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The Emerging Cost Advantage of Battery Electric Heavy-Duty Trucks and U.S. Policy Strategies to Unlock Their Full Economic Potential

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EXECUTIVE SUMMARY

From a 710 Freeway exit ramp, drivers can glimpse the constant motion at UPS's logistics hub in Compton, California—a place long defined by the rumble of heavy trucks and the scent of diesel exhaust. For decades, this corner of southern Los Angeles County has been a noisy workhorse of the goods economy. But recently, something quieter has taken root. Battery electric trucks now glide in and out of the yard, trading engine roar for a near-silent hum. This isn't some fringe experiment or California one-off—it's a sign that the economics are shifting. And that future, it turns out, is not only cleaner, but cheaper.

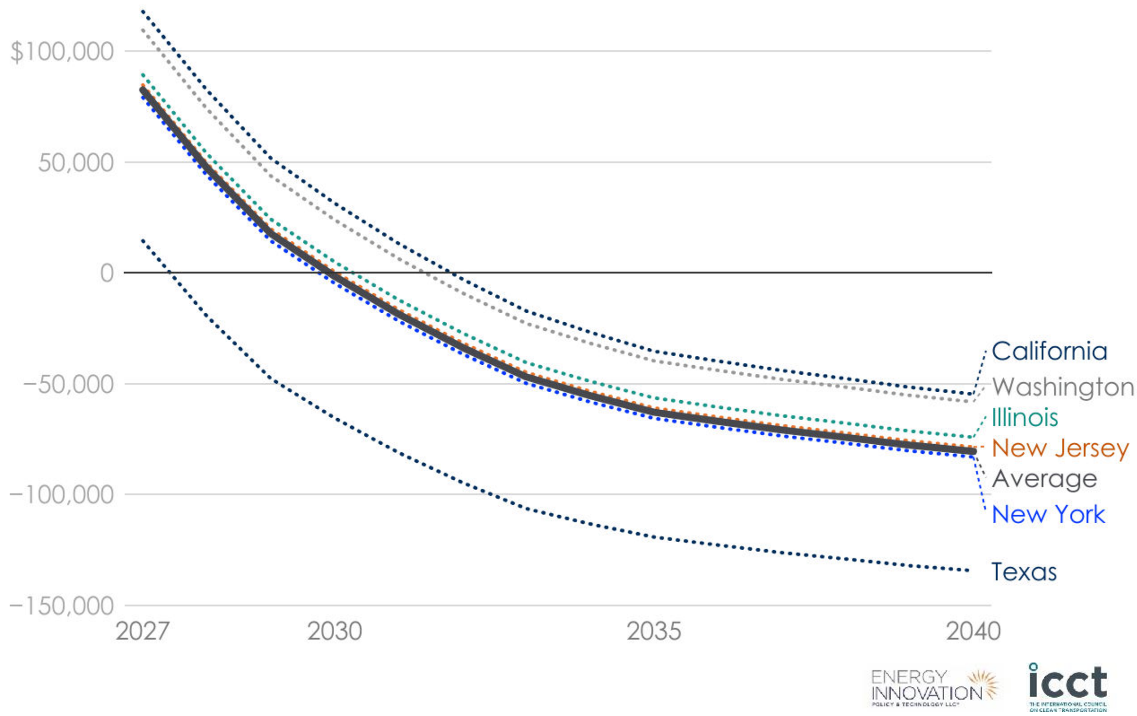
This report summarizes research finding that battery electric heavy-duty vehicles (HDVs) are on track to become the most cost-effective option for freight transport. Across all major vehicle segments, battery electric HDVs are projected to be cheaper on a per-mile basis than diesel models by 2030 in most states, provided policymakers address the factors currently driving new battery electric HDV prices in the United States above international norms. The growing affordability of battery electric HDVs is driven by the faster-than-expected convergence of heavy-duty battery costs with industry-wide average battery prices.[1] This shift has the potential to reduce freight costs—delivering economy-wide benefits by easing price pressures across a broad range of goods and services, lowering the cost of living.

Cost parity is a critical milestone, but hardly the end of the story. By 2035, modeled results show battery electric HDVs delivering tens of thousands of dollars in five-year ownership savings compared to diesel models. Such savings would deliver economy-wide benefits: lower freight costs can reduce price pressures across a wide range of goods and services, advancing the goal of a lower cost of living.

This analysis compares total cost of ownership (TCO) over five years across five common HDV segments. It includes all major expenses—vehicle acquisition, energy, maintenance, and charging infrastructure—and incorporates state-specific energy prices to reflect regional variation.

Figure ES-1 presents the modeled TCO difference between battery electric and diesel Class 8 long-haul tractor-trailers—often considered the most challenging HDV segment to electrify. The results identify Texas as the most favorable state for adoption due to its low electricity costs.

Figure ES-1. Battery electric vs. diesel TCO differential for Class 8 long-haul tractors



Note: TCO differential is calculated as the five-year ownership cost for the battery truck minus that of the comparable diesel model.

Results in Figure ES-1 exclude the effect of battery electric vehicle purchase incentives that narrow the cost gap with diesel and can significantly accelerate adoption. Though uncertainty has grown about the future of federal tax credits, state-level incentives can also be substantial. California's purchase rebate, though oversubscribed for some vehicle categories as of this writing, offers up to $120,000—enough to bring battery electric long-haul trucks to modeled TCO parity by 2027.

Low carbon fuel standards can also lower TCO for battery electric HDVs by lowering charging costs. California's 2024 update to its Low Carbon Fuel Standard was designed with this goal in mind. Our analysis estimates it reduces the state's public megawatt-scale levelized charging cost from $0.315 to $0.258 per kilowatt-hour (kWh).

Our analysis shows battery electric HDVs have a growing cost advantage over hydrogen fuel cell trucks. With greater technological maturity, lower fuel and capital costs, and faster real-world deployment, battery electric HDVs are pulling decisively ahead.

Retail price estimates in this study are based on bottom-up modeling grounded in U.S. data sources, primarily the 2024 Annual Technology Baseline.[2] The U.S. HDV battery pack price forecast is based on BloombergNEF's 2024 Electric Vehicle Outlook.[3] The model incorporates manufacturing costs, indirect expenses, and standard profit margins. The resulting price forecasts align with global trends observed in markets like Europe and China, where battery electric HDV prices are falling—not rising.[4]

In contrast, in the U.S., taking California as a proxy, battery electric Class 8 truck prices increased from 2021 to 2024.[5] Limited competition and weak pricing transparency may be contributing to higher than average margins and reduced market discipline.

Strategic U.S. policy actions can help close the gap between actual prices and modeled costs, aligning domestic markets with global trends and accelerating battery-electric HDV adoption. While HDV purchase incentives are essential to spur early uptake, they can inadvertently inflate buyers' willingness to pay, placing upward pressure on prices. Smart policy design can address this by coupling incentives with price eligibility caps, encouraging manufacturers to set prices below announced thresholds. Price disclosure requirements for eligibility can also enhance price transparency and foster competition.

Other policy priorities include strengthening battery electric HDV resale value, ensuring affordable electricity rates, and expanding charging infrastructure. Still, policy priorities must be grounded in political realism. As efforts to roll back past gains are now the focus of federal policy, the burden of leadership now falls squarely on the states.

Despite heightened uncertainty due to recent tariff policy developments, the trend remains clear: battery electric trucks are poised to become the 21st century's preferred HDV powertrain technology. Without sustained policy support, the U.S. risks continued dependence on costly diesel, pushing freight expenses higher and inflating consumer prices economy-wide. Conversely, robust policy strategies can position America to lead in transportation technology, cutting freight costs, boosting domestic manufacturing, and sharpening U.S. competitiveness.

INTRODUCTION

BE HDVs are on the cusp of becoming the most affordable option for freight and could transform trucking economics. This report finds that by 2030, and in many cases sooner, battery electric HDVs will be cheaper to own and operate than diesel trucks across all major vehicle segments in most U.S. states.

The stakes are high for getting this right. Trucking costs ripple across nearly every supply chain, shaping prices economy-wide. Lower freight costs can help ease these price pressures. As an added benefit, faster deployment of battery electric trucks also delivers major air quality and public health benefits. But while battery prices are falling and performance is rising, market barriers still block progress.

This research identifies when and where battery electric trucks are expected to reach cost parity with diesel models, breaking it down by state and truck type. We analyze what's driving progress, what's holding it back, and which policies can deliver affordability faster.

We also evaluate hydrogen fuel cell HDVs, often promoted as a competitive next-generation technology. Our analysis finds that battery electric trucks maintain a clear and widening cost advantage over FC models across capital, fuel, and total ownership costs. As a result, battery electric HDVs are likely to become the preferred technology in most use cases.

America's global position in clean truck manufacturing will be defined by decisions made now. The U.S. is surging in battery investment but lagging in truck deployment. Unlocking the full economic and clean air benefits of battery electric HDVs will require smart, targeted policy—at the federal, state, and local levels—to build a stronger domestic market, improve new battery electric HDV purchase price transparency, encourage manufacturer competition, strengthen resale confidence, and expand charging infrastructure.

