, although this pathway requires the highest upfront infrastructure investment (Burke et al. 2024). These findings highlight the significant infrastructure requirements associated with hydrogen fueling, particularly during early deployment stages when dedicated transport and supply networks are still limited. Cost estimates for hydrogen infrastructure are therefore subject to greater uncertainty compared with electricity grid upgrades, where utilities are already planning and deploying new capacity to accommodate large emerging loads such as transportation electrification and data centers.

Projected station build-out through 2040

The number of stations increases throughout the period with significant growth in later years. Due to the spacing requirements assumed for electric stations, at a greater density than for hydrogen stations, there are more electric charging stations every year.

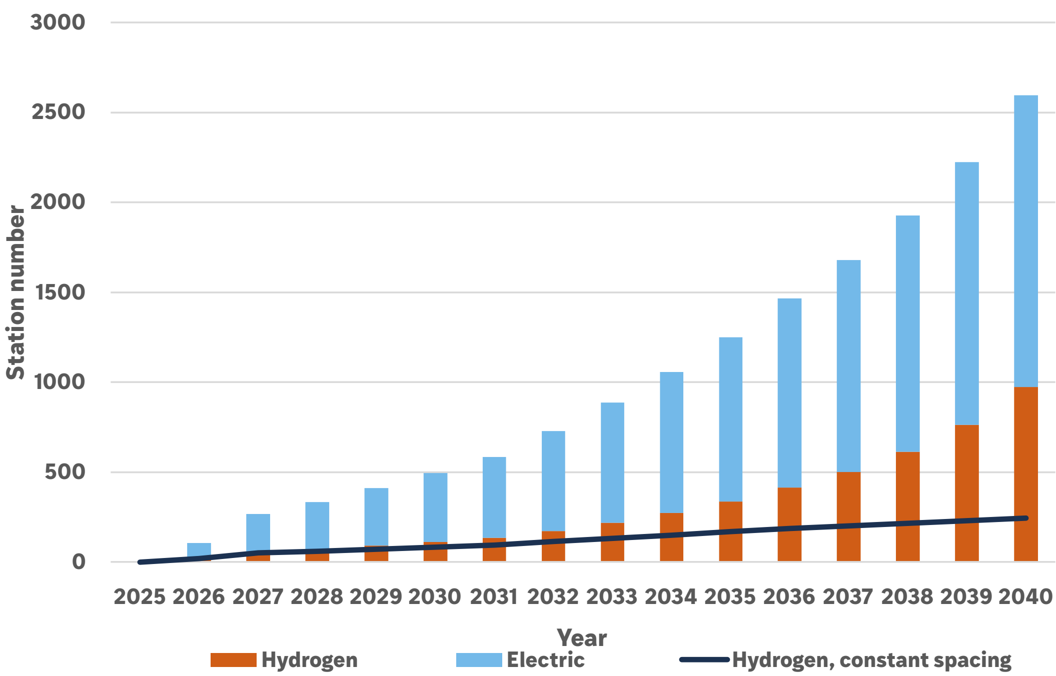


Figure 14. Station number over time by fuel type

Average capacity per station generally increases through 2030 and then remains flat, shown in figure 15 below. The range of values for average capacity are also within what can be expected for charging and hydrogen refueling stations based on current projections and discussions with external stakeholders.

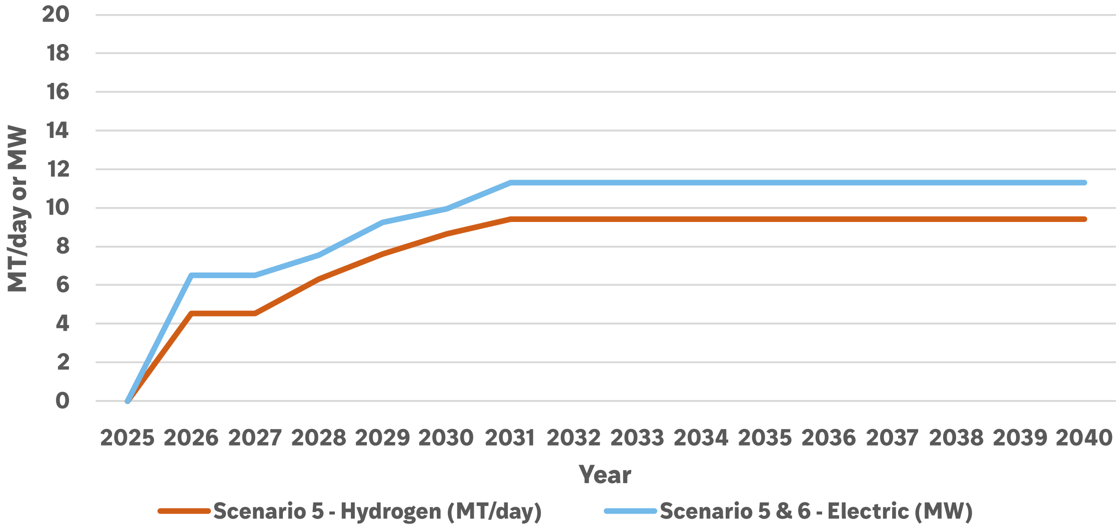


Figure 15. Average capacity per station, scenario 5

Total refueling capacity increases over the entire period as the number of vehicles, and therefore total fuel demand, increases over the entire period.

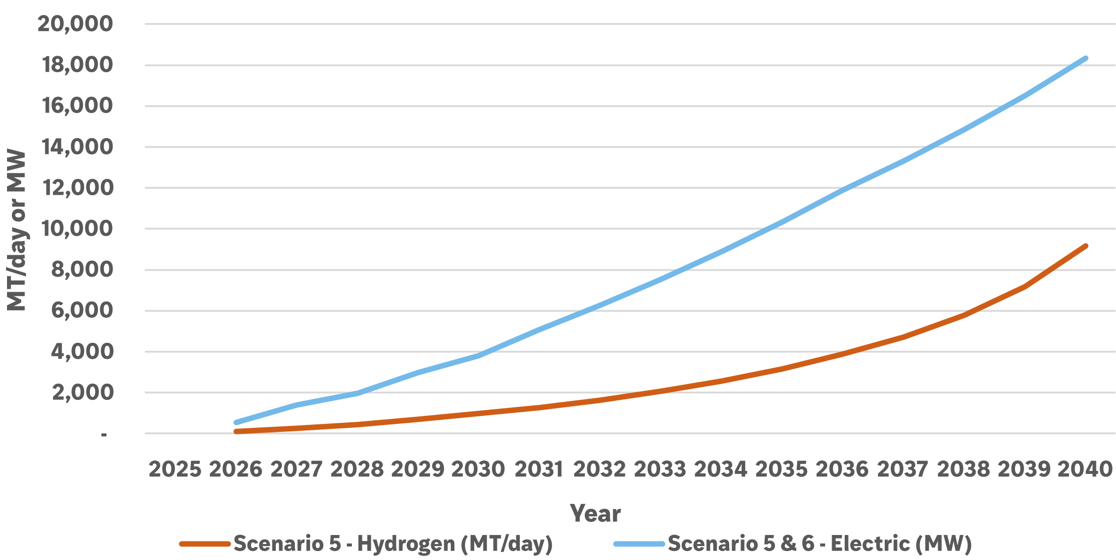


Figure 16. Total refueling capacity over time, scenario 5

Stations by state

The five states with the highest number of stations in 2040 are Indiana, Texas, California, Illinois, and Missouri. Certain states are built out more quickly than others, due to the phased assumptions derived from the NZEFCS. The allocation of stations among states in the model does not vary between the first five scenarios so while the number and total refueling capacities in each state vary, the proportions are the same. However, due to the nature of the NZEFCS, the top five states in terms of number of stations is not consistent throughout the build-out period. The top five states over time are generally states with large populations or significant freight activity that are critical to the national freight network. These estimates are illustrative of the station needs when a significant number of ZEV trucks are on the road. There is considerable uncertainty over ZEV refueling need in the short term and therefore more uncertainty around the 2030 estimates than the estimates for 2035 and beyond.

