Institute for Energy Economics and Financial Analysis

# Bad News for Blue Hydrogen

*The Small and Shrinking Market Potential for Hydrogen Fuel Cell Vehicles*

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# Key Findings

**The U.S. Department of Energy is negotiating with several selected companies to establish regional hydrogen hubs that derive hydrogen from methane. They will be costly, and DOE must ask hard questions before it commits the funding.**

**DOE is under pressure to put the cart before the horse—to build hydrogen projects based on unproven technologies and undemonstrated markets.**

**By the time DOE's selected applications are processed and the surviving projects are built, EV market trends will have expanded the already strong role of BEVs substantially, weighing against most vehicular uses of hydrogen.**

**If DOE fails to exercise discretion in reviewing and finalizing the hydrogen project proposals the result is likely to be a substantial waste of taxpayer dollars for an outsized hydrogen-based economy that will never arrive.**

# Executive Summary

The U.S. Department of Energy (DOE) is negotiating with several selected companies to establish regional hydrogen hubs (H2Hubs) that derive hydrogen from natural gas (methane). The Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law, makes $8 billion in funding available for such projects.[1] The hydrogen hubs are intended to be commercial-scale developments, not small pilot projects. They will be costly. DOE must ask hard questions before it commits the funding.

Producing hydrogen from fossil fuels does not make sense as a climate strategy. IEEFA's 2023 report, "Blue Hydrogen: Not Clean, Not Low Carbon, Not a Solution," shows that blue hydrogen—derived from the methane in natural gas, a fossil fuel—will not meet the federal definition of clean hydrogen, and would worsen greenhouse gas (GHG) emissions.[2]

The scale of the hydrogen push also does not make sense from an economic perspective. Despite the influx of federal funding, the long-term viability of the proposed hydrogen hubs will likely still be ruled by actual market forces. In a 2022 report, IEEFA found hydrogen had an extremely limited future in the market, warning that the H2Hubs may be obsolete before they launch.[3] With the rapid advances in battery electric technology and sustained growth in its market share, the market scenario for hydrogen in vehicular transportation is even more troubling today.

Public dollars should not be sunk into projects that are likely to fail to achieve financial viability due to a weak market.

Six of the seven hydrogen hubs selected by DOE to receive federal funding intend to market some portion of the hydrogen gas for use in transportation. The projects must be scrutinized closely for market risk, even if the developers identify initial offtakers. The infrastructure required will take some years to develop. Given market trends, time is not on hydrogen's side.

Most of the H2Hub proposals encouraged by DOE—and other privately funded projects—plan to market some of their product to the transportation sector. This IEEFA report, part of a series, examines the dwindling market for hydrogen in vehicular transportation. The report finds:

- DOE makes unrealistic assumptions about the vehicle market for hydrogen. In 2020, it projected hydrogen could power 18% of cars and 26% of light-duty trucks. Now, just three years later, the agency recognizes hydrogen technology has lost to battery electric technology in the light-duty vehicle market. Although DOE still expects broad use of hydrogen in medium-duty trucks, that is not likely to happen. Even the heavy-duty truck market is likely to be substantially smaller than expected.

[1] Infrastructure Investment and Jobs Act, P.L. 117-58, 135 Stat. 429 (enacted November 15, 2021).
[2] IEEFA. Blue hydrogen: Not clean, not low carbon, not a solution. September 12, 2023.
[3] IEEFA. Blue Hydrogen Has Extremely Limited Future in U.S. Energy Market. February 2022.

- Battery electric vehicles (BEVs) will dominate the U.S. market for zero-emission passenger cars, pickup trucks and other light vehicles because car manufacturers and customers have overwhelmingly moved in that direction.[4] BEV driving range per charge is improving and charging stations are rapidly rising in number and nationwide distribution. For hydrogen fuel cell electric vehicles (FCEVs), in contrast, filling station infrastructure essentially exists only in one state, California. Hydrogen has fallen too far behind to catch up.

- Battery technology is making significant inroads into bus and medium-duty truck sales, and is already predicted to dominate the zero-emission medium-duty truck market. Projections indicate battery technology also is likely to capture most of the short-haul heavy-duty truck market.

- BEVs may well encroach on the regional long-haul market. Only 9% of U.S. trucks are engaged in long-haul service, defined by DOE as trucking more than 250 miles, and within that segment, an even smaller portion accounts for trips of a distance of 1,000 miles or more. For example, a 2022 survey found such longer hauls constituted less than one-seventh of fleet operators' truck trips.

FCEVs lag far behind as BEVs move quickly to take market share. Market factors indicate hydrogen technology will not be the most economical, practical or widely-adopted option to decarbonize vehicles, with only very limited exceptions.

DOE is under pressure to put the cart before the horse—to build hydrogen projects based on unproven technologies and undemonstrated markets.[5] But the agency has statutory authority to use good judgment to avoid sinking tax dollars into white elephants.[6] DOE should scale any investment of tax dollars in hydrogen to the narrow realities of the market.

[4] Frequently, battery electric vehicles are simply called EVs, but vehicles powered either by batteries or by hydrogen fuel cells are electric vehicles, so the term BEV is more precise.
[5] IEEFA. The Energy Department's hydrogen gamble: Putting the cart before the horse. February 28, 2023.
[6] IEEFA. Energy Department should only spend public funds on hydrogen hub projects that are practicable. April 7, 2023.

# Background: Doubts Among Investors Regarding the Commercial Viability of Hydrogen

The Houston Chronicle ran a story in June that asked an insightful question: "Clean hydrogen is all the rage, so why is Wall Street holding back?"[7] Despite a whirlwind of publicity and project announcements following enactment of the Bipartisan Infrastructure Law in 2021, which was boosted by the Inflation Reduction Act (I.R.A.) of 2022,[8] the amount of private investment in hydrogen development has been comparatively small. Wind and solar project funding is almost 35 times greater. Investment in battery projects is roughly eight times greater.[9]

DOE acknowledges new hydrogen production projects are facing challenges in obtaining sufficient investment, primarily due to concerns about market demand. It admits:

> "Of the 12 MMT [million metric tons]/year of clean hydrogen production capacity announced in the U.S. to date, only ~10 percent has achieved final investment decision (FID), largely due to this lack of long-term offtake."[10]

The investment issue is even more stark globally. In its *World Energy Outlook 2023* report, the International Energy Agency (IEA) observed only 4% of announced projects for low-emissions hydrogen have taken a final investment decision (FID).[11] The IEA stated the small number of low-emission hydrogen projects reaching FID is "due to uncertainties around the future evolution of demand, the lack of clarity about certification and regulation and the lack of infrastructure available to deliver hydrogen to end users."[12] It recently reduced its projections of hydrogen's contribution to the overall energy mix in its 2023 Net Zero Roadmap, stating that neither the public nor private sector support has ramped up at the pace envisaged in its 2021 NZE (net-zero emissions) scenario.[13]

Federal funding commitments and incentives are not enough to move hydrogen projects forward if private lenders are not on board. The dearth in investment calls into question when—or whether—the hydrogen facilities selected by DOE will be completed.

Investor reluctance, in turn, is based on when or whether such projects will generate reliable profits. The Motley Fool recently advised investor caution, despite what it feels are potential roles for hydrogen, suggesting a wait-and-see approach:

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[7] Houston Chronicle. Clean hydrogen is all the rage, so why is Wall Street holding back? June 4, 2023.
[8] The Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law, P.L. 117-80, was signed into law in November 2021. The Inflation Reduction Act (I.R.A.), PL. 117-169, was signed in August 2022.
[9] Houston Chronicle, *op. cit.* Also see: Axios. Tracking the flow of clean energy investment. August 16, 2023.
[10] DOE. U.S. National Clean Energy Strategy and Roadmap. June 2023 (hereafter, DOE National Clean Energy Roadmap), p. 49.
[11] IEA. World Energy Outlook 2023. October 2023, p. 85.
[12] IEA. Tracking Clean Energy Progress. July 2023, hydrogen section. In this July publication, IEA had reported the percentage of projects reaching FID as 5%. By October, as noted above, its estimate had been lowered to 4%.
[13] IEA. Net-Zero Roadmap: A global pathway to keep the 1.5°C goal in reach. 2023 Update. September 2023 (hereafter, IEA Net Zero Roadmap 2023 Update), pp. 78-79.

> "[H]ydrogen is still developing as a commercially viable fuel source. The industry needs to scale and reduce costs to become competitive with fossil fuels and other emerging technologies like battery storage. Investors might want to watch the sector for a while as they gauge which companies have the best chances of emerging as long-term winners."[14]

The Houston Chronicle similarly observed that "it remains unclear to many who would buy the hydrogen once projects are built."[15]

It's rather late in the game for hydrogen to be in the position of having to bolster belief in its commercial viability.