INVESTMENT RISING, DEPLOYMENT DRAGGING

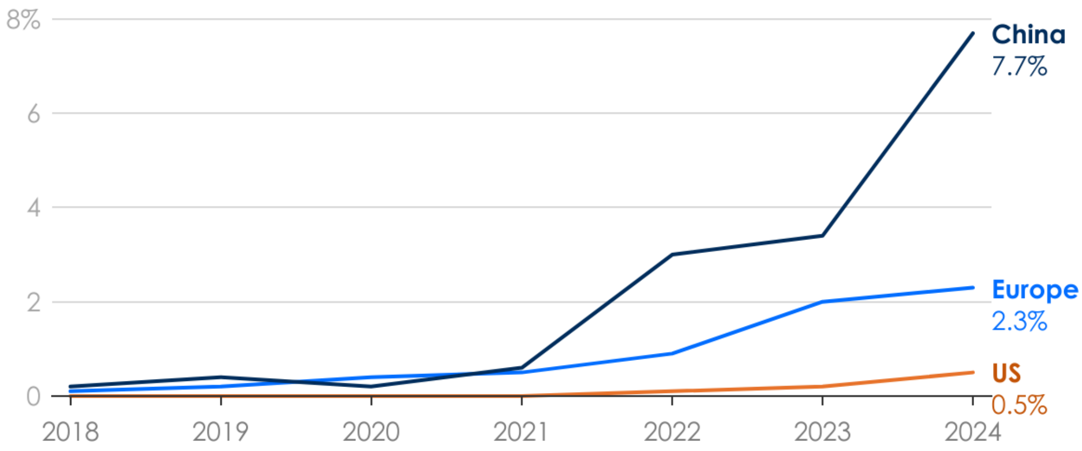
The global transition to EVs is no longer a question of if—but when. Battery electric technology is advancing rapidly, and adoption is accelerating globally across both passenger and freight segments. In this context, the central question for the U.S. is not whether to electrify HDVs, but whether we will capitalize on current investment momentum—or fall behind as other nations push forward.

Recent manufacturing investment suggests a strong starting position. Since 2021, the U.S. share of global EV-related investment has more than tripled, making it the world's leading destination for EV and battery manufacturing.[6] While China captured 60 percent of such investment from 2016 to 2020, its share has fallen to just 24 percent in recent years.[7] Through September 2024, private companies announced $209 billion in U.S.-based projects and are expected to generate more than 240,000 manufacturing jobs.[8]

A portion of this investment is explicitly geared toward commercial vehicles. Amplify Cell Technologies, for example, is building a battery cell facility in Marshall County, Mississippi, with an investment of more than $2 billion dedicated to the heavy-duty truck market.[9] The site will produce 21 gigawatt-hours of lithium-iron-phosphate cells annually—enough to support large-scale electrification of freight vehicles. Construction began in mid-2024, with production slated to start in 2027.[10] Mississippi Governor Tate Reeves, a Republican, has praised the project as a landmark for the state's economy and a clear sign of the opportunity presented by vehicle electrification, noting: "This project is the largest payroll commitment in state history and it will bring an incredible 2,000 new jobs to this community."[11]

But deployment tells a different story. Battery electric HDVs made up just 0.5 percent of new truck sales in the U.S. in the first half of 2024—well behind Europe's 2 percent and China's 7.7 percent. The U.S. badly trails other nations in deploying BE HDVs.

Figure 1. BE HDV sales in major markets (% of new sales)



Note: U.S. data refer to first half of 2024 only. Sources: BNEF 2024,[12] BNEF 2025.[13]

This disconnect poses a strategic risk. A strong domestic market is essential to sustaining private investment and accelerating innovation. Without it, manufacturers may scale back or shift production elsewhere. Continued policy support for vehicle purchases, infrastructure build-out, and supply chain development is critical to ensuring that the U.S. market keeps pace with its manufacturing potential.

The outcome will shape not just emissions trajectories and cost trends, but economic competitiveness. The U.S. can lead in the future of trucking—or become a fragmented, high-cost outlier in a freight system shaped by others.

BATTERY ELECTRIC TRUCK ECONOMICS

Battery costs are the largest driver of manufacturing expenses for BE vehicles—a dynamic that is even more pronounced for the heaviest trucks. As a result, the outlook for battery pack prices is central to understanding the economics of battery electric HDVs. This section begins with an overview of the learning curve effects that have driven down lithium-ion battery prices across multiple applications. It then turns to factors specific to HDV battery pack trends. Finally, we shift from the cell and pack level to the vehicle level, examining recent battery electric HDV price developments.

Lithium-ion battery innovation and cost reductions are happening at a breakneck pace. From 2010 to 2023, the real cost of vehicle battery packs dropped by 90 percent, while since 1991, lithium-ion battery prices have declined by 98 percent on average.[i] [14] In December 2024, lithium-ion battery pack prices reached a record low of $115 per kWh, marking a 20 percent decrease from 2023.[15]

Learning curve effects are at the root of this decades-long trend. As production scaled, manufacturers refined processes, gained new knowledge, and benefited from growing economies of scale, thereby improving efficiency and reducing costs. This created a virtuous cycle: lower prices enabled new applications, from EVs to grid storage, which further drove demand and cost reductions.

Battery pack cost reductions in recent years have also been supported by growing adoption of lower-cost lithium-iron-phosphate batteries.

Finally, oversupply of battery manufacturing capacity, particularly in China, is providing downward price pressure. At the same time, the effects of overcapacity are limited because most EV battery packs are designed for specific vehicle models, making surplus production harder to sell.[16]

Drivers of Accelerated HDV Battery Price Declines

Historically, HDV battery packs have cost more per kilowatt-hour than those used in light-duty vehicles. Several factors contribute to this gap: lower production volumes, more demanding performance requirements, and procurement models less suited to scale. Battery packs for HDVs have typically been built in smaller, customized batches, limiting the benefits of learning curve effects. They must also meet more rigorous durability standards, given the longer and harsher duty cycles in commercial applications—necessitating robust thermal management systems and enhanced safety features.

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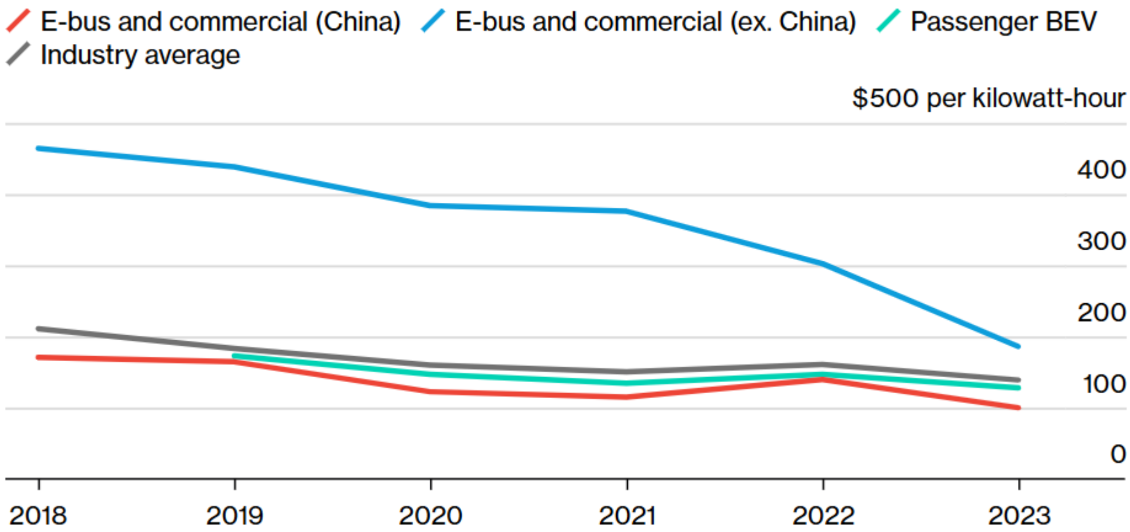
[i] Lithium battery prices fell from an average of $9129 per kWh in 1991 to $1431 per kWh in 2010 to $143 per kWh in 2023 for vehicle battery packs on an industry-wide basis (all dollar values 2024 real).

These barriers, however, are beginning to erode. One key development is the growing use of lithium-iron-phosphate batteries, which cost less, offer improved safety, and eliminate the need for cobalt—a historically expensive and supply-constrained input.

Procurement practices are also evolving. While light-duty EV manufacturers have long benefited from large-scale purchasing and long-term supplier contracts, HDV makers have until recently relied on smaller, often bespoke orders. This is changing as production scales and the market for battery electric HDVs begins to mature.[17]

Battery pricing dynamics are shifting accordingly. As shown in Figure 2, average lithium-ion battery prices are converging across applications.

Figure 2. Average lithium-ion battery prices are converging across end uses



Source: BloombergNEF[18]

BloombergNEF notes: “Battery prices across different applications are converging as vendors hunt down new sources of demand. The premium that truck makers pay for batteries is disappearing. That’s good news for commercial EV manufacturers in the years ahead.”[19]

The result: HDV battery prices are falling faster than the industry average—narrowing the gap with light-duty vehicles and accelerating the path to cost parity for electric trucks.

Purchase Price Dynamics and Evidence of Pricing Anomalies

In the U.S., the current purchase price of a battery electric HDV is roughly two to three times that of a comparable diesel truck. This sharp disparity runs counter to the trajectory of battery and vehicle component costs, which have been falling globally. In major markets like Europe and China, battery electric HDV prices are decreasing. The U.S. stands apart—and not in a good way. Current pricing here is increasingly difficult to reconcile with underlying techno-economic trends and appears to be shaped by a set of market-specific anomalies.

The California Air Resources Board (CARB) has conducted the most detailed recent evaluation of battery electric HDV price trends, revealing a significant gulf between California and European markets. From 2021–2022 to 2024, average battery electric Class 8 short-haul tractor prices rose by over $86,000 in California, while they fell by more than $12,000 in Europe.[20] After adjusting for performance differences, battery electric Class 8 short-haul tractors in California still came in nearly $57,000 more expensive.[21] These findings underscore that U.S. battery-electric HDV prices have been not only unusually high but were also rising over the 2021–2024 period—an outlier trend in a global context.