Table 7. Top five states by total number of stations and station number by type

2035			2040		
	Charging stations	**Hydrogen stations**		**Charging stations**	**Hydrogen stations**
Indiana	112	42	Indiana	168	113
California	105	39	Texas	159	98
Texas	101	38	California	135	83
Illinois	74	27	Illinois	104	66
Ohio	37	14	Missouri	65	41

Projected station costs through 2040, by state

The costs by state mirror the distribution of total stations by state. States with more highway miles in key corridors and greater freight activity have more stations and therefore greater costs. The states with the greatest annualized costs (over $30 million per year) for charging stations are states with significant freight activity. Some states with medium to small populations, but that are crucial for the freight network and see significant freight volumes, also have higher costs, like Oklahoma and Nebraska. Some medium and even large states with smaller freight volumes per mile of corridor also have lower costs, including Massachusetts and Maryland.

The ranking of states by annualized costs varies slightly when looking at costs for electric charging stations versus costs for hydrogen refueling stations. This is because the costs over time for each fuel type are different due to our assumptions and the phasing in of the infrastructure based on the NZEFCS.

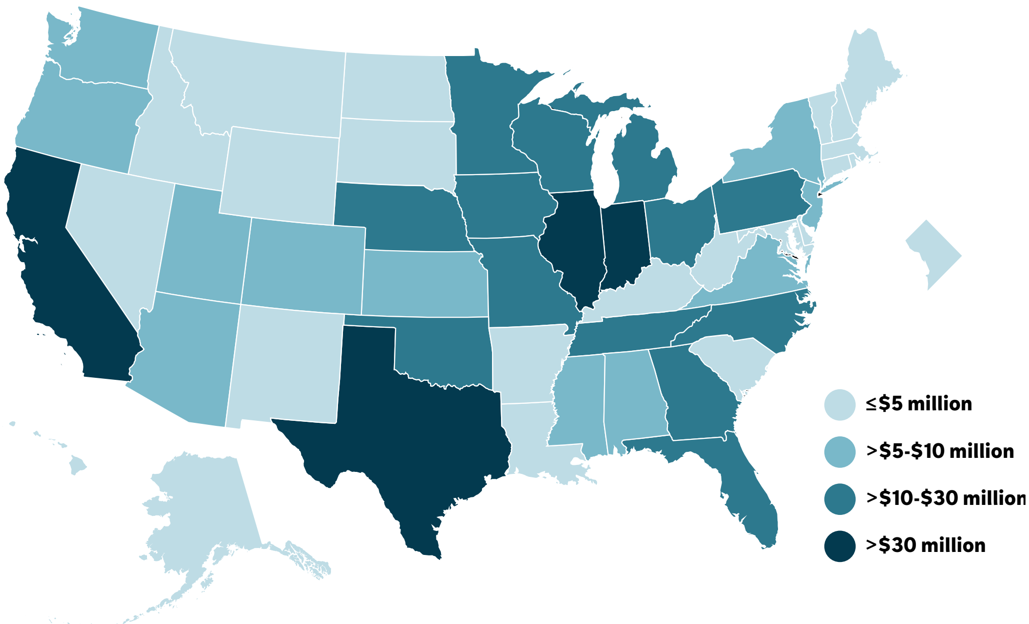


Figure 17. States by average cost per year for electric charging stations, scenario 5

Less than $5 million	>$5 to $10 million	>$10 to $30 million	>$30 million
Arkansas	Arizona	Missouri	Indiana
Kentucky	New York	Tennessee	Texas
South Carolina	Utah	Ohio	California
Louisiana	Washington	Oklahoma	Illinois
North Dakota	Alabama	Nebraska	
Idaho	Virginia	Georgia	
Montana	Kansas	Florida	
South Dakota	Colorado	Minnesota	
New Mexico	Mississippi	Pennsylvania	
Wyoming	Oregon	Michigan	
Nevada	New Jersey	North Carolina	
Alaska		Iowa	
Maryland		Wisconsin	
Massachusetts			
West Virginia			
Maine			
Connecticut			
New Hampshire			
Rhode Island			
Vermont			
Delaware			
District of Columbia			
Hawaii			

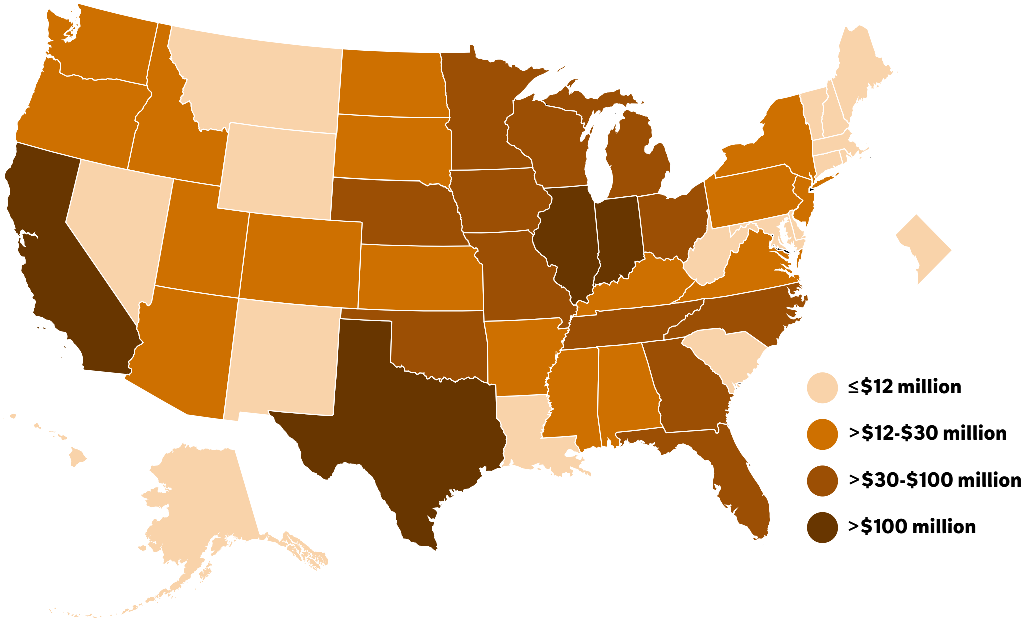


Figure 18. States by average cost per year for hydrogen refueling stations, scenario 5