BEVs and FCEVs have been competing to decarbonize vehicle transportation—a sector that accounts for 29% of GHG emissions in the United States, more than either electricity or industry.[16] Battery electric technology, however, has surged while hydrogen fuel cell technology and infrastructure lags far behind. The IEA cites only two sectors that are on track to achieve its 2021 recommendations for limiting global warming to 1.5 degrees Celsius above the pre-industrial average. The first is solar photovoltaic installations. The second is BEVs.[17]

# I. DOE's Assumption About the Future of Hydrogen Use in the Vehicle Sector Is Wrong

DOE reported in 2020 that hydrogen's existing market in U.S. transportation was negligible,[18] based on research by its National Renewable Energy Laboratory (NREL).[19] The NREL had projected at the time the potential market for hydrogen in fuel cell vehicles would be 29 million metric tons per annum (mtpa), including 21 mtpa for light-duty FCEVs and 8 mtpa for medium-to-heavy-duty FCEVs—not taking costs and competition into account.[20] But the NREL had calculated that the impact of cost and competition factors reduced its projection to 17 mtpa. The 17-mtpa projection assumed the use of 12 mtpa of hydrogen to power 18% of cars and 26% of light-duty trucks, plus 5 mtpa of hydrogen to power 22% of medium- and heavy-duty vehicles. DOE's 2020 Hydrogen Program Plan adopted the NREL 17 mtpa target in its Research & Development Success scenario, although it did not differentiate between light-duty and medium-to-heavy-duty FCEVs.[21]

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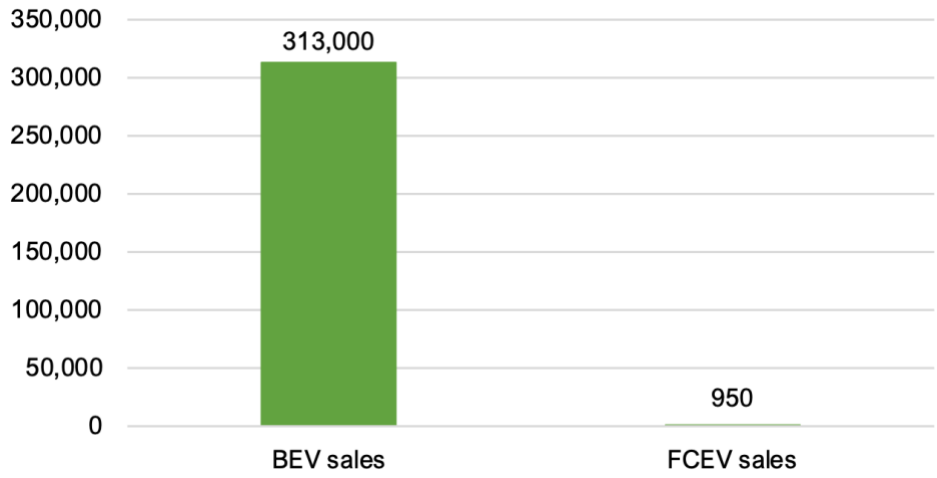
[14] The Motley Fool. 5 top hydrogen stocks to watch in 2023. Updated September 20, 2023.
[15] Houston Chronicle, *op. cit*.
[16] U.S. Environmental Protection Agency (EPA). Fast Facts on Transportation Greenhouse Gas Emissions. Last updated October 31, 2023 (hereafter, EPA Fast Facts on Transportation Greenhouse Gas Emissions).
[17] IEA Net Zero Roadmap 2023 Update, p. 13.
[18] DOE. Hydrogen Program Plan. 2020, p. 10, Table 2.
[19] NREL. The Technical and Economic Potential of the H2@Scale Concept Within the United States, NREL/TP-6A20-77610. October 2020 (hereafter, NREL H2@Scale Report), p. 48.
[20] *Ibid*, p. viii, Table ES-1. NREL based its predictions about hydrogen market potential on projections of market size in 2050. *Ibid*, p. vi, note 2.
[21] DOE. Hydrogen Program Plan, p. 10.

DOE's National Clean Hydrogen Strategy and Roadmap, issued in June 2023, abandons the 2020 assumptions about light-duty FCEVs. It continues to assume an 8 mtpa potential market for FCEVs, however, based on hydrogen fueling 10% to 14% of all medium-duty and heavy-duty trucks.[22]

Even that reduced projection is not likely to happen.

Consumers of zero-emission vehicles are already buying BEVs. U.S. purchases of BEVs during the third quarter of 2023 topped 313,000, and the year's total is expected to reach or exceed one million—four times higher than annual BEV sales In 2020 and a 49.8% increase from the same period just a year ago.[23] Light-duty vehicles account for the bulk of BEV sales, but—as discussed further in this report—significant inroads are being made in medium-duty vehicles and are expected even in heavy-duty vehicles. During the same quarter, only 950 FCEVs were sold.[24]

**Figure 1: Total BEV vs. FCEV Sales, First Through Third Quarter 2023[25]**




*Source: Cox Automotive.*

Six of the seven regional hydrogen hub proposals selected by DOE to receive federal funding intend to market some portion—as yet generally not publicly disclosed—of their produced hydrogen gas for use in transportation. In the early stage of DOE's H2Hub application process, the agency reviewed preliminary project descriptions. It has now begun negotiating with the selected applicants regarding project design and funding.[26] But this is just the beginning of the funding process. DOE contemplates four phases of development:

[22] DOE National Clean Energy Roadmap, pp. 17 and 19.
[23] Cox Automotive. Kelley Bluebook: Electric Vehicle Sales Report Q3 2023. October 12, 2023, p. 2.
[24] *Ibid*.
[25] *Ibid*.
[26] Also, Resources for the Future found most of the applications DOE encouraged before making its selection for funding, some of which may still go forward without that funding, included transportation among their targeted markets. Resources for the Future. Hydrogen Hubs: Get to know the encouraged applicants. February 7, 2023.

**Phase 1:** Initial planning and analysis to ensure each H2Hub's overall concept is technologically and financially viable.
**Phase 2:** Finalizing of engineering designs and business development, permitting, labor agreements and offtake agreements, with community engagement.
**Phase 3:** Installation, integration and construction activities.
**Phase 4:** Ramp-up to full operations.[27]

Conservatively speaking, the projects will not likely begin operations until some four to six years from now.[28] DOE's projected timeline for hydrogen market development does not show FCEVs playing a significant role until after 2030.[29] By then, the landscape for vehicles will have changed dramatically.

Although DOE has allocated $1 billion for development of demand-strengthening strategies,[30] each of the hydrogen hubs' long-term viability will likely depend on market forces. To the extent the hubs' market hopes depend on transportation, their profitability will be at risk due to the vigorous and rapidly advancing competition from BEVs.

# II. BEVs Will Overwhelmingly Dominate the U.S. Market for Zero-Emission Light-Duty Vehicles

Light-duty vehicles—such as passenger vehicles, sport utility vehicles (SUVs), minivans and other light-duty vans and pickup trucks—account for roughly 58% of GHG emissions from transportation in the United States.[31] Battery electric technology is dominating the field in decarbonizing these vehicles. The U.S. Energy Information Administration (EIA) reports that, as of the second quarter of 2023, electric vehicles and hybrids already make up 16% of light-duty vehicle sales,[32] and for reasons explained here, the percentage is likely to continue to increase.

[27] DOE. Bipartisan Infrastructure Law: Additional Clean Hydrogen Programs (§ 40214): Regional Clean Hydrogen Hubs Funding Opportunity Announcement, No. DE-FOA-0002779. Modified January 26, 2023.
[28] White & Case has developed a useful summary of the funding process. White & Case. Hydrogen hub projects awarded $7 billion by US Department of Energy. October 13,2023.
[29] DOE National Clean Energy Roadmap, p. 20, Figure 11.
[30] DOE. Request for proposals: Regional Clean Hydrogen Hubs demand side support, No. DE-FOA-003187. Last modified October 24, 2023. The deadline for applications was November 2. 2023.
[31] EPA Fast Facts on transportation Greenhouse Gas Emissions. The data is derived from EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2021.
[32] EIA. Electric vehicles and hybrids make up 16% of U.S. light-duty vehicle sales. September 7, 2023.