An analysis of market dynamics completed by CARB at the end of 2024 found no indications state's Advanced Clean Trucks (ACT) or other policies were root causes of recent price anomalies.[22] Structurally, the ACT is designed for flexibility. It does not impose requirements on individual manufacturers but instead sets a fleetwide sales standard, allowing compliance through credit banking and trading—across both manufacturers and model years.

Early data demonstrate manufacturers are already taking advantage of this design flexibility, CARB's analysis—based on model year 2023 compliance data—found that a significant volume of credits had been banked and carried into 2024. This suggests no immediate shortage of regulatory headroom. As CARB summarized: "The OEMs [Original Equipment Manufacturers] indicated that the product availability issues for the 2024 model year are not driven by the ACT regulation, as evidenced by the excess of ZEV [Zero Emission Vehicle] credits available based on the ACT credit summary through the 2023 model year. All of the regulated OEMs have ZEV [Zero Emission Vehicle] products available for the market in the 2024 model year, and many have already sold ZEVs in previous years to build up an early credit bank."

Several factors appear to be contributing to today's elevated prices. First is limited purchase price transparency. Pricing power due to market concentration may also be a factor. Prices are falling in lighter-duty HDV segments, where more manufacturers compete.[23] But in the Class 8 tractor segment—a more concentrated market dominated by a few firms—prices remain stubbornly high.

Manufacturers can command substantial margins in emerging markets like battery electric HDVs, where there may be fewer producers, technology is evolving, and pricing information is opaque.[24] As the market matures, increased transparency and competition should place downward pressure on prices—but that shift has yet to materialize.

Incentives remain pivotal to battery electric HDV adoption, but they also increase buyers' willingness to pay, which may be providing upward price pressure. In California, incentive levels for Class 8 battery electric trucks reach up to $120,000. While these subsidies help fleets overcome high up-front costs and remain critical to deployment, they may reduce pricing discipline among manufacturers. Policymakers can mitigate this risk with well-designed tools—such as eligibility caps, price ceilings, or reverse auction mechanisms that limit public expenditure while preserving strong adoption signals.

There is also international evidence that stronger policy requirements can put downward pressure on prices. In Europe, where carbon dioxide (CO_2) standards for trucks are being phased in via the VECTO vehicle certification program, some evidence suggests price competition increased among original equipment manufacturers as the 2025 model reporting deadline approached.[25] This suggests that stronger supply-side requirements on manufacturers can drive affordability through market discipline.

Despite the U.S. pricing challenges, there are signals that cost compression is imminent—even in the Class 8 long-haul tractor segment. Tesla stated that it will begin high-volume production of its Semi in 2026, with a facility that can produce 50,000 trucks per year expected to be completed in 2025.[26] A 2023 report pegged the price at around $250,000.[27] More recent media reports suggest the price may be closer to $415,000.[28] According to a recent news report, Tesla's plans to import Semi components from China have been disrupted following new U.S. tariffs.[29] This development appears likely to delay the company's near-term production strategy. Still, if resolved, Tesla's entry at scale has the potential to reshape pricing dynamics in the U.S.

Another emerging player is Windrose, which plans to offer a Class 8 BE sleeper truck in the U.S. at a starting price of $250,000.[30] The company is establishing final assembly operations in Savannah, Georgia.[31] Its long-haul tractor, boasting a 420-mile range on a single charge, recently completed a 2,800-mile U.S. cross-country field test using only public charging.[32] Windrose plans to offer U.S. availability in 2026. Though still unproven, Windrose could pressure incumbent manufacturers to reprice existing offerings if it delivers on cost and performance promises.

In sum, U.S. battery electric HDV prices do not reflect inevitable production costs, nor are they consistent with global price trajectories. While the exact combination of causes remains uncertain, rising prices amid falling input costs and growing international competition suggest that today's pricing is a function of market immaturity, limited competition, and policy design. Strategic action can help turn this corner. Policies that increase transparency, broaden competition, and align incentives with affordability will be critical to unlocking the full cost-saving potential of battery electric HDVs—and ensuring fleets and consumers share in the benefits of zero-emission freight.

METHODOLOGY: TCO

This centerpiece of this report is a TCO analysis. Such research seeks to account for all the main factors in vehicle acquisition, operation, and upkeep. TCO can be broken down into two main cost components: capital expenses and operational expenses. Capital expenses consist of the up-front investments required to acquire new vehicles and establish necessary infrastructure. Operational expenses encompass ongoing costs associated with vehicle use, including fuel, maintenance, repair, and insurance.

A Class 8 Long-Haul Tractor-Trailer

Results are shared in net present value terms, discounted at 7 percent annually based on five years of ownership. Monetary values are given in 2024 dollars. We rely principally on data inputs from the 2024 Annual Technology Baseline (ATB), produced annually by the National Renewable Energy Laboratory.[33] The ATB provides a consistent set of cost and performance data for energy technology analysis. The appendix provides a more detailed exploration of data and methodology.[34]

A Class 8 Short-Haul Tractor Truck

We analyze five HDV segments selected from those analyzed for the 2024 ATB. All have a gross vehicle weight rating (GVWR)—meaning fully loaded weight—of at least 14,000 pounds.

The largest two trucks we analyze are both Class 8 tractor-trailers, both with GVWRs of more than 33,000 pounds. A tractor-trailer truck—also known as a semi-truck, big rig, or 18-wheeler—consists of two main parts. The tractor is the front section, containing the engine and driver's cab, and is designed to tow a trailer. The trailer carries the cargo and is connected to the tractor by a pivoting joint. This setup forms an articulated vehicle, allowing the trailer to turn independently of the tractor.

We distinguish two types of Class 8 tractor-trailers. Short-haul tractor-trailers operate primarily within a single region. Long-haul trucks cover greater distances. Long-haul tractor trucks feature sleeper cabs for driver rest during extended trips and are equipped with significantly larger batteries. Short- and long-haul tractor trucks together account for about 63 percent of overall fuel consumption by medium-duty and heavy-duty trucks in the U.S.[35] Pictured on the previous page are a long-haul tractor towing a trailer and a short-haul tractor unconnected to a trailer.

A Class 7 Vocational Truck

A Class 6 Box Truck

Three of the five HDV segments we analyze are single-unit trucks, the largest of which is a Class 7 vocational truck. Class 7 trucks range in GVWR from 26,001 to 33,000 pounds. Vocational trucks can be configured for a range of uses, and serve as dump trucks, garbage trucks, tow trucks, or fire trucks. The two lightest HDV segments analyzed are Class 4 and Class 6 box trucks (with respective GVWR ranges of 14,001-16,000 and 16,001-26,000). Box trucks have an enclosed, rectangular cargo area attached to the chassis and serve a range of delivery uses.

A Class 4 Box Truck

Capital Expenses

The largest component of capital expenditures (capex) is the purchase price of new HDVs. For BE trucks, charging infrastructure costs are treated separately and incorporated into operational expenses using a levelized cost of charging approach, as discussed later in this report.

Vehicle purchase prices are modeled using a bottom-up methodology that begins with direct manufacturing costs—expenses tied to the materials, components, and labor required to build the vehicle.

To arrive at full vehicle prices, the bottom-up method adds an indirect cost markup to account for expenses beyond the factory floor. These include research and development, marketing, administration, overhead, and manufacturer profit. This study applies a 42 percent markup to direct manufacturing costs—more in line with industry literature—whereas the 2024 ATB assumes a 20 percent markup, a figure that understates the real-world cost structure compared to most published analyses.[ii] [36]

Finally, our capex estimates account for applicable taxes and fees, notably state sales taxes and the 15 percent federal excise tax levied on new Class 8 trucks.

The 2024 ATB serves as our primary source for cost estimates. However, we diverge from the ATB's projections for HDV battery pack prices. Instead, we develop a U.S.-specific forecast grounded in BloombergNEF's latest projections, drawn from Figure 199 of its 2024 *Electric Vehicle Outlook*.[37]

We make this shift for two reasons. First, BloombergNEF is widely regarded as a leading authority on battery costs. It is frequently cited by government agencies, research institutes, financial organizations, and the media. BloombergNEF forecasts are frequently updated, informed by in-depth modeling of technology pathways and supply chain dynamics, and underpinned by proprietary surveys of lithium market transactions—data few others can match.[38]

Second, the ATB's HDV battery price forecast relies on dated research, citing a 2021 International Council on Clean Transportation (ICCT) report.[iii] [39] While valuable for understanding past conditions, it likely underestimates the speed of current and future cost declines. The 2021 study found that Class 8 truck battery packs averaged $250/kWh

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[ii] The 2024 ATB "assumes a retail price equivalent factor of 1.5 for light-duty vehicles and 1.2 for medium- and heavy-duty vehicles to estimate retail prices based on manufacturing costs. These estimates may not reflect actual retail price trajectories, which may differ because of external market drivers not included in the ATB (e.g., automotive market supply and demand imbalances, original equipment manufacturer regulatory compliance and pricing strategies, taxes, and dealer incentives)."

[iii] According to the "Battery Electric Vehicle Assumptions" page on the 2024 ATB website (accessed April 14, 2025): "Battery assumptions in the Autonomie model refer to the ICCT E-Truck Virtual Teardown Study (ICCT 2021) for the difference in the Base Year costs." The 2024 ATB's Mid Trajectory scenario projects future cost reductions for HDV battery packs based on the low technology progress case from the Autonomie model.

in 2020, equivalent to roughly $303/kWh in 2024 dollars, based on a range of observed prices from $230 to $424/kWh.[40] This 2021 research projected costs could fall below $182/kWh (2024 dollars) by 2030. In contrast, the ATB's Mid-Trajectory scenario doesn't reach that level until 2038.[41]

This study adopts a more current and representative cost basis by relying on BloombergNEF's projections for battery pack prices, ensuring that capital cost estimates reflect the latest market dynamics rather than outdated assumptions.