Less than $12 million	>$12 to $30 million	>$30 to $100 million	>$100 million
South Carolina	Pennsylvania	Missouri	Indiana
Louisiana	Arizona	Oklahoma	Texas
Montana	Washington	Tennessee	California
New Mexico	New York	Nebraska	Illinois
Wyoming	Utah	Ohio	
Alaska	Kansas	Minnesota	
Nevada	Alabama	Florida	
Massachusetts	Mississippi	Georgia	
Maryland	Virginia	Iowa	
West Virginia	Arkansas	Wisconsin	
Maine	North Dakota	Michigan	
Rhode Island	Oregon	North Carolina	
New Hampshire	Colorado		
Connecticut	Kentucky		
Delaware	Idaho		
Vermont	New Jersey		
District of Columbia	South Dakota		
Hawaii			

Sample corridor cost

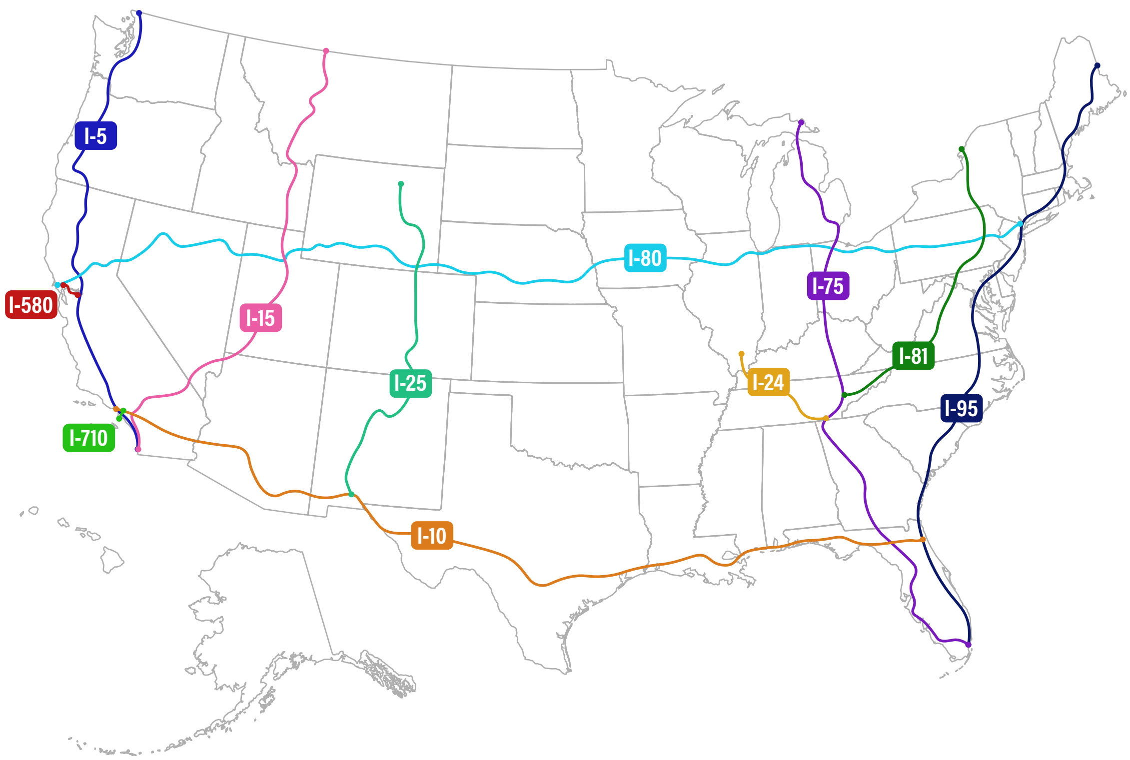


Figure 19. Key freight corridors identified in NZEFCS

Key corridors cross multiple states, requiring multistate cooperation and investment. One key corridor in the freight network is I-10, running from the east to west coast, from Florida to California along the southernmost stretch of the continental United States. This analysis focuses on the western portion of the corridor from California to Texas given its importance as a trade route and high freight volumes. There are already currently-built and planned stations on this section of the corridor, as shown in figures 6 and 7, demonstrating early investment activity. The costs to build out this corridor vary by scenario with the costs significantly higher in the scenarios where hydrogen refueling stations are built.

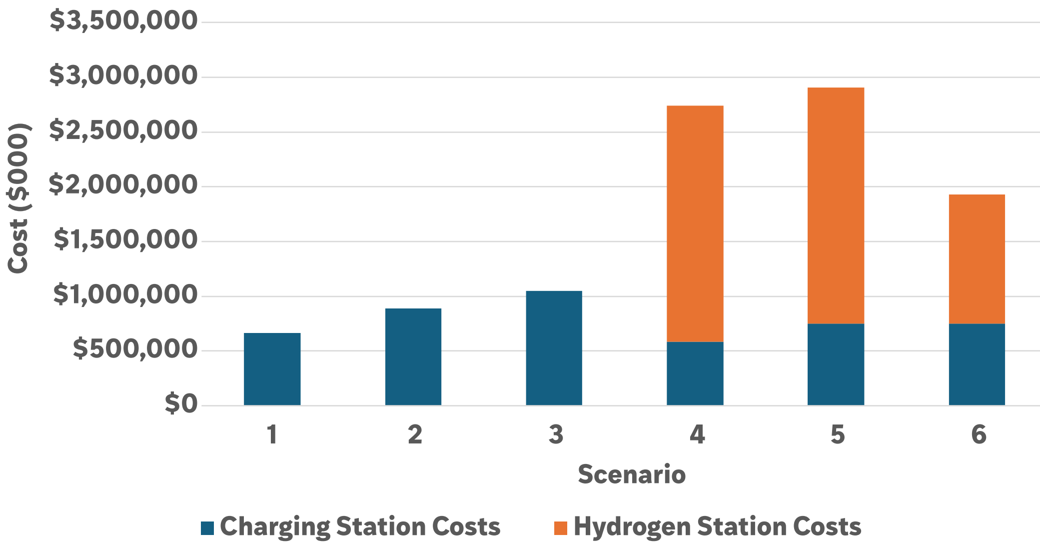


Figure 20. Charging and hydrogen refueling costs for I-10 by scenario

In scenario 5, the total cost to build sufficient refueling stations is almost $3 billion dollars, primarily driven by the costs to build hydrogen refueling stations. About half of the costs occur in the last five years and over 75% of the costs are for hydrogen stations, in line with the scenario overall.

Table 8. I-10 station costs, scenario 5

	2025–2030	2031–2035	2036–2040	Total
Electric charging station costs ($000)	$295,914	$226,898	$224,292	$747,104
Hydrogen station costs ($000)	$368,990	$497,911	$1,291,055	$2,157,957
Total station costs ($000)	$664,904	$724,808	$1,515,347	$2,905,060

Costs for the corridor were calculated using current freight traffic flow along segments of I-10. Texas accounts for the largest share of investment cost due to both the high freight volumes on I-10 in Texas and the fact that it contains over half of the mileage of the assessed segment of I-10 from California to Texas. As a result, Texas has the largest single investment in the corridor at almost $1.8 billion followed by California and Arizona at over $500 million and $470 million, respectively.