**Figure 2: Quarterly Light-duty Vehicle Sales in U.S. by Powertrain, 2014-2023**[33]


*Source: EIA.*
*Note: 2Q23 = second quarter of 2023.*

The trend for BEV dominance is strengthening. A Cox Automotive survey conducted in 2022 of 1,024 potential U.S. customers found 51% of them were considering buying a new or used electric vehicle, up from 38% in 2021.[34] The IEA boosted the projection in its most conservative scenario for BEVs' share of new vehicle sales globally in 2030 from 25% in its 2022 report to 40% in its 2023 report—a remarkable 15 percentage point increase.[35] IEA also hiked the prediction for BEVs' share of new sales in 2030 to two-thirds in its more proactive net-zero scenario.[36]

Shell's new 2050 scenario analysis issued in March 2023 is more emphatic:

> "Battery-powered cars have taken the world by storm … and by surprise. Twenty years ago, the future of passenger vehicles was supposed to be a mix of battery hybrid systems or hydrogen fuel cells. In this world, hydrogen filling stations were expected to gradually take over from pumps supplying petrol and diesel. The battery-electric passenger vehicle (BEV) was barely considered a possibility. Even as Tesla rose to prominence and other companies began introducing BEVs, the expectation was that the technology would not become dominant until well into the second half of the century. Sky 2050 now includes a complete transition to BEVs, from Amsterdam to Zanzibar, only 30 years from now."[37]

[33] *Ibid*.
[34] Cox Automotive. Path to EV Adoption: Consumer and dealer perspectives. June 2023, p. 2.
[35] IEA. World Energy Outlook 2023. October 2023, p. 149.
[36] *Ibid*. IEA notes plans that have already been announced for battery manufacturing capacity would be sufficient to meet demand for EV batteries in the NZE Scenario in 2030.
[37] Shell. Energy Security Scenarios. March 21, 2023, p. 80. Includes the Sky 2050 scenario.

BP's Energy Outlook 2023 similarly projects zero-emission passenger cars will be BEVs, reserving hydrogen for heavy-duty road transportation,[38] and BloombergNEF's 2023 Energy Outlook concludes that FCEVs "play no meaningful role in the passenger vehicle market."[39]

Most carmakers have recognized the greater popularity of BEVs. While some carmakers plan to offer FCEVs,[40] dozens of new BEV models are expected to enter the market by the end of 2024. Consumer Reports identified 17 carmakers, including GM, Stellantis, Ford, Nissan and others, that have new models in the queue and targets for going battery electric.[41]

Only two FCEV passenger car models are available globally, compared with more than 350 battery electric and plug-in hybrid vehicle models.[42] Even of the two FCEV models, just one accounts for most of the sales. In the first three quarters of 2023, roughly 94% of the hydrogen car sales were the Toyota Mirai; the Hyundai Nexo (SUV) accounted for the remainder.[43]

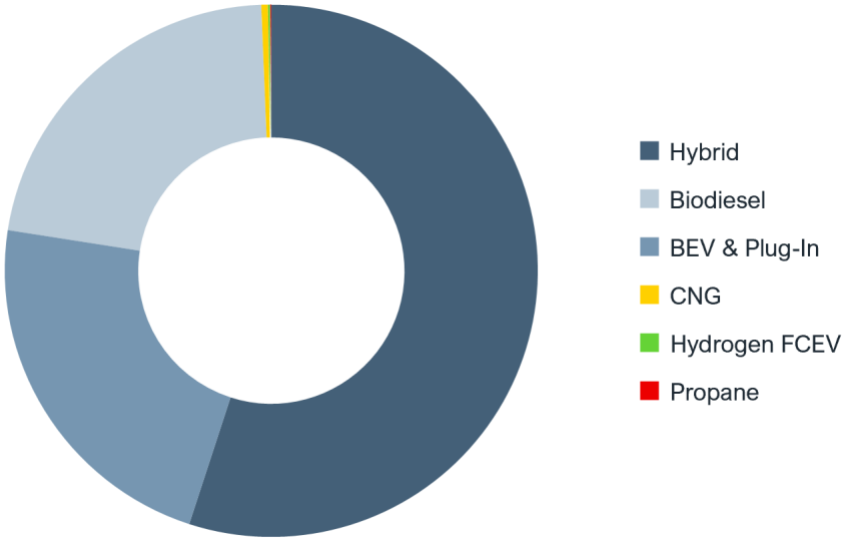
Light trucks,[44] such as pickups, are expected to go battery electric as well. GM's Chevrolet brand is rolling out battery electric versions of the Silverado pickup truck, the Blazer SUV and the Equinox SUV. Ford plans to triple production of its battery electric pickup truck, the F-150 Lightning.[45] In October 2023, light trucks accounted for 75% of hybrid vehicles sold, which represented an increase of 56% from October 2022.[46] Hydrogen fuel cell technology, in contrast, has had little success in the light-duty vehicle market.

From a market penetration perspective, BEVs and plug-in hybrids combined comprise 22.4% of alternative light duty vehicle registrations, following hybrids (55%) and just edging out biodiesels (22%). BEVs alone comprise 15% of the registrations.[47]

It's not that no light-duty FCEVs are being purchased. It's just that they comprised only 0.12% of the total number of registered alternative fuel light-duty vehicles.[48]

[38] BP. Energy Outlook 2023 – July 2023 update, p. 70.
[39] BloombergNEF. Electric Vehicle Outlook 2023. Executive Summary, p. 1.
[40] See Fastech. 8 vehicle manufacturers working on hydrogen fuel cell cars. July 7, 2023.
[41] Consumer Reports. Auto makers are adding electric vehicles to their line-ups. Here's what's coming. March 10, 2023.
[42] Inside EVs. US: Hydrogen fuel cell car sales improved in Q2 2023. July 31, 2023. Also see: P. Plotz. Hydrogen technology is unlikely to play a major role in sustainable road transport. Nature Electronics. 5:8-10. January 2022.
[43] Inside EVs. Toyota U.S. hydrogen fuel cell car sales keep growing in Q3 2023. October 29, 2023.
[44] Based on the Federal Highway Administration's vehicle classification system, light-duty vehicles include Class 1 (6,000 lbs or lighter) and Class 2 (6,001-20,000 lbs). EPA's emissions classifications for trucks varies somewhat. DOE Alternative Fuels Data Center. Vehicle Weight Classes & Categories. Accessed December 6, 2023 (hereafter, DOE Vehicle Weight Classes & Categories).
[45] E&E News (EnergyWire). How a strike imperils Detroit's drive to EVs. September 14, 2023.
[46] Argonne National Laboratory. Light duty electric drive vehicles: Monthly sales updates. Accessed December 6, 2023.
[47] Argonne National Laboratory. Light Duty AFV Registrations. Updated August 2022 (2021 data). The agency notes the data excludes flexible fuel vehicles since "those generally operate primarily on conventional gasoline." *Ibid.*
[48] *Ibid.*

**Figure 3: Alternative Fuel Light-duty Vehicle Registrations[49]**




*Source: Argonne National Laboratory.*

Hydrogen fuel cell vehicle technology is lagging due to several factors, including:

- Total costs for hydrogen vehicles are higher.
- Only California has more than one public hydrogen fueling station, but tens of thousands of public BEV charging stations exist across the country.
- Home-based hydrogen generation and refueling is not available, but most BEV owners have access to home charging and some generate their own power from solar technology.
- BEV range anxiety is declining with improved driving ranges per charge and increasing availability of BEV charging stations.

## A. BEVs Have a Fuel Cost Advantage Over FCEVs

The cost of hydrogen fuel is a problem. Hydrogen Insight recently determined that hydrogen fuel prices at California's largest hydrogen fuel retailer, True Zero, have almost tripled, rising from $13.15 per kilogram (kg) in April 2021 to $36/kg in September 2023. The analysis concluded it is almost 14 times more expensive to drive a Toyota Mirai (FCEV) in California today than a comparable Tesla battery electric car using public charging stations. BEV owners who charge at home would benefit from even cheaper costs.[50]

[49] *Ibid*.
[50] Hydrogen Insight. Analysis: It is now almost 14 times more expensive to drive a Toyota hydrogen car in California than a comparable Tesla EV. September 18, 2023.