Estimating Future U.S. HDV Battery Pack Costs

Because BloombergNEF's forecast reflects global trends, we adjust it to reflect U.S.-specific pricing conditions. This adjustment is grounded in Figure 2, which presents historical data distinguishing battery pack prices in China from those in other markets.

In 2023, battery packs for commercial vehicles in China were slightly cheaper per kilowatt-hour than those for passenger vehicles—highlighting how quickly prices for heavy- and light-duty batteries may converge. Outside China, however, commercial vehicle battery packs remained significantly more expensive—by 86 percent.[42] For passenger vehicles, the gap was far narrower: U.S. battery pack prices exceeded the global average by 11 percent, a figure corroborated by International Energy Agency data.[43]

To construct a U.S.-specific HDV battery price forecast, we assume that the differential compared to global prices gradually narrows over the next decade. By 2033, the U.S. aligns with the 11 percent industry-wide premium seen in 2023. Intermediate values are linearly interpolated, yielding a modeled U.S. premium of 56 percent in 2027 and 34 percent in 2030.

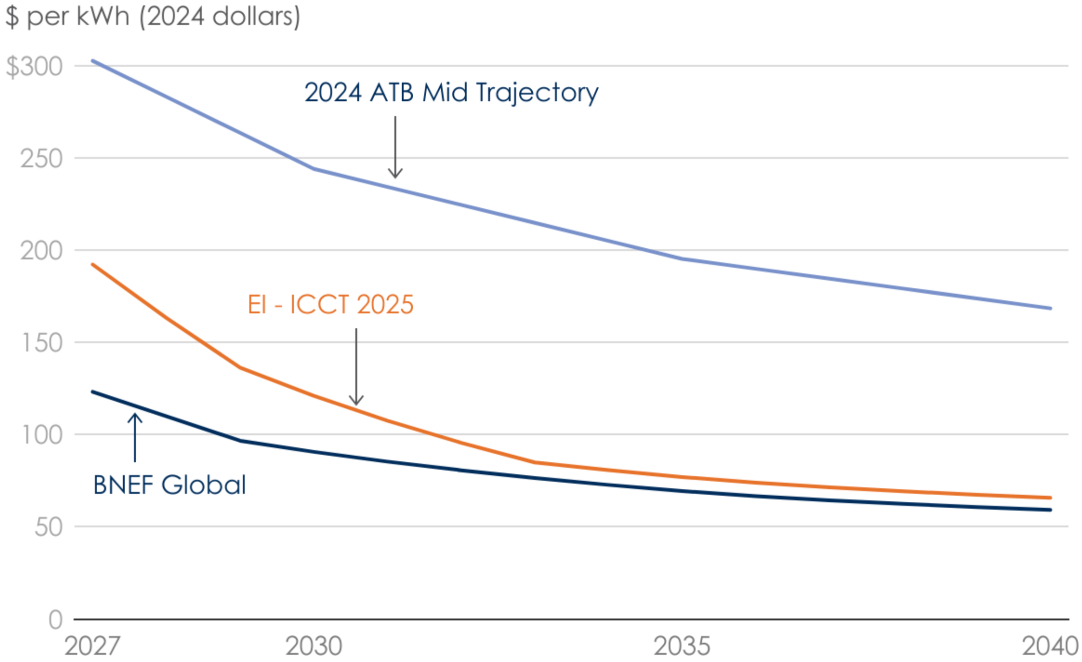
We project that the gap between U.S. and global HDV battery prices will narrow over time, driven by several converging trends.

First, China's cost advantage stems primarily from economies of scale, local supply chains, and vertically integrated production. As the U.S. accelerates domestic battery manufacturing and private-sector investment grows, these advantages are expected to erode.

Second, battery technologies are becoming increasingly standardized across markets. U.S. manufacturers are beginning to adopt innovations already widely deployed in China, such as lithium-iron-phosphate chemistries and cell-to-pack designs. As these cost-saving approaches diffuse globally, the structural price gap should continue to shrink.

Together, these trends support a trajectory in which U.S. HDV battery pack prices steadily converge with global averages over the coming decade. That said, recent tariff policy developments have added uncertainty to the outlook.

Figure 3. HDV battery pack price forecast comparison



Notes: Annual values for the 2024 ATB are linear interpolated between five-year forecast intervals. The 2024 ATB (Mid-Trajectory) retail price level is derived by applying the ATB's 20 percent retail price scalar to direct manufacturing cost. The BNEF forecast is extended from 2035 to 2040 by applying the historical 17 percent learning curve found in the 2024 EV Outlook. Sources: BNEF,[44] ATB,[45] and EI-ICCT analysis.

In addition to the future battery cost expectations, battery size significantly influences battery pack cost. Battery capacity in electric trucks depends primarily on daily mileage requirements, vehicle weight, and energy efficiency. Another factor determining modeled battery capacity is the imperative of preventing complete depletion, as fully discharging batteries can negatively impact their performance and lifespan. Following manufacturers' guidelines, we use an 80 percent maximum depth of discharge.

This analysis uses battery pack sizes from the 2024 ATB for Class 4, 6, and 7 trucks, while independently estimating battery capacities for short-haul and long-haul tractor-trailers. For these tractor configurations, battery size is based on HDV manufacturers' perceptions of fleet performance expectations.[46] Specifically, we adopt 2025 pack sizes of 432 kWh for Class 8 short-haul tractors and 873 kWh for Class 8 long-haul tractors.

By comparison, the 2024 ATB assumed larger batteries for short- and long-haul tractors—626 kWh and 1,194 kWh, respectively—reflecting an assumption that a truck should carry enough battery capacity to complete nearly all duty cycles without recharging during the day.[47]

Table 1. Battery capacity projected by year and vehicle type (kWh)

Class - Type	2025	2030	2035	2040
Class 4 Box Truck	147	139	127	124
Class 6 Box Truck	186	175	159	155
Class 7 Box Truck	328	307	282	273
Class 8 Short-Haul Tractor Truck	432	392	353	339
Class 8 Long-Haul Tractor Truck	873	774	696	670

Sources: ATB[48] and EI-ICCT analysis.

In practice, smaller battery packs may be feasible with the integration of brief daytime charging sessions. While our baseline modeling does not incorporate this flexibility, we evaluate its potential in a separate scenario. This alternative introduces on-route charging sessions at ——30 minutes for short-haul and one hour for long-haul tractors assuming megawatt scale, i.e. levels seen in commercial operation today. Assuming megawatt scale, i.e. much below three megawatt chargers already in commercial operation,[49] required battery capacities fall to 319 kWh and 655 kWh, respectively, while still meeting daily operational needs.

Operational Expenses

Operational expenses (opex) cover all recurring costs associated with vehicle operation. The dominant component of operational costs for HDVs is energy consumption (fuel), followed by maintenance, repair, and insurance expenses. According to research from the UC Davis Institute for Transportation Studies,[50] maintenance and repair costs for diesel vehicles are projected to remain stable, while those for battery electric and hydrogen FC models are expected to decline over time as these technologies advance.

Since energy costs have such a significant impact on vehicle TCO and vary by geography, this analysis incorporates state-specific fuel pricing. Diesel fuel and grid electricity prices for each state are based on observed 2024 market prices. For future projections, the Energy Information Administration's Short-Term Energy Outlook is used to estimate prices for 2025 and 2026, while the 2023 Annual Energy Outlook, the most recent available, provides forecasts for 2027 and beyond.[51]

State diesel fuel prices vary most between California and Texas, ranging from $4.93 to $3.46 based on the 2024 average. California's higher prices reflect the cost of a specialized fuel blend designed to mitigate air pollution, which the state's topography can otherwise trap at hazardous levels.

Energy costs for battery electric HDVs are addressed below in the "Levelized Cost of Charging" section.

RESULTS: WHERE AND WHEN BATTERY HDVS WIN

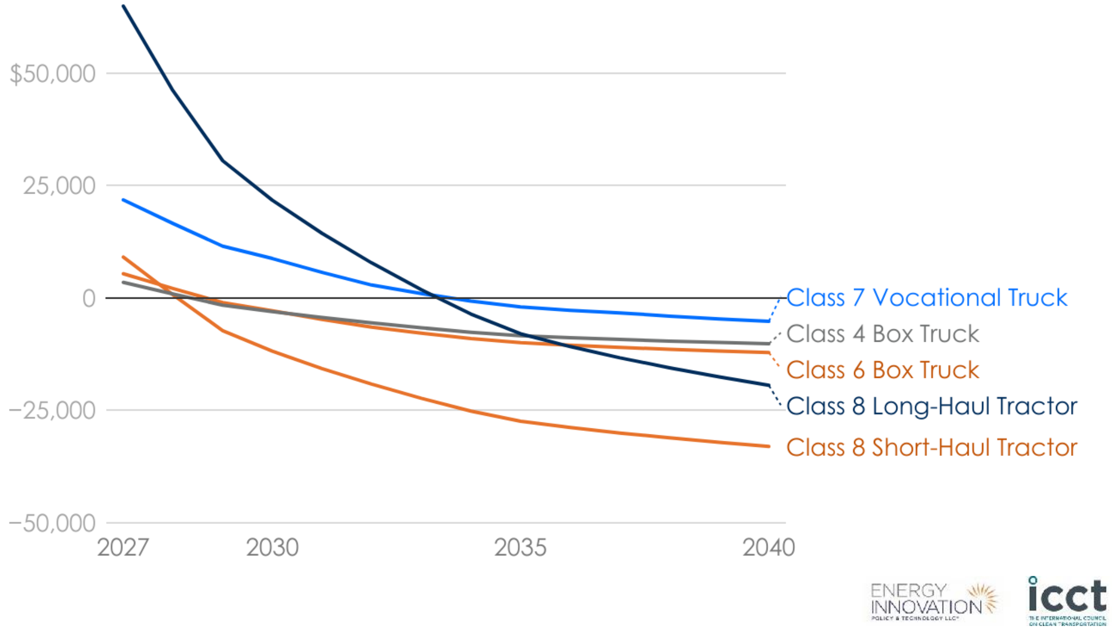
This section answers the core question: when and where will battery electric HDVs become more cost-effective than diesel trucks? Based on a five-year TCO analysis, the results show that battery electric HDVs are on track to deliver cost savings across all major vehicle types by 2030 in most U.S. states. In some cases, parity arrives sooner. These findings reflect modeled conditions—not current prices—and assume that policy support aligns with factors driving affordability, including battery cost declines and manageable electricity prices.