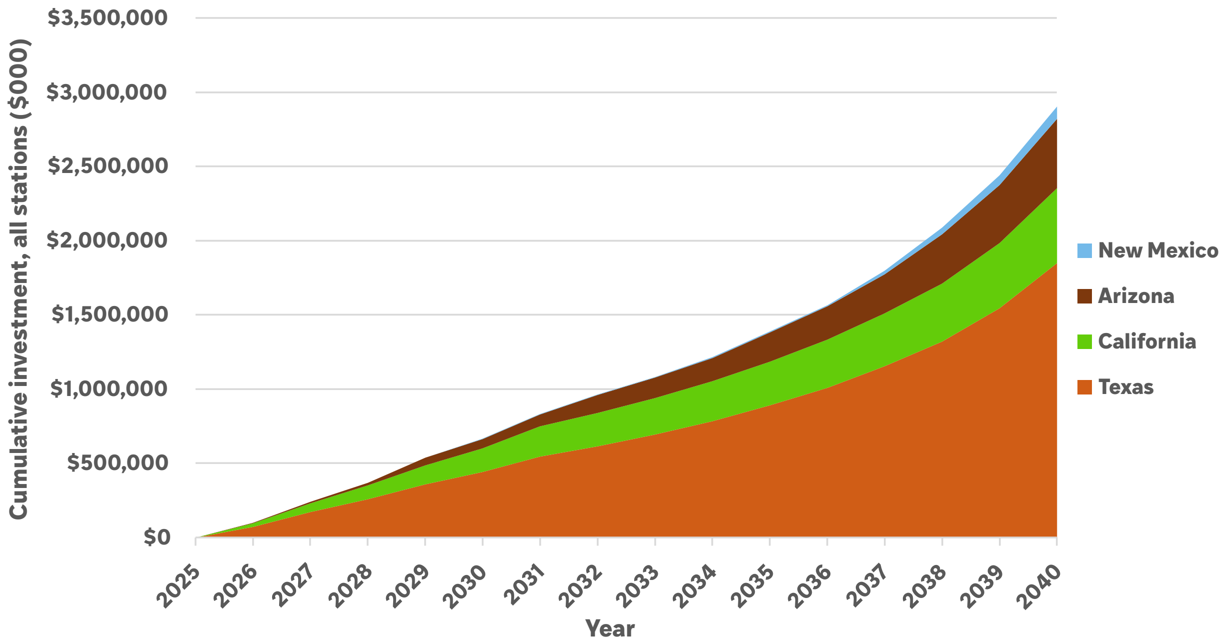


Figure 21. I-10 cumulative investment by state, scenario 5

Opportunities for coordination and alignment

Coalitions of states, freight industry stakeholders, charging companies, fuel and utility companies, and nonprofits across the United States are working to plan, facilitate, and fund the installation of zero-emission MHDV (ZE-MHDV) infrastructure. Some of these coalitions are focused at the corridor-level, working to plan or deploy infrastructure along a certain highway. Table 9 below describes several corridor coalitions and interstate projects, and the technology that each coalition has prioritized.

Table 9. Ongoing ZEV corridor initiatives

Highway	Coalition name	Lead	Primary MHDV technology
I-95	Clean Corridor Coalition	New Jersey Department of Environmental Protection	Electric charging
	East Coast Commercial Zero–Emission Vehicle Corridor Planning Partnership	CALSTART	Electric charging and Hydrogen refueling
	Northeast Freight Corridor Charging Plan	National Grid	Electric charging
	Eastern Transportation Coalition	Staff-led	Electric charging
I-81	MD-NJ-PA-WV Charging Ahead Partnership[2]	Maryland Department of Transportation	Electric charging
I-80	Medium-Duty, Heavy-Duty Zero Emissions Vehicle (MD-HD ZEV) Infrastructure Planning	Cummins	Electric charging and Hydrogen refueling
I-75	Southeast to Southwest Ohio Responsive Interregional Deployment of Electrification Solutions (RIDES)[3]	Southeast Ohio Public Energy Council	Electric charging
I-25	Colorado with Hydrogen Refueling Infrastructure on the I–25 Corridor (Hy–25)[4]	Colorado State University	Hydrogen refueling
I-24	CFI Round 2 Corridor Proposal[5]	Tennessee Department of Environment and Conservation	Electric charging

[2] www.fhwa.dot.gov/environment/cfi/grant_recipients/round_2/cfi-awardees-round2.pdf.
[3] www.fhwa.dot.gov/environment/cfi/grant_recipients/round_1b/cfi-awardees-project-description-table_round_1b.pdf.
[4] www.fhwa.dot.gov/environment/cfi/grant_recipients/round_1a/cfi-awardees-project-description-table.pdf.
[5] www.fhwa.dot.gov/environment/cfi/grant_recipients/round_2/cfi-awardees-round2.pdf.

Highway	Coalition name	Lead	Primary MHDV technology
I-15	Wasatch Front Multi-Modal Corridor Electrification Plan[6]	Utah State University ASPIRE Center	Electric charging and Hydrogen refueling
	Mega Charging the I-15 Corridor[7]	Greenlane Infrastructure	Electric charging
I-10	I-10 Shipper-Carrier Coalition	Smart Freight Centre	Electric charging
	Houston to Los Angeles (H2LA) I-10 Hydrogen Corridor Project	GTI Energy	Hydrogen refueling
	Supercharging the Southwest: Charging Deployment Along the I-10 Corridor[8]	Terawatt Infrastructure	Electric charging
I-5	San Joaquin Valley I–5 Electric Freight Corridor (Valley EFC) Project[9]	San Joaquin Valley Unified Air Pollution Control District	Electric charging
	West Coast Truck Charging and Fueling Corridor Project	Caltrans	Electric charging and Hydrogen refueling
I-580	Bay Area Medium and Heavy-Duty Vehicle Electrification Report	RMI	Electric charging
I-710	First to Last Mile: Creating an Integrated Goods Movement Charging Network around the I-710 Corridor	Los Angeles Cleantech Incubator (LACI)	Electric charging

As table 9 illustrates, some coalitions are working to deploy electric charging infrastructure along highways, while others are prioritizing hydrogen infrastructure. Technology priorities and planning approaches can vary in different sections of a corridor as well as within the same corridor. For example, GTI Energy was awarded $1.25 million by the DOE to develop a blueprint for a hydrogen refueling network along I-10 between Houston, Texas, and Los Angeles, California. The DOE also awarded $20 million to Terawatt Infrastructure to develop a charging site along I-10 in Arizona ("Supercharging the Southwest"), featuring MCS chargers, battery storage, and solar panels. Meanwhile, the I-10 Shipper-Carrier coalition is working to test electric truck operation between Los Angeles and El Paso, Texas. Finally, some coalitions are investigating or investing in both types of infrastructure.

This corridor-by-corridor approach may lead to fragmentation as described above, with some corridors lacking the hydrogen refueling infrastructure needed to support hydrogen trucks and others lacking sufficient electric charging infrastructure. Funding both networks along the same corridor, as we see in I-10 and other corridors, also risks delaying the completion of either network.