## B. BEVs Have a Substantial Public Charging Infrastructure Advantage Over FCEVs

The refilling infrastructure build-out for BEVs compared to FCEVs reveals a stark contrast. Currently, more than a thousand times more BEV charging stations than FCEV refilling stations are sited in the United States.[51] In California, which has the most BEV charging stations, a state report found about 81% of California residents live in Census tracts with population centers within a 10-minute drive of a public direct-current fast-charging station.[52] California's charging distribution effort is an impressive success story, although it seeks to improve build-out to reach more rural communities.[53] Nationally, DOE data identifies 6,518 additional public BEV charging stations since 2022, compared to only four additional public FCEV filling stations.[54]

Perhaps most revealing, all but one of the 58 publicly accessible FCEV filling stations are in California, mostly in its coastal counties. The remaining single publicly available FCEV refilling station documented by DOE is in Hawaii.[55] And based on DOE data, not a single state other than California added a new public FCEV filling station in the past year.[56]

**Figure 4: Public BEV Charging Stations Versus FCEV Filling Stations in the United States[57]**

Electric Charging Stations

Hydrogen Filling Stations


*Source: U.S. Department of Energy.*

[51] DOE Alternative Fuels Data Center. Alternative Fueling Station Counts by State. Updated December 6, 2023 (hereafter, DOE Alternative Fueling Station Counts by State)
[52] California Energy Commission. 2022 S.B. 1000 California Electric Vehicle Infrastructure Deployment Assessment: Drive Times to Direct-Current Fast chargers. CEC-600-2022-059. July 2022, pp. 1-2.
[53] *Ibid*.
[54] DOE Alternative Fueling Station Counts by State.
[55] *Ibid*. California also includes one non-public hydrogen cell fueling station.
[56] *Ibid*. .
[57] DOE Alternative Fuels Data Center. Alternative Fueling Station Locator. Accessed November 27, 2023.

Even with regard to private stations, federal data indicates BEV charging stations have already been established at 3,817 locations (not including residential chargers), compared with 131 or more FCEV filling stations, most of which are designed for forklifts.[58]

This gap is likely to widen. The Federal Highway Administration will make more than $2.5 billion available over five years for publicly accessible charging and alternative fueling infrastructure at the community level (schools, parks, grocery stores, etc.). The federal Department of Transportation also has finalized new standards to improve the convenience and reliability of EV chargers.[59]

But what is particularly striking is the level of private investment. The Biden administration recently reported the private sector has invested more than $100 billion in EV, battery, and EV charging manufacturing in the United States to date.[60] The evidence of private sector support is compelling.

- A 2022 survey found 26.6% of hotels offer battery chargers to allow their customers to recharge their cars overnight, and the percentage is even greater in major cities, ranging from 37% in Orlando, Fl., to 66% in San Francisco, Ca.[61] Two of the largest hotel chains in the United States, Hilton and Marriott, have recently announced plans to install Level 2 battery chargers at thousands of locations.[62]

- In October, BP announced a $100 million deal with Tesla to establish thousands of ultra-fast chargers across its network, starting in 2024 in Houston, Phoenix, Los Angeles, Chicago, and Washington, DC. The chargers will be compatible with both North American Charging Standard (NACS) and Combined Charging System (CCS) connectors, so it will be compatible with non-Tesla EVs. BP plans to invest as much as $1 billion in EV charging across the United States by 2030, spending $500 million within the next two to three years.[63]

- Seven leading automakers—BMW Group, General Motors, Honda, Hyundai, Kia, Mercedes-Benz Group, and Stellantis NV—announced in July 2023 a new joint venture to install at least 30,000 high-powered charge points in urban and highway locations in the United States and Canada, leveraging public and private funds and accommodating both NACS and CCS connector technology. They plan to open the first charging stations in the United States in the summer of 2024.[64]

- General Motors, partnering with FLO, plans to work with dealers to install up to 40,000 public Level 2 EV chargers in local communities by 2026.[65]

[58] The DOE database lists only 16 private hydrogen fueling stations. DOE Alternative Fueling Station Counts by State. The DOE data does not, however, include the construction of over 115 forklift fueling stations for commercial warehouses, as part of a federally funded project. DOE National Clean Energy Roadmap, p. 18.
[59] White House, *op. cit.*
[60] *Ibid*.
[61] Greenview, Responsible Stay and AHLA. Green Lodging Trends: U.S. market report. May 2022, pp. 116-117.
[62] E&E News/EnergyWire. The new Wi-Fi? Hotels go big on EV charging. October 26, 2023.
[63] BP. BP boosts EV charging network with $100 million order of Tesla ultra-fast chargers. October 26, 2023.
[64] BMW Group, *et al.* Seven automakers unite to create a leading high-powered charging network across North America. July 26, 2023.
[65] White House. Fact Sheet: Biden-Harris Administration Announces New Standards and Major Progress for a Made-in-America National Network of Electric Vehicle Chargers. February 15, 2023.

Roughly 23% of public battery electric stations are direct-current (DC) fast-charging stations that typically provide enough charge for 100 to 300 miles in 30 minutes.[66] Such charging ports increased by 7.6% in the first quarter of 2023.[67] Roughly 77% of the stations are Level 2 chargers that typically provide a charge good for 25 miles for each hour of charging.[68]

Although about 61% of public DC fast ports are designed only for Tesla vehicles, which currently comprise more than half of vehicle sales,[69] the situation is likely to improve. The White House issued guidance in February 2023 that EV manufacturers, to be eligible for federal funding, must make their chargers able to accommodate all EV brands. The guidance also stated Tesla has agreed to open up for public use 3,500 new and existing superchargers and 4,000 Level 2 charging docks by the end of 2024.[70]

Ford announced a deal with Tesla in May 2023 to allow access to its 12,000 North American supercharger locations starting in 2024, and to integrate Tesla's NACS charging standard into Ford's future vehicles.[71] In June, GM announced a similar collaboration with Tesla to access its supercharger network in 2024 and to adopt the NACS into GM's new vehicles starting in 2025.[72]

The 2022 Cox Automotive survey found prospective car buyers with concerns about charging infrastructure had dropped eight percentage points, from 40% to 32%.[73] A survey of U.S. car buyers by consulting firm EY saw a higher rate of concern about charging (57%), but also found 81% of BEV owners are likely to consider buying a BEV again, compared with only 42% of traditional vehicle owners, and nearly half (48%) of car buyers intend to buy a BEV—up 19% from the 2022 survey.[74]

Even in California, where nearly all the hydrogen filling stations are located, BEVs accounted for 763,557 light-duty vehicles on the road in 2022, along with 335,574 plug-in hybrids, while the number of hydrogen fuel cell light-duty vehicles only amounted to 11,897.[75]

[66] DOE Alternative Fueling Station Counts by State, *op. cit.* Also see: EPA. Plug-in electric vehicle charging: The basics. Accessed December 6, 2023.
[67] EPA. Plug-in electric vehicle charging: The basics.
[68] DOE Alternative Fueling Station Counts by State.
[69] Barron's Daily. U.S. EV sales hit a record and Tesla's market share slips. July 14, 2023 (62% inf the first quarter, 59% in the second quarter of 2023).
[70] White House, *op. cit*.
[71] Ford Newsroom. Ford EV customers to gain access to 12,000 Tesla superchargers; company to add North American Charging standard port in future EVs. May 25, 2023.
[72] GM Newsroom. General Motors doubles down on commitment to a unified charging standard and expands charging access to Tesla supercharger network. June 2023.
[73] Cox Automotive. Path to EV Adoption: Consumer and dealer perspectives. June 2023, p. 2.
[74] Ernst & Young Global Ltd (trade name EY). EY research: Nearly half of US car buyers intend to purchase an EV. June 27, 2023.
[75] California Energy Commission. Light-Duty Vehicle Population in California. Updated April 2023.

## C. BEVs Have the "Home Court" Advantage Over FCEVs

The BEV rollout started with a "home court" advantage. Roughly 80% of EV drivers report they rely primarily on their home charging system.[76] The NREL reports that although prospective buyers want fast charging, consumer preferences tend to shift after purchase, since customers find they prefer home charging in terms of both cost and convenience.[77]

Home refueling for FCEVs, by comparison, is not an option.[78] Although FCEVs can travel further distances on a single fill-up, they need access to public or worksite refilling stations from the outset. The home charging feature gave BEVs a head start—people could buy and use BEVs before substantial charging infrastructure was established.

## D. BEV Range Is Growing Quickly

The U.S. Department of Transportation reports many light-duty BEVs have a driving range of about 300 miles on a full charge, while some have a driving range of more than 400 miles on a full charge.[79] Stellantis has pushed the envelope substantially further with its announcement in April 2023 of the electric 2025 Ram 1500 REV, a light-duty pickup truck. The company states the truck will have a range of 500 miles (805 kilometers) on a single charge if the buyer chooses the option of installing a 229-kilowatt-hour (kWh) large battery pack. (The standard 168 kWh battery pack offers a range of up to 350 miles).[80]

[76] DOE NREL. Incorporating Residential Smart Electric Vehicle Charging in Home Energy Management Systems. Conference paper NREL/CP-5D00-78540. April 2021.
[77] NREL. The 2030 National charging Network: Estimating U.S. Light-Duty Demand for electric Vehicle Charging Infrastructure. June 26, 2023, p. vi.
[78] P. Plotz, *op. cit*.
[79] National Highway Traffic Safety Administration, U.S. DOT. Electric and hybrid vehicles. Accessed December 6, 2023.
[80] Stellantis. Press Release: All-new, all-electric 2025 Ram 1500 REV unveiled at New York International Auto Show with targeted range of up to an unsurpassed 500 miles. April 5, 2023. Also see: CNN. Ram electric pickup truck can go 500 miles on a charge, says Stellantis. April 5, 2023.