Capex and Opex Results

We begin by reviewing results for the two main components of TCO: capex and opex.

Capex includes financed vehicle costs and taxes, but excludes charging infrastructure, which is addressed under opex. Purchase prices are modeled using a bottom-up method based on direct manufacturing costs, indirect expenses, and a profit margin. Vehicle costs are adjusted to reflect state-specific sales tax and the federal excise tax on new Class 8 trucks. Capex estimates assume a 20 percent down payment, a 5 percent annual interest rate, and a 7 percent discount rate.

Figure 4. Battery electric vs. diesel capex differential projected by vehicle type

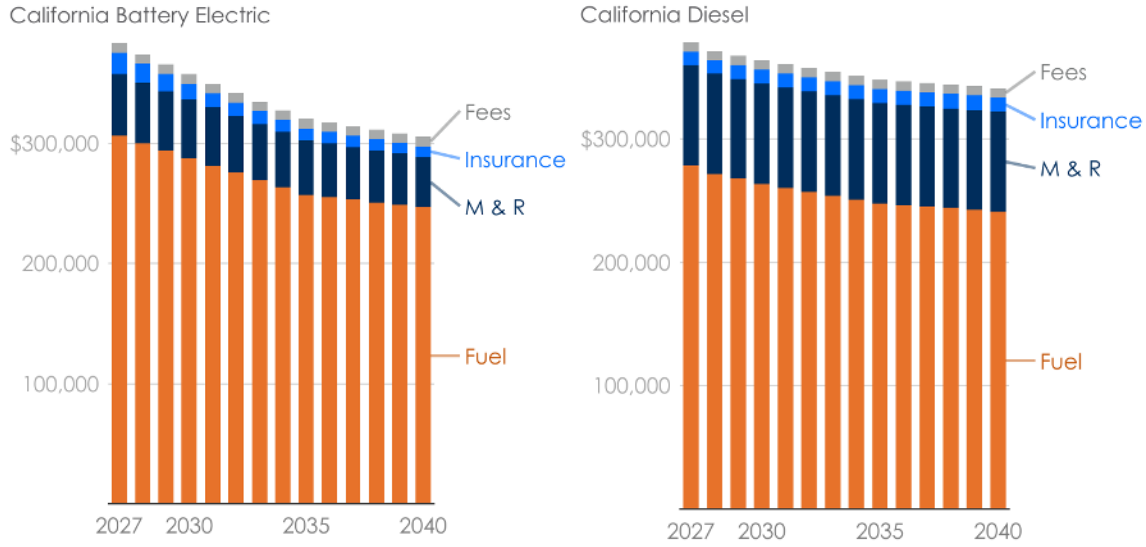


Notes: Results are calculated as the BE value minus the diesel value. A result below zero indicates that the battery electric vehicle is estimated to cost less. Results are presented in 2024 dollars, consistent with the rest of this report.

Figure 4 shows modeled capex for battery electric versions falling below diesel capex before 2030 for the Class 8 short-haul tractor, Class 6 box truck, and Class 4 box truck. For the Class 8 long-haul tractor and the Class 7 vocational truck, modeled capex for battery electric versions falls below diesel capex in 2034.[iv]

Our capex results are similar to those of BNEF, which concludes: "Battery trucks are more expensive now, but price parity could be near in some segments."[52] [v]

Figure 5.a. California opex: battery electric vs. diesel for Class 8 long-haul tractors

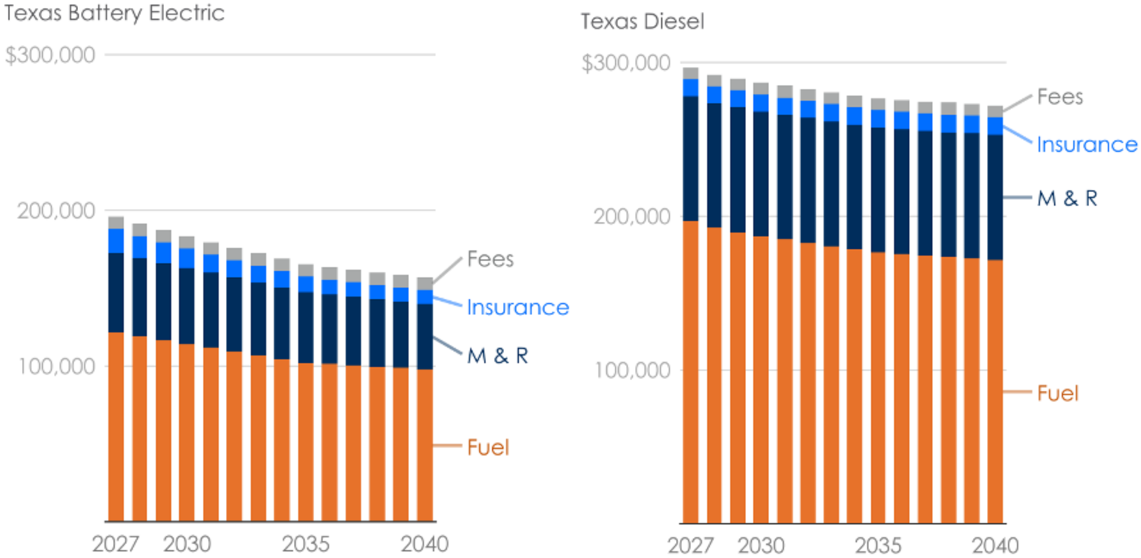


[iv] For more detail about the composition of capex by vehicle and powertrain type, see the following numerical tables:

- Class 8 Long-Haul Tractor, https://datawrapper.dwcdn.net/toCvK/
- Class 8 Short-Haul Tractor, https://datawrapper.dwcdn.net/15Mjy/
- Class 7 Vocational Truck, https://datawrapper.dwcdn.net/5q1Lh/
- Class 6 Box Truck, https://datawrapper.dwcdn.net/rRXRA/
- Class 6 Box Truck, https://datawrapper.dwcdn.net/iUyK7/

[v] This footnote provides additional context on BNEF's conclusions. The document referenced in endnote 57 defines defining medium-duty as Class 4-5 trucks with 250 miles of range and heavy-duty are Class 8 trucks with 500 miles of range and states: "Medium-duty battery trucks can be about a quarter more expensive than equivalent diesels [today]. However, that gap rapidly closes and before 2030 they could be as cheap or cheaper to produce due mainly to falling battery costs. Heavy-duty battery trucks for long-haul operations are about 1.5-2 times as expensive as equivalent diesels, but could approach their prices around 2030," page 39.

Figure 5.b. Texas opex: battery electric vs. diesel for Class 8 long-haul tractors



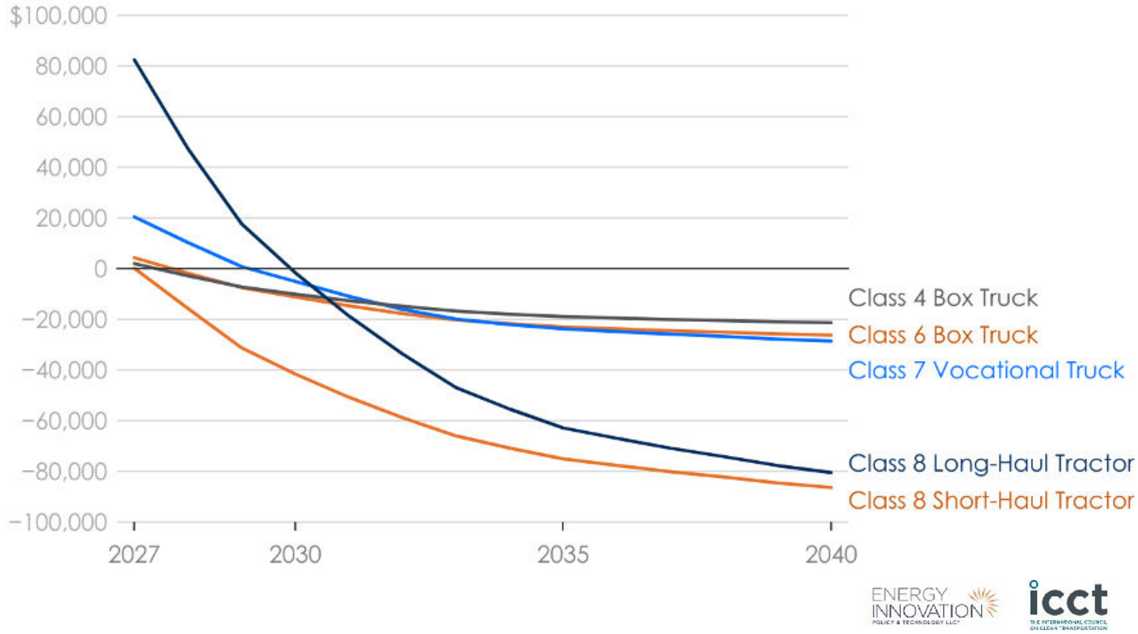
Note: M & R refers to maintenance and repair expenses.