[6] utahelectrification.com/2024/10/25/multi-modal-planning/.
[7] www.energy.gov/eere/articles/doe-invests-68-million-innovative-heavy-duty-electric-vehicle-charging-solutions.
[8] www.energy.gov/eere/articles/doe-invests-68-million-innovative-heavy-duty-electric-vehicle-charging-solutions.
[9] www.fhwa.dot.gov/environment/cfi/grant_recipients/round_1a/cfi-awardees-project-description-table.pdf.

Strategic recommendations

Develop partnerships to ensure corridor connectivity

State departments of transportation (DOTs) and state energy offices can formalize cross-border coordination by entering memoranda of understanding (MOUs) with neighboring states along key freight corridors. One example of a series of states already coordinating is the Clean Corridor Coalition of New Jersey, Connecticut, Delaware, and Maryland collaborating on rolling out charging infrastructure along a portion of I-95. Together, states can jointly identify gap segments where infrastructure is missing and develop joint grant funding and coordinate grant applications. Regular interstate coordination meetings can help ensure projects remain synchronized as plans evolve. Leveraging existing networks such as the National Association of State Energy Officials (NASEO)/American Association of State Highway and Transportation Officials (AASHTO) EV Charging Network Regional Working Groups can help corridor coalitions learn from others.

Identify ZEV-ready sites

A key function of state corridor partnerships can be to proactively designate priority nodes along freight corridors and at major freight hubs where zero-emission infrastructure is most likely to be viable over time. Better leveraging existing planning efforts, such as state freight plans, metropolitan planning organization (MPO) long-range transportation plans, port master plans, and corridor studies can maximize the value of prior data collection and stakeholder engagement and reduce duplication of effort in siting decisions.

States can work with MPOs, freight stakeholders, utilities, and local governments to develop a prioritized inventory of sites prime for development along key corridors and near major freight hubs, including ports, intermodal facilities, warehouse and distribution clusters, and major truck stops with adequate parking and driver amenities. Site consideration can also include grid capacity considerations when possible. This inventory can guide funding decisions, support coordinated utility planning, and provide clarity to private developers and fleets. Over time, these priority sites can be rapidly activated as vehicle adoption increases and technology choices become clearer, enabling a more adaptive and cost-effective transition to zero-emission freight corridors.

To preserve flexibility while managing risk, states can invest in preparation to make sites attractive to developers. This can include nonfunded approaches such as ensuring compatible zoning, creating expedited permitting pathways, and providing clear interconnection guidance and single points of contact within state agencies. More extensive approaches can include leveraging publicly controlled properties when appropriate, upgrading or reserving electrical interconnection capacity, and planning for expansion for existing sites receiving state or federal funds by installing conduit and/or designing truck-accessible layouts that can accommodate future expansion. By advancing these enabling steps, states reduce development timelines and uncertainty for future charging or fueling projects. These additional ZEV-ready sites can also help resolve truck parking issues, a perennial problem and major safety issue.

Treat grid readiness as the critical path

Grid readiness is likely to be a primary constraint on the pace of zero-emission freight corridor deployment, particularly as charging hubs grow to multimegawatt scale. Utilities should prioritize grid upgrades and align capital investments with anticipated charging hub development. Coordinating with DOTs and energy offices can help utilities plan substation and feeder upgrades more efficiently, while make-ready programs can reduce uncertainty and upfront costs for developers.

At the site level, charging companies should engage utilities early and design hubs that can scale over time rather than installing maximum capacity upfront. Fleets can support grid readiness by participating in managed charging programs where possible, helping to reduce strain on the grid. State DOTs and energy offices can reinforce grid readiness by convening utilities, developers, and freight stakeholders early in the planning process and by integrating electrical constraints into corridor siting decisions.

ZEV-ready site planning should be paired with utility proactive planning, make-ready programs, hosting-capacity mapping, and clear cost-allocation rules. Public utility commissions (PUCs) play a central role by directing utilities to incorporate freight charging load into proactive distribution and transmission planning and by requiring hosting capacity maps. Since grid planning in states typically follows a reactive approach, PUCs also have the authority to direct utilities to undertake proactive grid planning. Massachusetts, Minnesota, and New York are three states where long-term grid upgrades and proactive planning are underway as part of commission dockets (MDPU 2025; MNPUC 2024; NYPSC 2024). Utilities can also coordinate with their regulatory commissions to pursue proactive grid planning dockets, starting with a preliminary assessment of potential electric fleet loads in their service territory followed by initial discussions and consultations with the commission to justify the need for a proactive planning grid proceeding. ACEEE's Utility Planning for Electric Truck and Bus Fleets toolkit provides a seven-step process for how utilities can work closely with the utility regulators to propose and implement a proactive grid planning proceeding for medium- and heavy-duty EV loads (Nadel 2024b).

State and site-level planning must also coordinate with broader regional grid planning efforts. Grid-readiness is an issue that reaches beyond state boundaries and requires additional and proactive regional planning and coordination to ensure adequate and reliable power while minimizing impacts on current ratepayers. For example, recent Federal Energy Regulatory Commission (FERC) orders (1920, 1920-A, and 1920-B), all relate to ensuring that long-term regional transmission planning is conducted in partnership with states. Long-term capacity needs and policy goals of individual states must roll up into regional planning efforts when developing new transmission plans and determining cost-allocation processes (FERC 2025). Some regional grids, such as PJM, are already facing critical capacity constraints that limit interconnection of new large loads (Howland 2026). Improved state and regional coordination can help limit capacity issues that may slow transition timelines.

Prioritize shared charging hubs

States should prioritize public investment in shared, high-throughput charging hubs with the goal of attracting private capital. Public funds should be used to de-risk early investments. Funding criteria should favor MHDV hubs that serve multiple users and vehicle classes, including a mix of regional and long-haul operations. Guidance released in August 2025 explicitly permits using National Electric Vehicle Infrastructure (NEVI) formula funds for medium- and heavy-duty charging infrastructure. Other sources of funds from federal, state, and regional programs offer a variety of innovative funding mechanisms to encourage private sector investment.

To reinforce shared use, state programs can require public or subscription-based access as a condition of funding. Subscription models may be appropriate where reservations or fleet coordination are needed, but programs should avoid allowing public funding for exclusive access sites that prevent broader freight use. States can also encourage interoperability by requiring common payment systems and standardized connector types to ensure drivers can reliably access charging across locations and operators.

In addition to chargers themselves, states should fund truck-accessible site design that reflects the operational needs of MHDVs. This includes pull-through parking for tractors with trailers, sufficient queuing space to prevent spillback onto public roads, and circulation designs that accommodate large turning radii. Supporting amenities such as restrooms, lighting, security, and food access improve driver experience and help align charging events with federal hours-of-service requirements. These design elements are often cost prohibitive for private developers to finance alone but are essential for making hubs functional and able to meet the needs of truck drivers.

States can further accelerate deployment by coordinating with local governments and land-use authorities to streamline zoning, permitting, and environmental review for large freight charging hubs. This may include prezoning industrial or logistics areas for high-power charging, establishing clear permitting pathways for multimegawatt electrical infrastructure, and creating standardized design templates to reduce project-by-project review. In some cases, particularly in more remote locations, states may also play a role in land assembly or long-term site control to reduce risk for developers.