# III. Battery Electric Technology Is Making Significant Inroads Into Bus and Medium-Duty Truck Sales and Is Predicted to Dominate the Zero-Emission Market for Such Vehicles

Because of their greater weight and vehicle miles traveled, medium- and heavy-duty trucks produce 23% of the GHG emissions emitted by the U.S. transportation sector, even though they make up only 5% of the vehicle population.[81] Decarbonization of this sector is important, but the role of hydrogen fuel cell technology will be limited.

Although DOE's March 2023 policy document, "Pathways to Commercial Liftoff," abandoned its 2020 assumptions about cars and light-duty trucks, the agency still expects substantial use in medium-duty trucks,[82] such as commercial delivery vans, medium-weight trucks and other uses that typically involve less than 250-mile trips.[83] DOE announced $7.4 million in funding for seven projects to develop innovative medium- and heavy-duty EV charging and hydrogen corridor infrastructure plans across 23 states.[84]

A substantial role for hydrogen in medium-duty trucks, however, is not likely to happen.

## A. BEVs Already Are Gaining Traction in the Medium-Duty Truck Market

BEV medium-duty vehicles are winning the market race against FCEVs. Globally, the IEA reports with regard to zero-emission vehicles, "The majority (over 90%) of the already available medium-duty and heavy-duty trucks models are battery electric."[85] A 2023 survey report involving 223 fleet operators and decision-makers in the United States revealed interest in BEV technology is widespread. The survey found 65% had used a BEV in the past two years and 92% of fleets with BEVs plan to expand their use in the next five years.[86]

Bloomberg NEF notes that municipal buses, in particular, are electrifying quickly. It projects the U.S. will begin to catch up with China in this market and EVs will reach 24% of municipal bus sales,

[81] EPA. Fast Facts on transportation Greenhouse Gas Emissions.
[82] DOE. Pathways to Commercial Liftoff: Clean Hydrogen. March 2023 (hereafter, DOE Pathways to Commercial Liftoff), pp. 18, 40 and 79. DOE also hiked its 2050 target to 50 mtpa. *Ibid.*, p. 1. Also see: DOE National Clean Energy Roadmap, pp. 17 and 19,
[83] DOE National Clean Energy Strategy and Roadmap, *op. cit.*, p. 74. Medium-duty trucks include Class 3 (10,001-14,000 lbs), Class 4 (14,001-16,000 lbs), Class 5 (16,001-19,500 lbs) and Class 6 (19,501-26,000 lbs). DOE Vehicle Weight Classes & Categories.
[84] White House, *op. cit*.
[85] IEA. Global EV Outlook 2023: Trends in heavy-duty vehicles. April 2023.
[86] State of Sustainable Fleets 2023 Market Brief, p.10.

respectively, by 2026.[87] Across the United States, 3,043 battery electric school buses have been funded, ordered, delivered, or deployed as of December 2022.[88]

Three years ago, Fleet Equipment Magazine hailed the roll-out of electric medium-duty trucks by Peterbilt, Kenworth, Navistar, Daimler, Freightliner, Cummins and other companies, serving customers such as PepsiCo's Frito-Lay and Penske Truck Leasing.[89] This year, in reporting that Mack Truck, Isuzu and Hino Trucks unveiled medium-duty BEV models at a trade show in Indianapolis, Freight Waves commented the new electric trucks enter "a crowded field."[90] Volvo announced in June 2023 a new medium-duty truck model with a range of 280 miles (450 km) when fully charged.[91]

By comparison, DOE reported the existence of only between 80 and 150 hydrogen fuel cell buses in 2023,[92] and no hydrogen fuel cell school bus is on the market yet.[93] In terms of roll-out timing, the agency places medium-duty FCEVs in the "second wave" of its hydrogen applications strategy, after "first wave" uses are developed in long-haul heavy-duty trucks and transit buses.[94] The 2023 survey of fleet operators, however, did not document evidence of growing interest in hydrogen fuel cell buses, stating public announcements indicate transit agencies are prioritizing filling existing orders in 2022 rather than placing new orders.[95]

Shell's 2050 scenario concludes:

> "Tests of hydrogen bus fleets through the 2010s have come and gone, with most cities now adopting battery-electric buses. Some Chinese cities are already well on their way to fully switching their bus fleets to batteries. A similar story is unfolding for municipal trucks, with the City of London Corporation becoming the first UK authority to run a full fleet of electric refuse collection vehicles in 2021. In late 2022, Tesla named PepsiCo as the first customer for its battery-powered semi long-haul truck."[96]

Alexander Vlaskamp, CEO of the second largest truck-maker in the world, MAN, told Austrian paper *der Standard* with regard to BEV trucks that, "The technology is mature and most efficient. In our estimation, 80[%] or even 90% of logistics trucks will be electrically driven."[97]

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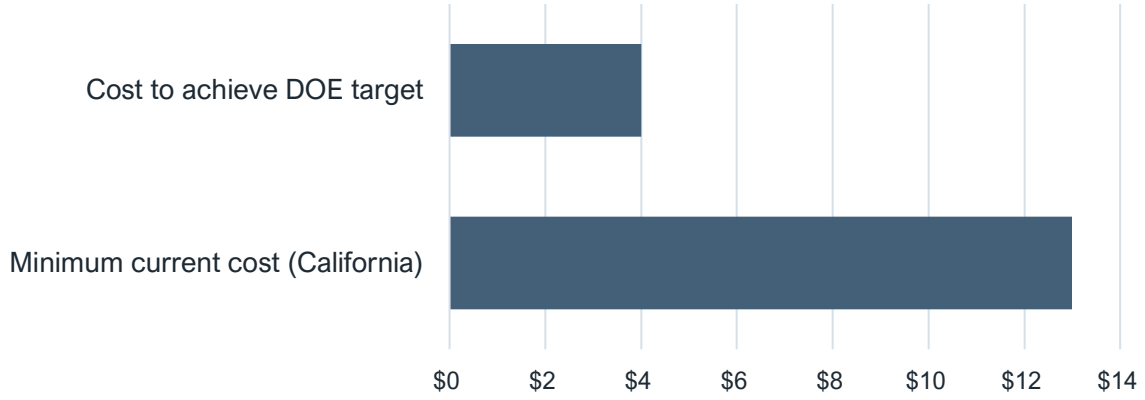
[87] BloombergNEF. Electric Vehicle Outlook 2023. Executive Summary, p. 3.
[88] Calstart. Zeroing in on Electric School Buses. May 2023, p. 1.
[89] Fleet Equipment Magazine. Manufacturers continue to roll out electric medium-duty trucks. January 6, 2020.
[90] FreightWaves. 3 legacy manufacturers unveil medium-duty electric trucks. March 8, 2023.
[91] Volvo. Press release: Volvo presents electric trucks with longer range. June 20, 2023.
[92] DOE National Clean Energy Roadmap, p. 14. NESCAUM provided an estimate of "nearly 200" FCEV buses. NESCAUM. Multi-State Medium- and Heavy-Duty Zero-Emission Vehicle Action Plan. July 2022, p. 16.
[93] School Transportation News. Are fuel cells now a viable option for school buses? April 26, 2023.
[94] DOE National Clean Energy Roadmap, p. 73-74.
[95] State of Sustainable Fleets 2023 Market Brief, p. 11.
[96] Shell, *op. cit.*, p. 80.
[97] Hydrogen Insight. 'Far too expensive' – Europe's second-largest truck maker says hydrogen will not be a major road freight fuel. June 23, 2023.