TCO Crossovers by Vehicle Type and Location

TCO crossover occurs when the net present value of five-year ownership costs for a BEV drops below that of its diesel counterpart. Throughout this analysis, results are expressed as the difference between battery electric and diesel TCO, where negative values indicate cost savings for battery electric HDVs.

Results displayed in Figure 6 show that all five truck segments deliver TCO savings by 2030 across the six states, on average. Class 4 and Class 6 box trucks reach crossover earliest, followed by short-haul tractors, vocational trucks, and finally long-haul tractors.

Figure 6. Battery vs. diesel TCO differential by vehicle segment (state average)



Note: TCO differential is calculated as the state average five-year ownership cost for the battery electric HDV minus that of the comparable diesel.

Figure 7 shows the range of TCO outcomes by state. Texas consistently delivers the greatest savings, driven by its low electricity prices.

Figure 7.a. Class 8 long-haul tractor: battery vs. diesel TCO differential

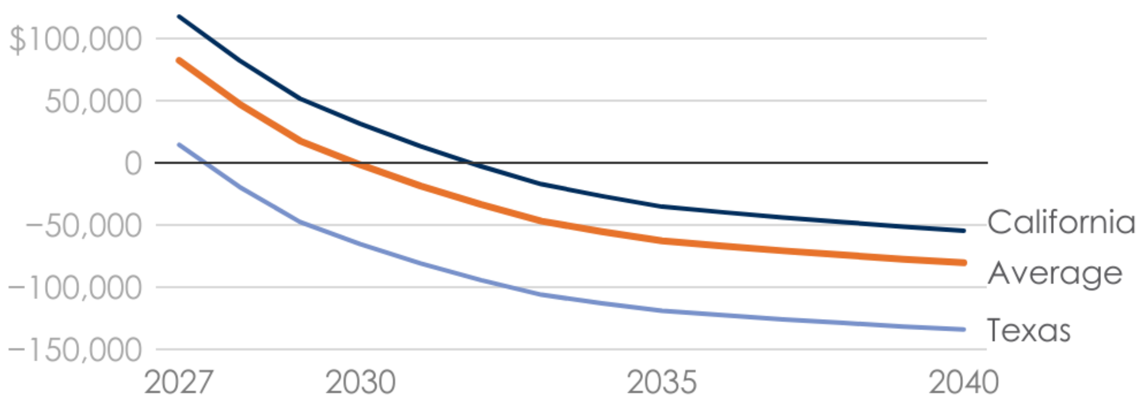


Figure 7.b. Class 8 short-haul tractor: battery vs. diesel TCO differential

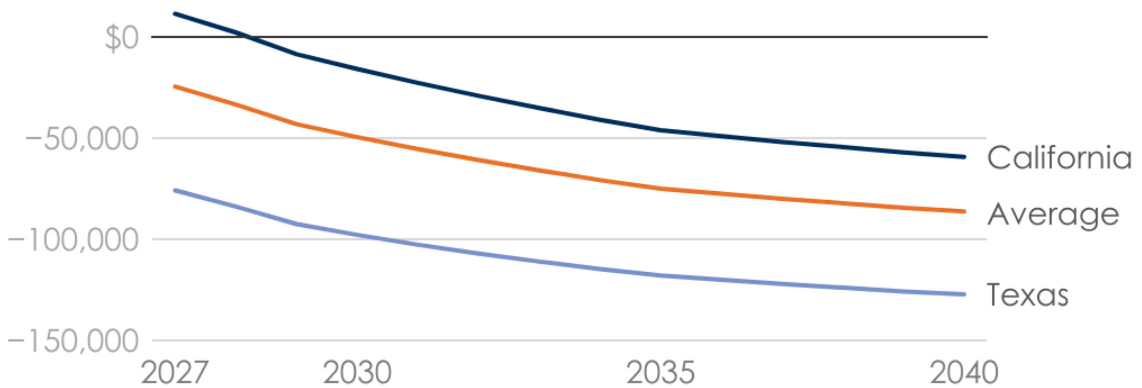


Figure 7.c. Class 7 vocational truck: battery vs. diesel TCO differential

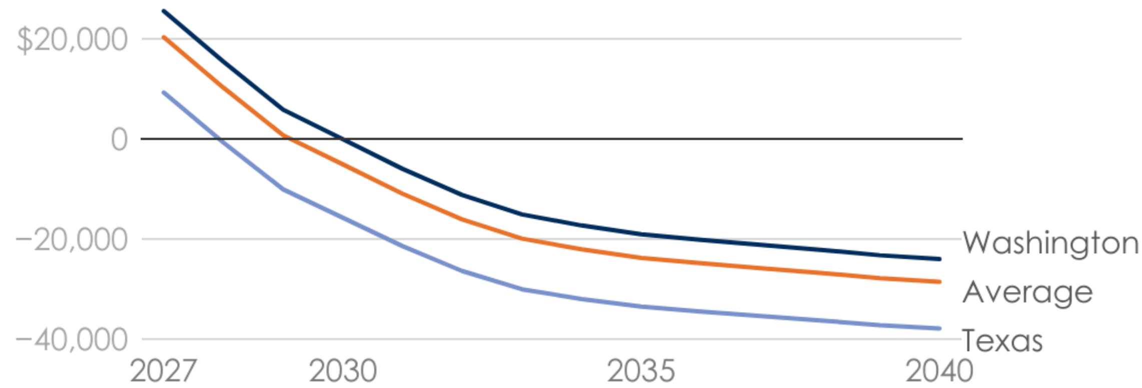


Figure 7.d. Class 6 box truck: battery vs. diesel TCO differential

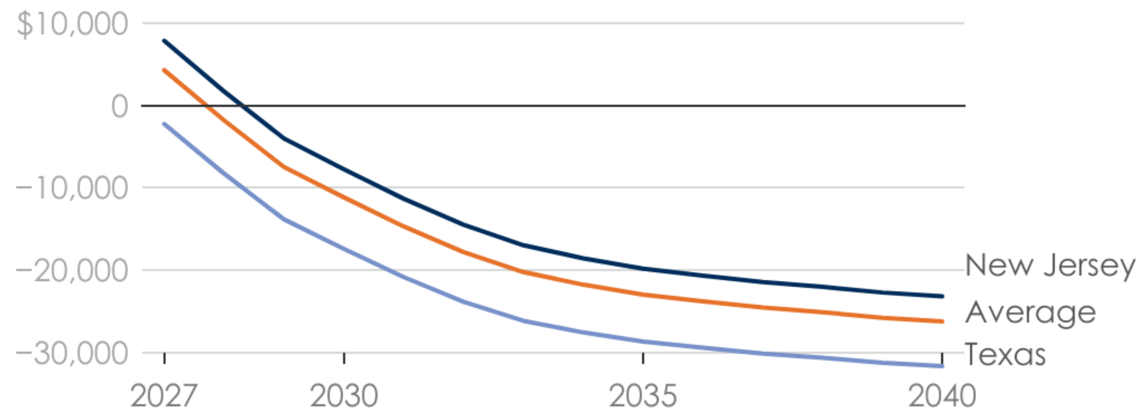
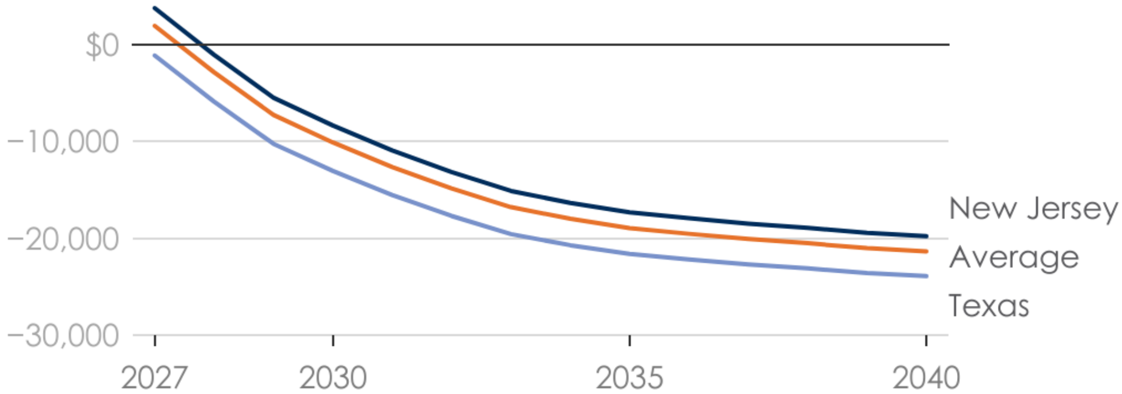


Figure 7.e. Class 4 box truck: battery vs. diesel TCO differential



Notes: TCO differential calculated as battery electric version TCO minus the diesel version TCO. For each vehicle type, the figures show the average TCO change across the six states analyzed along results for the states exhibiting the largest and smallest TCO differences.