Use stage gates to prevent stranded hydrogen assets

A technology-neutral corridor map is a useful tool for early alignment, but infrastructure investment decisions are not neutral. As the analysis in this report shows, hydrogen refueling systems are significantly more capital intensive than charging infrastructure. Hydrogen infrastructure also carries higher utilization and fuel-supply risk, particularly in early deployment phases. These risks are magnified when public funding is limited and must support near-term, reliable corridor functionality. State DOTs, energy offices, and corridor coalitions should therefore shift from technology-neutral planning to technology-disciplined investment, treating battery electric truck charging as the default, near-term "no-regrets" backbone.

This does not diminish hydrogen's potential value across the broader energy system. Hydrogen may ultimately play a more significant role in other sectors such as industrial processes or energy storage. As this paper's cost results demonstrate, attempting to build both charging and hydrogen networks for trucks under constrained funding risks fragmenting investment, underbuilding both systems, and delaying real-world corridor usability.

Where states and regions seek to preserve hydrogen optionality for freight, they should adopt phased, conditional, stage-gated investment frameworks that test not only market demand but also technology readiness and operational performance. Assessments of future infrastructure demand for electric and hydrogen infrastructure should be better coordinated. Corridor plans should be revisited regularly to reassess technology assumptions based on deployment data and on-the-ground experience. Taken together, a technology-disciplined, stage-gated approach allows states to support learning and innovation around hydrogen where it is most appropriate while avoiding locking public dollars into underutilized, high-cost assets.

Center community protection in siting decisions

Because pollution from medium- and heavy-duty vehicles is concentrated around freight corridors and facilities, infrastructure planning should explicitly prioritize community health and protection. States and MPOs can do this by integrating air quality, health, and environmental justice data into corridor planning and directing early zero-emission freight investments to communities with the highest exposure to diesel pollution. Targeting these locations first can deliver near-term public health benefits while accelerating diesel displacement where it matters most. Success should be measured not only by stations installed, but by outcomes such as diesel displacement and improvements in local air quality.

States can pair charging hub investments with complementary measures like truck parking management, anti-idling enforcement, and local workforce pathways to reduce impacts and share benefits. Meaningful community engagement early in the siting process can help identify concerns and inform design.

Conclusion

Zero-emission freight corridors will only succeed if states plan and invest beyond their own borders. Coordinated action on station siting, deployment timelines, and funding strategies is essential to create continuous, usable networks and avoid fragmented, high-cost infrastructure. As battery electric truck technology continues to improve, including the recent introduction of longer-range semi models, poor coordination and delayed infrastructure deployment risk becoming a binding constraint on adoption. Early preparation of ZEV-ready sites and alignment with utility proactive planning can significantly shorten deployment timelines, reduce future upgrade costs, and preserve flexibility as freight demand grows.

In the near term, battery electric charging represents the lowest-risk and most mature investment pathway and should form the backbone of early corridor development. Charging technology is commercially proven, can be deployed incrementally, and aligns with existing grid planning processes. In contrast, hydrogen refueling technology remains less developed, significantly more expensive, and dependent on uncertain fuel supply and demand dynamics. It is unclear whether hydrogen infrastructure will advance quickly enough to match the pace and reliability of battery electric systems. As a result, hydrogen investments should proceed cautiously through phased, demand-tested approaches to avoid stranded, underutilized assets.

To maximize public return on investment, states should prioritize shared, truck-ready charging hubs that serve multiple fleets and vehicle classes and are designed for real-world freight operations, enabling high utilization and scalable growth. While the private sector will bear much of the infrastructure cost, targeted public investments and coordinated planning can reduce permitting delays and de-risk projects, accelerating deployment and unlocking substantial public benefits in air quality and climate outcomes. Targeting early deployments in communities with the highest diesel exposure helps ensure that freight electrification delivers visible air quality, health, and equity benefits alongside emissions reductions.

Appendices

Appendix A. Detailed methodology

Fuel demand

The total fuel demand projections are determined using the projected share of electric and hydrogen fuel cell trucks with the estimates of Classes 4–8 truck stock, vehicle miles traveled (VMT), and current and projected efficiency levels for each zero-emission vehicle (ZEV) type. The VMT are limited to trips of 200 miles or greater. These factors determine the total electricity and hydrogen demand by vehicle type and class. The vehicle stock data and VMT data are based on the U.S. Department of Transportation's (DOT) Vehicle Inventory and Use Survey (VIUS) data and are projected based on the Department of Energy's (DOE) Annual Energy Outlook projections (EIA 2025; Bureau of Transportation Statistics 2025). The model then allocates this total fuel demand between public and private stations based on the scenario assumptions. The estimated fuel demand at public stations is then divided by the projected number of stations each year (described below) to determine the average fuel demand by station.

The on-road ZEV projection is based on a ZEV sales projection and a fleet-turnover model using assumptions on survival rates and annual VMT by age of a vehicle from Argonne National Lab's VISION model (Argonne National Laboratory n.d.-b). The sales projection is based on California's Advanced Clean Trucks rule which requires 55% ZEV sales by 2035 (California Air Resources Board n.d.). Sales then grow linearly until they reach 95% ZEV sales in 2040 to mirror the goal in the National Zero-Emission Freight Corridor Strategy (NZEFCS). The adoption rate is the same across all classes and between battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs). We assume 95% to allow for a small amount of conventional trucking where ZEVs may not be suitable.

Our fleet turnover model projects how many vehicles of a model year will be on the road in each year using survival rates from the VISION model, which is the percentage of vehicles that are retired at every year of age. Many trucks, especially Classes 7 and 8 trucks, can stay on the road for decades but are not driven the same throughout their life. Older vehicles have lower annual VMT so projecting the percentage of on-road trucks that are ZEVs would underestimate the percentage of VMT that are from ZEVs given that ZEVs will be younger than many ICE trucks. For fuel demand projects, the percentage of VMT from ZEVs is more important than the percentage of trucks on the road that are ZEVs, so the model weights the survival rates by the annual VMT rate assumptions in the VISION model as well. The assumptions in the VISION model for Classes 7–8 diesel sleeper trucks were used because the vast majority of trips over 200 miles are by Classes 7–8 trucks and sleeper trucks have higher annual VMT than day cab trucks, the other option in VISION (Argonne National Laboratory n.d.-b).

In 2040, only 35% of on-road Classes 4–8 trucks are ZEVs but they represent 55% of VMT in that year, as shown in figure A1. By 2050, 70% of on-road trucks are ZEVs and they represent 87% of VMT. Using our VMT-weighted survival rates, over 10% of VMT are still being driven by trucks 17 years and older so the percentage of VMT from ZEVs does not reach 95% (the peak sales percentage) until past 2060.