## B. DOE Acknowledges Hydrogen Fuel Costs Would Have to Drop By at Least Two-Thirds or More to Achieve the Market Share DOE Projects

DOE expresses hope for hydrogen use in buses with long driving ranges,[98] but the agency acknowledged this year that the total fuel costs for hydrogen produced, delivered, compressed and dispensed, including infrastructure, must reach about $4/kg to achieve the 10% to 14% market share for medium- to heavy-duty vehicles.[99] Actual operational data in California, the one state that has invested heavily in hydrogen filling station infrastructure over several years, shows the delivered cost of hydrogen to fueling stations is at least $13/kg—more than three times the threshold for meeting the target.[100]

**Figure 5: Delivered Cost for Hydrogen Use ($/kg)[101]**




*Source: U.S. Department of Energy.*

Overall, battery electric designs for medium-duty trucks already have an economic advantage. The 21st Century Truck Partnership Electrification Technologies Sector Team (ETST), in its in-depth review of truck electrification technology, projected that the levelized cost of driving medium-duty Class 6 trucks will be cheaper for BEVs than both conventional vehicles and FCEVs by 2030, and the gap will widen by 2040. The analysis considered vehicle purchase price, vehicle resale value, annual mileage, ownership period and price of energy used.[102] The NREL in a 2022 report similarly found BEVs tend to become cost-competitive in comparison with internal combustion vehicles for "almost all light-medium and medium trucks" before 2030.[103] For example, a 2021 NREL report concluded

[98] *Ibid.*, p. 32.
[99] *Ibid.*, p. 19. Also see: J. Marcinkoski. DOE Advanced Truck Technologies: Technical targets for hydrogen-fueled long-haul tractor-trailer trucks. October 31, 2019.
[100] DOE National Clean Energy Roadmap, p. 25. The figure is based on data from California, the only U.S. state that has a network of hydrogen fueling stations. California Fuel Cell Partnership. Cost to refill. Accessed December 6, 2023.
[101] *Ibid.* pp. 18 and 25.
[102] ETST. Roadmap. September 2023, pp. 19 and 22, plus Appendix A.
[103] NREL. Decarbonizing Medium-&-Heavy-Duty On-Road Vehicles: Zero-Emission vehicles cost analysis. March 2022, p. 30.

although the Class 4 parcel delivery BEV for trips up to a 120-mile range was estimated to be about 80% more expensive than diesel in 2018, it projected the BEV would likely become 8% cheaper by 2025 and ultimately 14% cheaper.[104]

Hydrogen is behind the curve in the medium-duty vehicle sector. Given the lag in production of FCEV models, the fuel cost barrier, and the time still required to achieve the necessary hydrogen infrastructure build-out—as well as the progress medium-duty BEVs already are making in market presence—no compelling reason is evident to believe hydrogen fuel cell technology will catch up to battery electric technology in the medium-duty market.

# IV. Battery Electric Technology Is Likely to Take Over Most Short-Haul Heavy-Duty Trucking and May Encroach on the Long-Haul Market

A 2021 study, observing that FCEVs were not permeating the passenger car and light vehicles market, declared, "Decades of development of cost-effective and durable polymer electrolyte membrane fuel cells must now be leveraged to meet the increased efficiency and durability requirements of the heavy-duty vehicle market."[105]

Such advice is becoming less and less compelling.

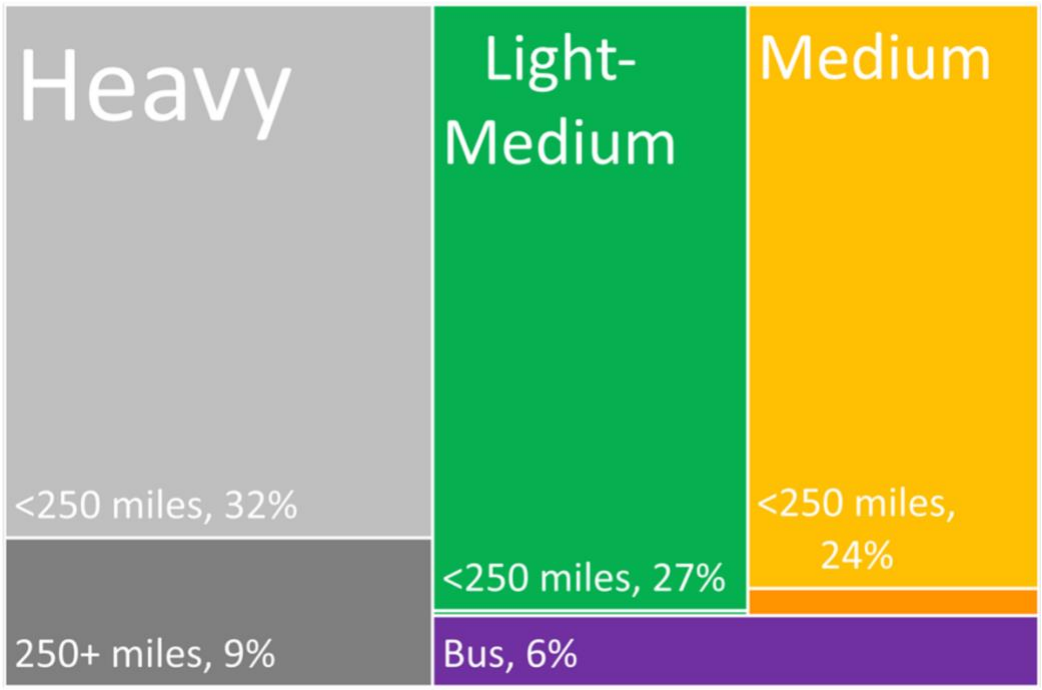
The nature of the heavy-duty trucking market, defined by DOE as vehicles over 26,000 pounds,[106] is broadly misunderstood. What typically comes to mind is trucks traveling thousands of miles. In fact:

- Only 9% of heavy-duty trucks are engaged in long haul trucking, defined by DOE as more than 250-mile-long truck trips.[107]
- Within that segment, an even smaller portion accounts for over-the-road (OTR) trucking (typically understood to mean driving too many miles to return home for the night).[108] For example, trips of 1,000 miles or more constituted less than one-seventh of trips in American Transportation Research Institute's survey of fleet operators conducted in 2022.[109]

[104] NREL. Spatial and temporal analysis of the total cost of ownership for Class 8 tractors and Class 4 parcel delivery trucks. Technical Report, NREL/TB-5400-71795. September 2021, pp. vi and 69. The NREL reports DOE's "Ultimate scenario" assumptions are assumed to occur in 2050 for fuel prices but are otherwise "temporally agnostic." *Ibid.*, p. 22.
[105] D. Cullen, *et al.* New roads and challenges for fuel cells in heavy-duty transportation. *Nature Energy*. 6:462:471. March 25, 2021.
[106] Heavy-duty trucks include Class 7 (26,001 to 33,000 lbs) and Class 8 (33,001 lbs and heavier). DOE Vehicle Weight Classes & Categories.
[107] NREL. Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-emission vehicles cost analysis. March 2022 (hereafter, NREL zero-emission trucks cost analysis), p. 17.
[108] For a profile of the life of an over-the-road truck driver, see: New York Times. The real reason America doesn't have enough truck drivers. February 9, 2022.
[109] ATRI, *op.cit.*, p. 13.

- The American Transportation Research Institute's survey of fleet operators found regional trips—between 100 and 500 miles in length—are the most common, accounting for more than one-third of the sample in 2022.[110]

**Figure 6: Types of Trucks and Share of Total Stock 2019[111]**




*Source: NREL.*

Also, the trend in heavy-duty truck hauling may shift toward more regional hauling. A 2023 report on freight operational efficiency issued by a team that included a dozen trucking and auto-making industries, along with federal agencies and research laboratories, stated:

> "The forecasted changes in freight needs (such as the potential shift from long-haul cross-country freight movement to more regional operation through hub-and-spoke warehouses) often imply changes to the structure of our freight system, so system optimization is important to making the most of technologies and operations for freight efficiency. For example, electrification technologies are currently difficult to incorporate into the freight system at scale, but the hub-and-spoke distribution model employs reduced route lengths that are better suited to battery electric vehicle range capabilities, thereby allowing fleets to take advantage of these technologies."[112]

[110] ATRI, *op.cit.*, p. 13.
[111] NREL zero-emission trucks cost analysis, p. 17.
[112] 21st Century Truck Partnership Freight Operational Technical Sector Team. Roadmap. September 2023, p. 16. For a list of the Partnership's members, see DOE. 21st Century Truck Partnership. Accessed December 6, 2023.

The North American Council for Freight Efficiency (NACFE) notes that increases in e-commerce, GPS-based asset tracking systems and load-matching systems, coupled with trends in driver retention, may result in an increased market share for regional hauling.[113]

So, a reasonable market analysis must break down the heavy-duty vehicle category, by miles traveled.

Such analysis must also consider the impact of competition and comparative time of entry into the market, as well as investor interest in the technology and infrastructure required. First-mover technology has an advantage because few companies are willing to gamble on technology that is different than their competitors, possibly exposing them to a comparatively higher risk profile. Given the low margins in the industry, companies are unlikely to choose a far less commonly used technology unless they feel the competitive cost advantage is certain.