As with capex, these TCO findings align with BNEF's recent conclusions. For example, BNEF notes: "Zero-emission, long-haul trucks can also become competitive around 2030 by controlling fuel costs."[53]

IMPORTANT FACTORS BEYOND MODELED TCO

The gap between current market prices for battery electric HDVs and our modeled estimates is addressed in the "Purchase Price Dynamics" section. Here, we turn to two additional factors not captured in the core TCO modeling: potential labor cost savings from improved driver experience and the enhanced value proposition of battery electric HDVs when viewed over their full service life.

Easier Driver Recruitment, Better Retention for Battery Electric HDVs

The transition to battery electric HDVs could generate favorable impacts on labor cost for battery electric HDVs. They offer a superior driving experience—quieter, smoother, and less physically demanding—which assists with driver recruitment and retention. A fleet electrification manager at PepsiCo noted that electric trucks have been "well-received by drivers, which can aid retention and help reduce recruiting costs. There has been this excitement and positive reaction."[54]

These benefits are likely to boost job satisfaction and reduce attrition. For an industry facing chronic driver shortages, this represents a meaningful competitive advantage.[55]

These labor-related advantages help offset concerns that battery electric HDVs may increase labor costs due to longer charging times compared to diesel refueling.

Additionally, the length of time needed to charge an HDV is rapidly decreasing. Direct current chargers rated at 750 kW can recharge Tesla's Class 8 tractors in about 45 minutes[56]—adding an estimated 350 miles of range to their 850–900 kWh battery packs.[57]

Lifetime Savings Further Strengthen the Economic Case

TCO analysis typically reflects the perspective of a vehicle's first owner. But that's only part of the picture. Since most trucks remain in service well beyond the initial ownership period, a lifecycle perspective—considering use until a vehicle retires—reveals even greater value from electrification.

BE HDVs generate consistent savings on fuel and maintenance—benefits that accrue over the full lifetime of the vehicle, which often extends well beyond the five-year ownership period analyzed in this study. Accounting for these longer-term savings would significantly increase the economic advantage of battery electric HDVs over diesel models.

Discount rate assumptions also shape the analysis. This study uses a 7 percent rate, aligned with private-sector investment decisions. But for public-sector analysis, where long-term societal and environmental benefits are paramount, a lower rate is more appropriate. Applying that lens makes the lifetime value proposition of battery electric HDVs even more compelling—and reinforces the case for accelerating deployment.

SENSITIVITIES

Impact of Vehicle Purchase Incentives

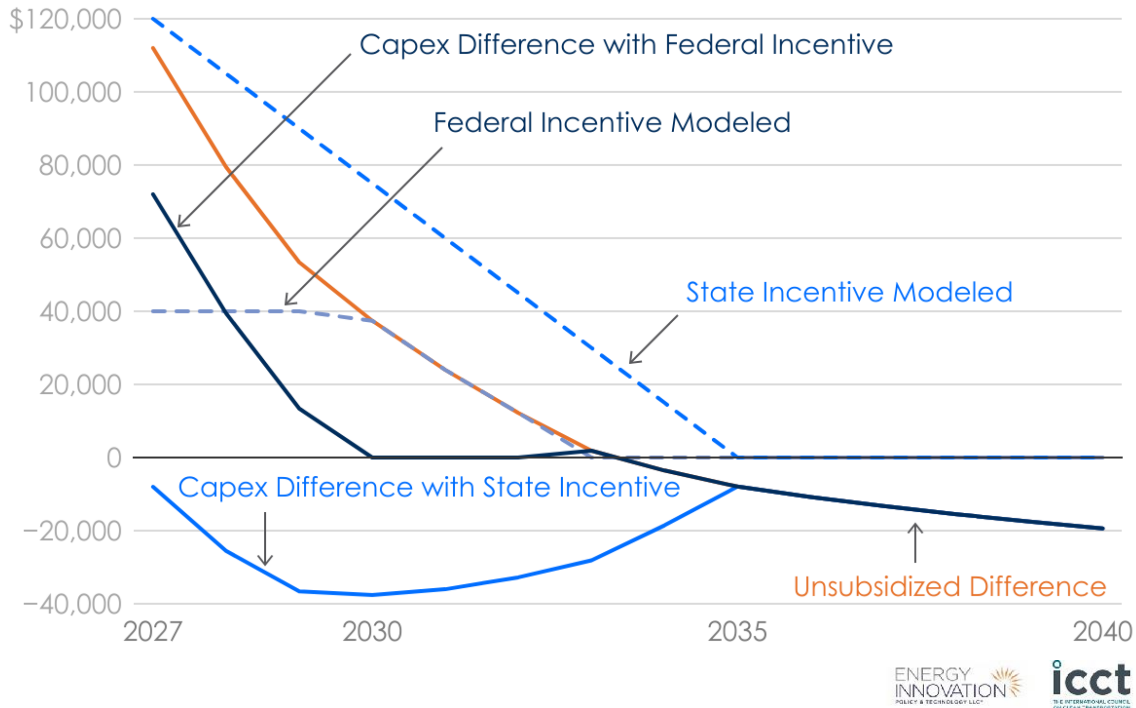
The results presented above do not include available federal or state vehicle incentives, i.e., monetary support for purchases in the form of direct rebates or tax credits. Both federal tax credits and state rebates on battery electric or fuel cell HDV purchases are available at the time of publication.

Under tax code provision 45W of current federal law, new battery electric HDV buyers may qualify for tax credits worth up to $40,000. Actual credit value equals 30 percent of the purchase cost or the incremental cost above a comparable gasoline or diesel vehicle, whichever is lower.[58] Though the federal tax credit is at risk politically, the federal incentive is set by current law through 2032.

States also offer vehicle incentives. For example, California has provided vouchers for Class 8 long-haul tractor purchases worth up to $120,000 for battery electric models and up to $240,000 for hydrogen fuel cell electric models.[59]

Figure 8 analyzes the effect of vehicle purchase incentives on capex in the case of Class 8 battery electric tractors. We model a hypothetical state incentive that starts in 2027 at $120,000, trending linearly to zero in 2035.

Figure 8. Vehicle incentive impacts on capex differential: battery electric vs. diesel Class 8 long-haul tractors



Results in Figure 8 show that including the current federal incentive brings capex for battery electric long-haul tractors to diesel parity in 2029. By design, the federal incentive does not push the capex difference into cost-savings territory. However, the state incentive, as modeled, is large enough to yield an up-front cost advantage for the battery electric version in 2027.

Resale Value: The Hidden Key to Total Cost

Resale value, also known as residual value, represents the amount a vehicle's first owner can expect to recover upon resale. In a TCO analysis, it serves as a negative cost term, offsetting part of the initial capital investment. Furthermore, higher residual value also reduces financing costs for fleets that rely on leasing or financing. Resale value is determined by depreciation and, like all future values, it is incorporated into our analysis in present value terms.

With battery electric HDVs, still in the initial stages of adoption in the U.S., market data on resale value remains limited. A recent CALSTART study helps address this gap by providing insights into secondary-use markets for BE truck components. The research finds that, on average, diesel HDVs retain 30 percent of their original purchase price after five years of usage.[60] In comparison, the typical BE HDV yard tractor's components currently retain between 15 to 25 percent of their original value after year 5, due to demand for secondary applications such as battery pack use for stationary energy storage.[61] This analysis is supported by companies like Zenobe, Connected Energy, and Moment Energy who are demonstrating real-world second-life battery-repurposing projects that purchase used battery electric HDV batteries.

This study's TCO results are based on CALSTART's recent research as follows. Diesel HDV resale values are assumed to remain constant at their current 30 percent level. For BE HDVs, we adopt the midpoint of CALSTART's estimated range—one-fifth of the original value—as the 2024 value, increasing it linearly to equalize with diesel HDVs in 2035.

The approach we use aligns with CALSTART's recent research on how to assess residual value given the current secondary use market. However, this differs from how lenders and fleets typically conceptualize and quantify residual value. CALSTART's findings indicate that the resale value for battery electric HDVs is typically much lower than is justified by the expected value of secondary use.[62]

Risk-averse lenders—unfamiliar with the technology and facing limited resale data—typically assign lower residual values. The result of this market myopia is that fleets purchasing battery electric HDVs must finance a larger portion of the vehicle cost: "The low [residual value] assumption from financing companies means that the full asset value of the vehicle needs to be financed during the lease term, resulting in high monthly lease payments to the fleet."[63]

To explore the financing impact of low residual value assumptions, we quantify the effect of doubling the annual interest rate from 5 to 10 percent over a five-year loan term. The higher interest rate delays the point at which the purchase price of battery electric Class 8 trucks falls below that of diesel trucks to 2040, compared to 2034 if battery electric long-haul trucks receive the same 5 percent interest rate as diesel. This result illustrates the importance of addressing confidence in battery electric HDV resale value.