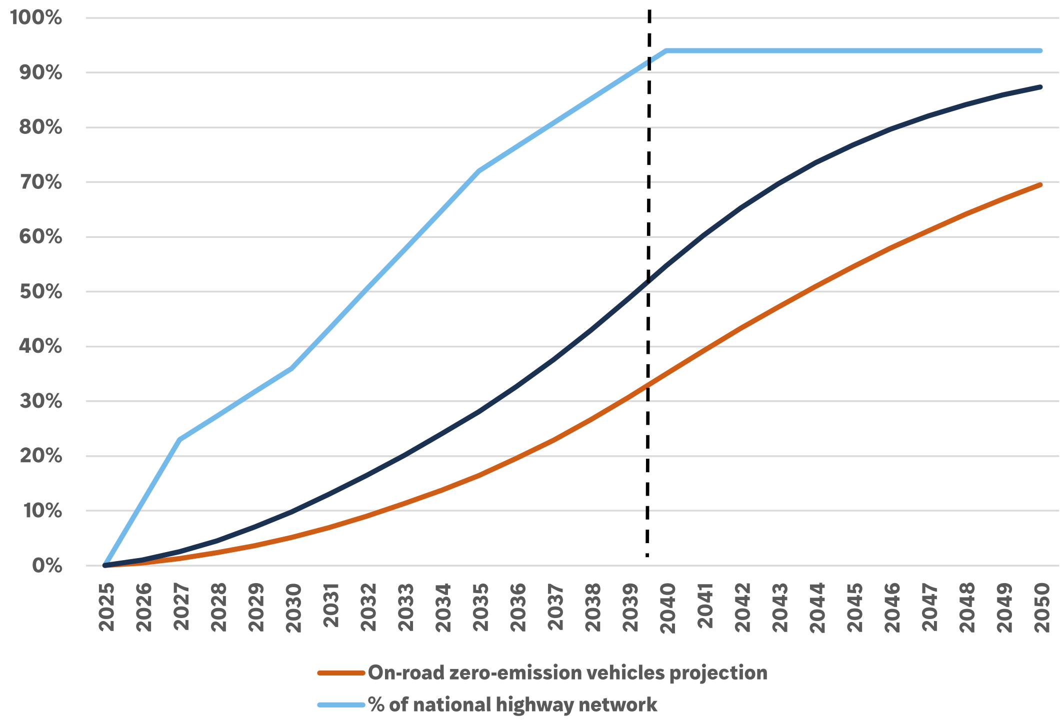


Figure A1. Percentage of vehicles on-road that are ZEVs, percentage of on-road VMT from ZEVs, and percentage of national highway network that is ZEV capable.

Our efficiency levels are based on numerous sources and we improve efficiency for all classes and fuel types over the 2025–2040 period, although at different rates, ranging from 0.5% to 1.8%. We also have the same efficiency rates for Classes 4–6, in line with many of our sources (California Transportation Commission 2023; Basma et al. 2023; Wood et al. 2024; Burke and Sinha 2020). Our efficiency rates are shown in table A1.

Table A1. Efficiency levels for ZEVs by class and fuel type

Fuel type	Vehicle class	Unit	2025	2026	2027	2028	2029	2030	2031	2032
Hydrogen	4	kg/mi.	0.060	0.060	0.059	0.059	0.059	0.059	0.058	0.058
Hydrogen	5	kg/mi.	0.060	0.060	0.059	0.059	0.059	0.059	0.058	0.058
Hydrogen	6	kg/mi.	0.060	0.060	0.059	0.059	0.059	0.059	0.058	0.058
Hydrogen	7	kg/mi.	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11
Hydrogen	8	kg/mi.	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12
Electric	4	kWh/mi.	0.70	0.70	0.69	0.69	0.68	0.68	0.68	0.67
Electric	5	kWh/mi.	0.70	0.70	0.69	0.69	0.68	0.68	0.68	0.67
Electric	6	kWh/mi.	0.70	0.70	0.69	0.69	0.68	0.68	0.68	0.67
Electric	7	kWh/mi.	2.20	2.17	2.13	2.10	2.07	2.04	2.01	1.98
Electric	8	kWh/mi.	2.30	2.26	2.22	2.18	2.14	2.10	2.06	2.03

			2033	2034	2035	2036	2037	2038	2039	2040
Hydrogen	4	kg/mi.	0.058	0.057	0.057	0.057	0.056	0.056	0.056	0.056
Hydrogen	5	kg/mi.	0.058	0.057	0.057	0.057	0.056	0.056	0.056	0.056
Hydrogen	6	kg/mi.	0.058	0.057	0.057	0.057	0.056	0.056	0.056	0.056
Hydrogen	7	kg/mi.	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10
Hydrogen	8	kg/mi.	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11
Electric	4	kWh/mi.	0.67	0.66	0.66	0.66	0.65	0.65	0.64	0.64
Electric	5	kWh/mi.	0.67	0.66	0.66	0.66	0.65	0.65	0.64	0.64
Electric	6	kWh/mi.	0.67	0.66	0.66	0.66	0.65	0.65	0.64	0.64
Electric	7	kWh/mi.	1.95	1.92	1.89	1.86	1.84	1.81	1.78	1.75
Electric	8	kWh/mi.	1.99	1.95	1.92	1.88	1.85	1.82	1.78	1.75

State by state build-out

The percentage of network miles nationwide that have ZEV-refueling stations is based on the NZEFCS, which has the build-out occurring in four phases between 2025 and 2040. Each phase has different segments of corridors being made ready for ZEVs until 94% of the network has stations by 2040. We modified the years for each phase slightly from the NZEFCS given that their build-out starts in 2024 while ours starts in 2025. We use this phasing to determine the rate at which corridor miles are built out. We use the data from the NZEFCS to calculate for each phase what percentage of its total miles are attributable to each state. The outputs from the model are based on each phase, values detailed in table A2. As a result, some states build-out their networks faster than others based on the prioritization inherent in the NZEFCS.

To determine the number of stations in each state, we assume states receive enough stations to have a minimum viable network on their corridors that have been built out according to NZEFCS. This number of stations is lower than the nationwide spacing requirement for the two types of stations. Additional stations to meet the nationwide spacing requirement are allocated to states based on their average freight volume per mile of freight corridor. This ensures that states with significant freight volume receive more stations but that each state has a minimum viable network.

Table A2. Phases of build-out in model

	Phase 1	Phase 2	Phase 3	Phase 4
Years	2025–2028	2029–2031	2032–2036	2037–2040
Percentage of network miles made ZEV capable	27%	16%	33%	18%

Station number and capacity

The nationwide number of hydrogen refueling and electric charging stations are determined by dividing the number of miles in the freight network that are ZEV-capable in a given year by the minimum spacing for each station type. The minimum spacing for hydrogen stations begins at a station every 200 miles in 2025 but that value falls linearly to every 50 miles by 2040 in all scenarios except for scenario 6. In scenario 6, the spacing for hydrogen stations stays constant at 200 miles and provides a lower bound estimate for the number of hydrogen stations required. For charging stations, it is every 50 miles in 2025 falling linearly to every 30 miles in 2040. The 2025 values represent the minimum density of stations of each type to ensure vehicles can reach stations when they need to refuel given their ranges. These values represent a minimum viable system and we assume that over time more stations will be built, reflected in lower spacing values in 2040.