## A. Hydrogen Technology Has Not Yet Demonstrated Commercial Success in the Heavy-Duty Truck Market

Despite all the discussion of its potential role for long-haul trucking, plus demonstrations and pilot-testing of Class 8 heavy-duty FCEVs,[114] heavy truck models that run on hydrogen fuel cells are only now starting to appear.[115] In an amicus brief recently filed in federal court seeking to overturn a California regulation mandating transition to zero-emission trucks, the U.S. Chamber of Commerce, the American Trucking Associations and other trade associations said no hydrogen fuel cell tractor trucks are available commercially in North America or Europe. The brief also argued: "[T]hat technology is not likely to be developed within the next ten years."[116]

Although the U.S. Chamber of Commerce brief raises several criticisms of current battery electric truck technology, the trade associations acknowledge the California truck regulation "effectively forces the industry to shift to reliance on battery-electric vehicles."[117]

In contrast with heavy-duty FCEVs, several models of battery electric class 8 trucks weighing more than 33,000 pounds when fully loaded with cargo are already in the commercial market in the United States.[118] A survey of truck fleet operators by the American Transportation Research Institute

[113] NACFE. More Regional Haul: An Opportunity for Trucking? April 2019.
[114] See Toyota. Toyota, Kenworth prove fuel cell electric truck capabilities with successful completion of truck operations for ZANZEFF Project. September 22, 2022. Also see: RunonLess.com. Early lessons learned from Run on Less – Electric Depot. September 18, 2023. Also see: Fleetowner. The dawn of hydrogen trucks. May 9, 2022.
[115] See, Axios. Hydrogen-powered trucks look for a lane in the fight against climate change. August 11, 2023. Commercial Carrier Journal. Hundai bringing fuel cell truck to the U.S. May 3, 2023. Also see: P. Plotz, *op. cit*.
[116] Chamber of Commerce of the United States of America, American Trucking Associations, *et al*., Brief for Amici Curiae, in *Western States Trucking Association, et al. v. U.S. Environmental Protection Agency*, No. 23-11343, U.S. Court of Appeals for the District of Columbia Circuit, November 13, 2023, p. 33.
[117] *Ibid.*
[118] Environmental and Energy Study Institute. Factsheet: The future of the trucking industry: Electric semi-trucks. May 11, 2023.

reported 5.1% of respondents had at least one battery electric vehicle in 2022, but none were using an FCEV.[119]

Shell's 2050 scenario projects a role for hydrogen in long-haul, heavy-duty trucking, but a greater role for BEV trucks overall, including heavy-duty vehicles:

In Sky 2050, part of the road freight fleet moves to hydrogen fuel-cell technology for long-distance haulage. Hydrogen takes a 25% share of this market by 2070 and is growing in absolute terms. Even so, it is battery power that wins overall.[120]

Shell further adds, "Of course, scenarios can be wrong, so is it just a question of time before all forms of road transport use battery-electric power?"[121]

## B. Investor Reluctance and Evolving Expectations About Cost

Investor reluctance is part of the issue. DOE comments that:

> "[F]uel cell heavy-duty truck adoption will be highly dependent on the build-out of refueling infrastructure, advancements in fuel cell vehicle technology, certainty of hydrogen supply, and the cost of alternatives (e.g., diesel, battery electric vehicles and their associated costs of charging infrastructure) and regulatory drivers. On the financing side, perceived credit risk will be high for hydrogen projects while these challenges remain unresolved, delaying timelines for low-cost capital providers to enter the market." [122]

The IEA, in explaining its reduced projections for certain energy technologies, states for some of the technologies, "the downward revision is based on recent investment trends from technology manufacturers against other low-emissions alternatives," noting, "One example is a reduced role for hydrogen-fuelled trucks."[123]

Bloomberg NEF expects heavy-duty FCEV costs to decline, but finds "uncertainty on their trajectory is high."[124]

Ultimately, the businesses that buy heavy-duty trucks will define the trend, and comparative cost will be a major factor.[125] Although some debate remains, cost factors are leaning toward the heavy-duty

[119] American Transportation Research Institute (ATRI). An Analysis of the Operational Costs of Trucking: 2023 Update. June 2023, p. 15. The survey included operators of 169,770 truck-tractors and 498,068 trailers.
[120] Shell, *op. cit.*, p. 80. Also see: IEA World Energy Outlook 2023, p. 45: As a measure of the disappointing progress of FCEV technology in the market, the IEA this year, characterizing the heavy-duty FCEV as a "technology under development," reduced its share as a strategy to achieve net-zero emissions in the NZE Scenario for 2050.
[121] Shell, *op. cit.*, p. 80.
[122] DOE Pathways to Commercial Liftoff: Clean Hydrogen, p. 3.
[123] IEA Net Zero Roadmap 2023 Update, pp. 58-59. It further notes the decreased expectation for hydrogen and carbon capture and storage (CCS) "reflects slower technological and market development progress than envisaged in 2021 and stronger electrification prospects." *Ibid.*, p. 55.
[124] BloombergNEF. Electric Vehicle Outlook 2023. Executive Summary, p. 3.
[125] Hydrogen Insight. 'Far too expensive' – Europe's second-largest truck maker says hydrogen will not be a major road freight fuel.

BEV's side. The International Council on Clean Transportation (ICCT) compared total cost of ownership over a five-year period for Class 8 tractor-trailer trucks (including purchase price and maintenance and operation expenses) in seven states. The ICCT concluded:

- Battery electric heavy-duty trucks already have a lower total cost of ownership than hydrogen-powered trucks despite a higher purchase price, even taking I.R.A. tax incentives into account. Maintenance and operation costs overwhelm purchase price.
- The total cost of ownership of heavy-duty BEVs that average 500 miles of daily travel will likely be lower than diesel trucks by 2030, and also may be lower for those with average mileages of as much as 750 miles per day if day-to-day variability is low.
- Heavy-duty FCEVs using green hydrogen won't reach parity with diesel trucks unless green hydrogen prices range from $3/kg to $6.50/kg, rather than the $9/kg to $11/kg expected in 2030 with federal tax incentives.
- BEVs will be the least costly option for almost two-thirds of long-haul trucking by 2030, rising to 84% by 2040 due to lower battery prices and more charging infrastructure.[126]

The NREL report on medium-to-heavy-duty vehicles, released last year, was somewhat more optimistic for heavy-duty FCEVs, projecting they would be cost-competitive with diesel trucks for trips longer than 500 miles by 2035.[127] The NREL projected a longer trajectory toward diesel truck parity for heavy-duty BEVs for trips under 500 miles, predicting they would be cost-competitive with diesel trucks before 2035 rather than 2030.[128]

The ETST predicts duty Class 8 regional haul BEVs may be competitive with conventional trucks by 2030,[129] but that Class 8 long-haul BEVs may not be competitive with diesel powered vehicles "for some time."[130] Still, it projects a faster rate of vehicle improvements for heavy-duty BEVs, and estimates the levelized cost of driving per mile differential between BEV and conventional or fuel cell trucks drops from $0.6/mile in 2020 to less than $0.1 per mile by 2040.[131]

[126] ICCT. Total Cost of Ownership of Alternative Powertrain Technologies for Class 8 Long-Haul Trucks in the United States. April 2023, pp. i-iii.
[127] NREL zero-emission trucks cost analysis, p. 30. The report did not differentiate between use of green hydrogen and fossil-fuel based blue hydrogen.
[128] *Ibid*.
[129] ETST, *op. cit.*, p. 21.
[130] *Ibid.*, p. 3.
[131] *Ibid.*, pp. 19-20 and Appendix A.

## C. Battery Range and Charging Time Is No Longer an Insurmountable Barrier for Regional Heavy-Duty Vehicles

Although FCEVs require fewer stops and fueling time,[132] battery power no longer appears to be an insurmountable barrier to regional duty heavy-duty BEVs. The potential for BEV use in the heavy-duty truck market for regional and local trips is important. Heavy-duty trucks that travel less than 250 miles comprise 32% of the total U.S. truck stock.[133]

NACFE had reported in 2022 that short and medium regional heavy-duty tractors were already electrifiable for ranges of 200 miles, with about 3,000 to 4,000 pounds of freight capacity penalty compared to diesels.[134] It concluded available heavy-duty BEVs could meet the needs of about half of the regional heavy-duty truck market, and the next generation of BEVs would improve performance and financials to meet more demanding requirements.[135]

Such improvements are already occurring. A testing program has identified significant achievements in heavy-duty BEV range. The Tesla semi trucks at PepsiCo's Sacramento Beverage depot completed 384 miles on one charge and 806 miles in a 24-hour-day, enabled by fast 750-kilowatt (kW) charging.[136] As a participant in DOE's Supertruck 3 funding project, Volvo has developed and launched a Class 8 BEV truck capable of a 275-mile (400 km) range on a single charge.[137]

An electrification program manager at PepsiCo reported in 2023 that Tesla's installation of 750kW Megachargers at its facilities has enabled charging to 80% capacity in less than 45 minutes.[138]

Hydrogen fuel cells have often been cited as appropriate for heavy-duty trucks that travel long distances and need fast recharging or refueling,[139] since they typically report a truck range of about 500 miles per fill-up.[140] As both battery charging time and range per charge improve, the suitability of heavy-duty BEVs for long-haul trucking is likely to expand to longer trips, competing with FCEVs in the sector.

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[132] Clean Air Task Force. Zero Emission Long-Haul Heavy-Duty Trucking. March 2023, p. 4.
[133] NREL zero-emission trucks cost analysis, p. 17.
[134] NACFE. Electric Trucks Have Arrived: The use case for heavy-duty regional haul tractors. May 5, 2022, p. 9.
[135] *Ibid*., p. 10.
[136] North American Council for Freight Efficiency and RMI. Early lessons learned from Run on Less – Electric Depot. September 18, 2023.
[137] Volvo. Volvo Trucks launches electric truck with longer range. January 14, 2022. Also see: Dieselnet. Conference report: US DOE Vehicle Technologies Annual Merit Review 2023. July 5, 2023. With DOE funding, Volvo is working with the University of Minnesota to conduct extreme weather testing (heat and cold) on freight routes exceeding 250 miles per day. Volvo. Volvo Trucks, University of Minnesota team up with local fleets to conduct extreme weather field testing on Volvo VR electric trucks. June 22, 2023.
[138] Electrek. Pepsico explains how it uses tesla demi-electric trucks in glimpse of the future of trucking. August 4, 2023.
[139] See, *e.g.*, Shell, *op. cit.*, p. 80. Predicts passenger cars will be electric but hydrogen fuel cells will have a role for long-haul trucking.
[140] See, e.g., FleetOwner. The dawn of hydrogen trucks. May 2022.

## D. Battery Weight Is an Issue for Certain Uses But Viable Strategies Can Mitigate It

One concern often raised about battery use for long-haul trucking is weight, but the thinking behind the objection is often simplistic. Rick Mihelic, Director of Emerging Technologies for NACFE, states:

> "Adding more battery packs to get range is a very unimaginative way of extending BEV range, and more creative solutions are out there ... Increasing the range of electric trucks is not constrained to just adding battery packs."[141]

Mihelic points out that range can be reliably extended without adding battery packs, through effective use of regenerative braking. Regenerative brakes use electric motors rather than a traditional friction braking system to slow and stop a vehicle, capturing the kinetic energy and transferring it into the vehicle's batteries. Mihelic notes the Run on Less – Electric demonstration, discussed above, documented that four Class 8 BEVs achieved as much as 25% energy recovery from regenerative braking. He comments, "This effectively makes a 400-kWh battery operate as if it were 500 kWh."[142]

PepsiCo reported in August 2023 that its Tesla Semi was able to be energy neutral on a trip from Sacramento going down through Donner Pass (with an elevation topping 7,000 feet) to Nevada, simply by recovering energy from braking.[143]

# V. Looking Ahead: Emerging Technologies May Propel BEVs in the Longer Term

Improvements in battery technology can reasonably be expected to propel BEVs even further ahead of hydrogen fuel cell technology. Research and experiments at DOE's Pacific Northwest National Laboratory are underway to develop sodium-ion batteries, which would be free of lithium, nickel, cobalt or graphite.[144] The Sweden-based Northvolt AB has developed a sodium-ion battery that is targeted for energy storage, and hopes to develop a vehicle model as well.[145]

Toyota announced in June 2023 its plan to commercialize its new solid-state battery—with a 745-mile range and 10-minute charging time—by 2027.[146] ReThink Technology predicts all-solid-state-

[141] Rick Mihelic. Belaboring the obvious. Commercial Carrier Journal. July 6. 2022.
[142] *Ibid*. For an explanation of regenerative braking, see DOE. How regenerative brakes work. Accessed December 6, 2023.
[143] Electrek, *op. cit*.
[144] Pacific Northwest National Laboratory. Longer lasting sodium-ion batteries on the horizon. July 13, 2022. Also see: Y. Jin, *et al.*, Low-solvation electrolytes for high-voltage sodium-ion batteries. *Nature Energy. 7*:718-725. 2022. Also see: Argonne National Laboratory. Pivotal battery discovery could impact transportation and the grid. March 23, 2022.
[145] Bloomberg. Battery maker develops futuristic cobalt-free cell for electric cars. November 21, 2023.
[146] Reuters. How could solid-state batteries improve next-gen EVs? June 13, 2023.

batteries will become commercialized in 2025-26, ramping up from 2028 into the 2030s.[147] These advances, which are helpful to avoid volatile supply chains, are expected to result in cheaper, lighter, safer batteries.[148]

ETST suggests that modular design has the potential to allow replacement of individual modules rather than an entire battery pack, which would reduce maintenance costs and improve sustainability of battery electric trucks, especially for long-range and heavy cargo hauling.[149] ETST also notes battery recycling could reduce costs for enhanced lithium-ion batteries, an effort that is the target of DOE-funded research.[150]

Momentum for innovation in the heavy-duty truck market is likely to increase. California's Advanced Clean Truck (ACT) regulation is exerting pressure on this sector for the transition. ACT requires manufacturers of medium- and heavy-duty vehicles to make zero-emissions or near-zero-emissions vehicles an increasing percentage of their annual sales from 2024 to 2035. Also, California's new Advanced Clean Fleet regulation requires certain types of heavy-duty truck fleet owners to purchase only zero-emission vehicles starting Jan. 1, 2024, and declares the goal to convert all Class 7-8 trucks at intermodal seaports and railyards in the state by 2035.[151]

A memorandum of understanding signed by 17 states and the District of Columbia, which together account for 43% of the U.S. population and more than one-third of the nation's medium-and-heavy-duty vehicles,[152] sets a goal of 100% zero-emission sales for medium- to heavy-duty vehicles by 2050.[153]

[147] ReTHINK Technology. Global Battery Market Forecast to 2040. September 29, 2023.
[148] S&P Market Intelligence. Batteries next: EVs to use silicon, solid state for next generation batteries. June 9, 2023.
[149] ETST, *op. cit.*, p. 33.
[150] *Ibid.*, p. 38.
[151] California Air Resources Board. Advanced Clean Fleets Summary. Accessed December 6, 2023. Also see: Final Regulation Orders: Advanced Clean Fleets, effective October 1, 2023.
[152] NESCAUM, *op. cit.*, p. 3.
[153] Multi-State Medium- and Heavy-Duty Zero-Emission Vehicle Memorandum of Understanding. July 13, 2020.

# Conclusion

Hydrogen has very little future in the vehicular transportation sector. Although the Bipartisan Infrastructure Law instructs DOE to promote diverse uses for hydrogen produced by federally funded projects, the statute also gives DOE discretion to determine if a proposed end use is impracticable. By the time DOE's selected hydrogen project applications are fully processed and the surviving projects are built, the market trends cited in this report will have expanded the already strong role of BEVs substantially, weighing against most vehicular uses of hydrogen.

DOE should use the current project negotiation period to scrutinize the applicants' marketing assumptions, including assumptions about uses in the vehicular sector, and require changes in project scale where assumptions are unrealistic. If DOE fails to exercise its discretion diligently in reviewing and finalizing the hydrogen project proposals currently before it, the result is likely to be a substantial waste of taxpayer dollars for an outsized hydrogen-based economy that will never arrive.

# About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

# About the Authors

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Suzanne Mattei is an attorney with over 30 years of experience in public interest law and policy. She has analyzed the Federal Energy Regulatory Commission's policies related to interstate pipeline approval. She has also conducted research on blue hydrogen, petrochemical projects, gas flaring and fossil fuel extraction on public lands.

Suzanne is a former regional director for the New York State Department of Environmental Conservation, where she supervised permitting and enforcement in New York City, with a population of about 8 million. Previously, in City government oversight positions, her analysis helped spur the City to abandon a risky plan to sell its drinking water supply system to a state-run authority and to reject a costly, ill-advised plan to build garbage incinerators. Her investigation on behalf of Sierra Club exposed the federal government's failure to curb exposure to pollution from the 9/11 World Trade Center disaster. Her testimony to Congress helped lead to a law that aids 9/11 responders and survivors.

Suzanne helped to establish free legal assistance and secure federal aid for bereaved families after the 9/11 disaster, and for Ground Zero workers suffering from negative health impacts.

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