The total fuel demand each year is divided up by the total number stations each year, for each fuel type, to determine the fuel demand at each station. This value represents the actual fuel distributed at each station and does not vary across stations. However, this value is lower than the maximum refueling capacity of a station, which is needed to determine costs. Both station types have a utilization rate measured as the percentage of maximum capacity that is actually delivered over the course of a day or year. For hydrogen refueling stations that value is 40% and is constant across all years. For charging stations, the value is 20% in 2025 and rises linearly to 40% by 2040. There is lower utilization in the beginning for charging stations to account for need to ensure minimum refueling coverage for relatively small number of electric trucks on the road. As the number of electric trucks on the road grows, the utilization at each charging station grows. Fuel cell trucks have greater range and need fewer stations, meaning the utilization at each station can be greater in the beginning.

In addition to utilization, the built capacity of stations is also determined by hydrogen loss rates for hydrogen refueling stations and charger efficiency rates for charge stations. The hydrogen loss rate is 2% per year, meaning that only 98% of the maximum refueling capacity can actually be delivered (Trapani et al. 2025). For charging stations, the efficiency rate is 90%, meaning that chargers can only deliver 90% of their nameplate efficiency. Dividing the fuel demand at each station by utilization and either the hydrogen loss rate or charger efficiency, for hydrogen and charging stations respectively, determines the built capacity. Additionally, for charging stations, the actual build capacity is also adjusted to be the sum of a discrete number of 350-kW and 1-MW chargers with a 60%–40% breakdown between the two. For example, if the calculation using utilization and charger efficiency determines the built capacity per station to be 4 MW this value would be adjusted to be a station made up of seven 350-kW chargers and two 1-MW chargers totaling 4.45 MW.

Per-station capacities are calculated for each year and that is the value that new stations in that year are built to. Existing stations are also upgraded annually to match that value such that all stations, regardless of when or where they were first built, have the same capacity in each year. While it is more likely that stations would receive larger upgrades periodically than receive small upgrades annually, this simplifying assumption should not affect average per-station capacity or overall capacity. Small annual upgrades at all stations can be thought of as the average of larger upgrades to a smaller subset of stations each year. The model also assumes that built capacity never declines because we assume stations would not lose capacity over time so there can be years when existing stations do not need to be upgraded to a greater capacity level.

Station costs

Costs are calculated based on the costs of building new stations and additional costs to upgrade existing stations to a higher refueling capacity. We assume that all stations of each fuel type have the same capacity each year and that existing stations are brought up to this new capacity every year. The costs for H_2 refueling stations and charging stations are determined using different methodologies. H_2 refueling stations have a fixed cost based on construction and other related costs and a cost associated with capacity, informed by real-world data collection efforts and stakeholder consultation, expressed in $ per kg/day of capacity. The real-world data collection efforts consisted of compiling a dataset of 148 projects planned or built in the United States between 2009 and 2029. Data were compiled from the U.S. Department of Energy's (DOE) Alternative Fuels Data Center, H2StationMaps.com, the California Fuel Cell Partnership station map, regulatory filings with the California state government, and public news releases. The capacity costs begin at about $2,500 per kg/day of station capacity and decline 1% annually reaching about $2,200 per kg/day. The decline in cost over time is in line with other forecasts.

The fixed cost stays constant in real terms at about $1.2 million in 2025 dollars and the per-capacity costs decline over time due to economies of scale. We assume all H_2 refueling stations have offsite H_2 production and annual upgrades in capacity do not trigger additional fixed costs. Our hydrogen station costs were calculated based on real-world data collection, were adjusted to 2025 dollars, and were validated by external estimates and stakeholder consultation (Bracci et al. 2024; Fulton et al. 2024). Charging station costs consist of equipment costs and installation costs for each charger type: 350-kW or 1-MW chargers. Equipment costs decline in real terms over time due to improved manufacturing while construction and installation costs decline based on economies of scale. Charger equipment costs begin at about $180,000 per 350 kW charger and about $440,000 per 1 MW charger in 2025. The greater number of chargers installed at a site, the lower the per-charger installation costs. These values are drawn from literature and adjusted to $2025 (Wang et al. 2023; Lanz et al. 2022; Wood et al. 2024, 2023; Argonne National Laboratory n.d.-a).

Appendix B. Glossary of terms

Advanced Clean Trucks (ACT): This California heavy-duty zero-emissions vehicle sales mandate requires greater sales of zero-emissions vehicles (ZEVs) by 2035 and can be adopted by other states. Sales requirement varies by vehicle class: 40% ZEVs by 2035 for Classes 7–8 tractor trucks, 55% for Classes 2b–3, and 75% for Classes 4–8 non-tractor trucks.

Battery capacity: The amount of energy that a battery can store, often measured in kilowatt-hours.

Battery electric vehicle or truck (BEV or BET): Vehicle or truck that relies on a battery for propulsion and is charged via the electricity grid.

Built capacity: For refueling stations, the maximum refueling capacity or how much fuel they can deliver over a period of time.

Clean hydrogen: Hydrogen with a carbon intensity of less than or equal to four kilograms of CO_2 equivalent produced for every kilogram of hydrogen produced.

DC fast charging (DCFC): Chargers using direct current (DC) power to charge battery electric vehicles at high speed, typically 150 kilowatts or higher. Also known as Level 3 charging.

Depot: Private location for fleet managers to store, service, maintain, or refuel commercial vehicles.

Dwell time: Time spent by a driver at a facility to load or unload cargo.

Green hydrogen: Hydrogen produced using an electrolyzer that uses electricity generated from renewable sources to split water into hydrogen and oxygen.

Hydrogen fuel cell vehicle or truck (FCEV or FCET): Vehicle or truck that uses an electric motor and has a battery that is charged using an on-board fuel cell to produce electricity using hydrogen.

Infrastructure Investment and Jobs Act (IIJA): Also known as the Bipartisan Infrastructure Law, this 2021 law invests significant sums in transportation investment, including $7.5 billion to expand electric vehicle charging infrastructure along key corridors.

Medium- and heavy-duty vehicles (MHDV): Medium-size and large commercial vehicles that have a gross vehicle weight rating of more than 14,000 lb.

National Highway Freight Network (NHFN): The highway network with the most critical portions of the U.S. freight transportation system as well as rural and urban corridors that provide access and connection to the highway freight system, ports, public transportation facilities, and other intermodal transportation facilities.

National Zero-Emission Freight Corridor Strategy (NZEFCS or Freight Corridor Strategy): National strategy to catalyze public and private investment and support utility and regulatory planning and action at local, state, and regional levels toward a comprehensive zero-emissions freight refueling network.

Payload: Revenue-generating cargo that is being moved by the vehicle.

Peak load or demand: Highest electrical demand observed over a period of time that often drives distribution, transmission, and electrical generation investments.

Public and semi-public stations: Stations that are either fully public and available to any fleet or requiring a reservation or subscription to access and shared between fleets.

Regional and long-haul trucking: For the purposes of this analysis, defined as trips of 200 miles or more.

Total cost of ownership (TCO): All costs to own or lease, operate, and maintain a truck over its life.

Upstream emissions: Emissions released during the production or generation of a fuel source, electricity or hydrogen.

Utilization: Percentage of time a refueling station is used or, as used for the purposes of this analysis, percentage of maximum refueling capacity that is actually delivered over a period of time.

Vehicle classes: All vehicles are broken into classes numbered 1 through 8 based on their weight.

Zero-emission vehicles (ZEV): Vehicles without tailpipe emissions including electric vehicles and hydrogen fuel cell vehicles.

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