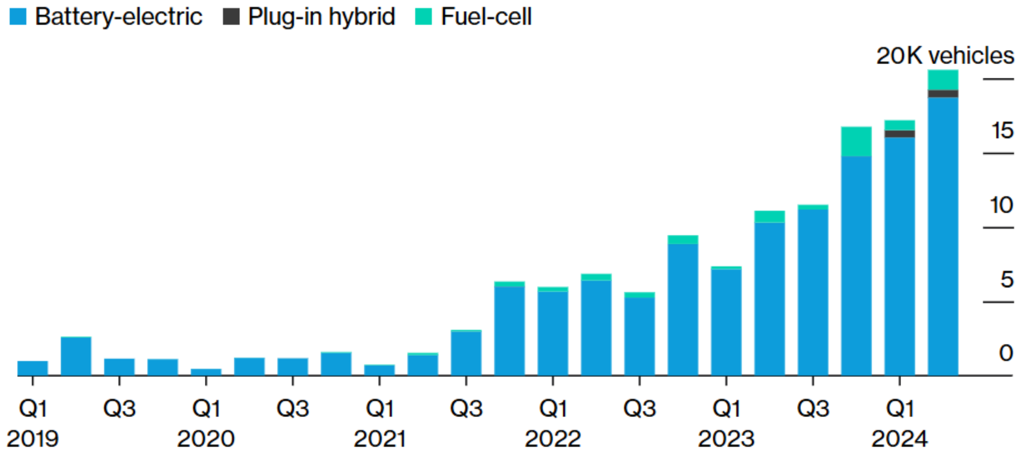
HYDROGEN TRUCKS: COST, VIABILITY CHALLENGES

This section begins with a review of the status of hydrogen fuel cell truck technology. It then outlines the study's methodology, starting with assumptions for future hydrogen fuel prices and followed by estimates for key vehicle component costs. Next, we present results for capex, opex, and TCO, comparing fuel cell trucks with both diesel and battery electric alternatives. The analysis focuses on long-haul and short-haul tractor segments—where fuel cell technology is often viewed as most viable. Even in these cases, however, our results show battery electric trucks offer significantly stronger economic performance. Continued advancements in battery range, charging speed, and energy density are likely to sustain—and further enhance—the competitive edge of battery electric trucks.

Technology Status: Vehicle and Infrastructure Deployment

Hydrogen fuel cell HDVs, which generate electricity onboard from hydrogen, lag far behind battery electric HDVs across key market indicators: vehicle sales, model availability, or fueling infrastructure availability. Globally, battery electric trucks currently outsell fuel cell trucks by approximately 10 to 1, reflecting stronger market momentum toward BE freight solutions.[64]

Figure 9. Global battery electric vs. fuel cell HDV sales (thousands, quarterly)



Source: BNEF[65]

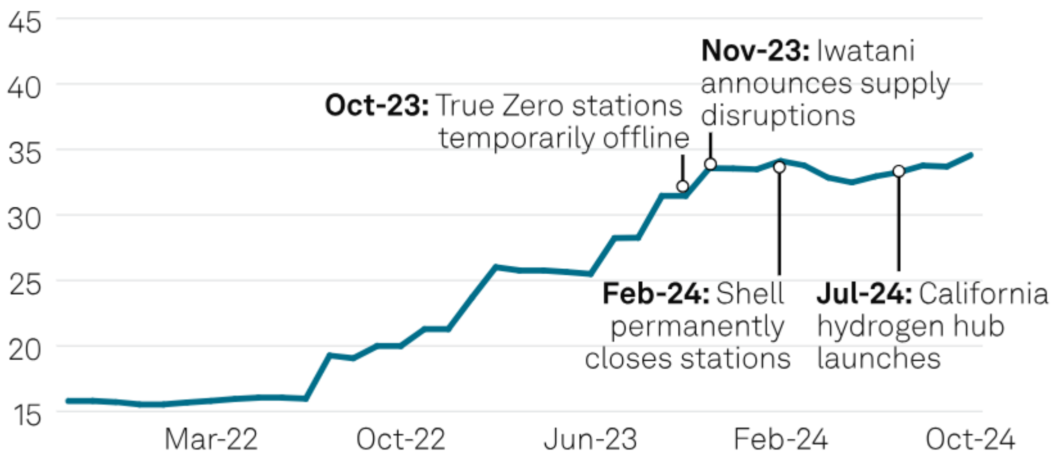
As of March 2025, California remained the only U.S. state with publicly accessible hydrogen refueling infrastructure, positioning it as the primary indicator of domestic trends in fuel cell HDV adoption.[66] As of late 2023—the most recent data available at the time of publication—California had 26 times more BE than fuel cell heavy-duty trucks, with 863 battery electric trucks compared to just 30 fuel cell trucks. [67] These figures exclude buses and vans. Nikola, once the leading U.S. supplier of fuel cell HDVs, reportedly delivered 235 fuel cell HDVs to customers by the end of 2023 before filing for Chapter 11 bankruptcy in 2025.[68]

The wide gap in deployment between battery electric and fuel cell HDVs is further illustrated by data on vehicle availability. In 2024, the U.S. market offered 187 battery electric truck models compared to just 20 fuel cell models.

Finally, there is an infrastructure deployment gap.[69] There were more than 16,250 charging ports installed in California as of March 2025, compared to fewer than 70 hydrogen refueling nozzles. [70]

Information on hydrogen refueling costs for medium- and heavy-duty vehicles is sparse. One reference point is California's average retail hydrogen price for light-duty vehicles, which was $16.51 per kilogram in 2019.[71] Since then, hydrogen prices have increased significantly, driven by supply disruptions, higher production costs, and volatility in Low Carbon Fuel Standard credits values.[72]

Figure 10. Light-duty vehicle hydrogen prices in California ($ per kg, monthly)



Source: S&P Global[73]

Hydrogen Fuel Price Scenarios

The relatively immature state of the hydrogen fuel cell HDV market contributes to greater uncertainty regarding future fuel price trends. To capture this uncertainty, this analysis employs two distinct scenarios: a Low-Price scenario and a High-Price scenario. Given the wide variation in prices, our study does not introduce additional state-level differences.

The Low-Price scenario is based on hydrogen cost projections from the 2024 ATB.[74] This scenario reflects an optimistic outlook, assuming rapid scale-up in hydrogen fuel production and widespread adoption of fuel cell HDVs, supporting high utilization rates at refueling stations. Utilization rates for fuel cell HDV fueling stations reach at least 70 percent in the Low-Price scenario. Achieving such high utilization rates depends on several factors, including:

- Vehicle adoption rates: The number of hydrogen-powered medium- and heavy-duty trucks in operation directly influences station usage.
- Station reliability: Consistent operational performance ensures that stations can meet demand without significant downtime.
- Fuel availability and cost: Competitive pricing and reliable hydrogen supply are essential to attract fleet operators.

In terms of insights from existing empirical data, research on the operation of California's hydrogen fueling stations found that in 2021 these stations were spending more time down for maintenance than refueling vehicles.[75]

In the High-Price scenario, utilization rates are projected to be lower, starting at 30 percent in 2030 and rising to 50 percent by 2050—levels evaluated in a 2024 national laboratory report that serves as the foundation for delivery and dispensing cost estimates.[76] In the High-Price scenario, hydrogen production costs are based on the highest of three regional estimates from BloombergNEF's January 2025 report on the levelized cost of hydrogen, subtitled, "Forget $1 Per Kg."

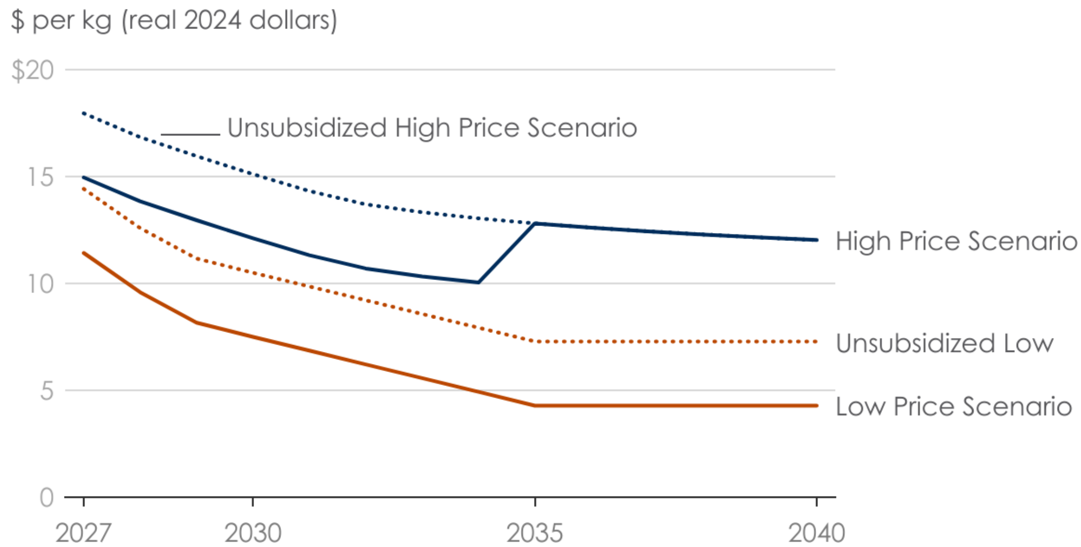
The Low-Price scenario is based on the 2024 ATB hydrogen fuel price projections for FC trucks, which offer two future cost forecasts: one assuming low innovation (higher costs) and another assuming high innovation (lower costs). To generate an annual time series for TCO analysis, we follow the method used in a recent U.S. Environmental Protection Agency (EPA) regulatory impact assessment, assigning the higher-cost projection to 2030 and the lower-cost projection to 2035. Beyond 2035, the price remains constant in real terms, resulting in the plateau seen in the graph.

Both scenarios incorporate the federal 45V tax credit, valued at up to $3 per kilogram for hydrogen produced with clean electricity. To qualify, projects must begin construction by December 31, 2032, but a "safe harbor" provision allows facilities completed and entering service as late as December 31, 2036, to remain eligible. Once operational, projects can claim the credit for up to 10 years. For example, a facility that starts production in 2034 could receive credits through 2044.

Figure 11 presents hydrogen fuel price projections with and without the 45V credit. In the Low-Price scenario, the credit persists through the full 10-year window, holding prices steady after 2035 (in constant 2024 dollars). In the High-Price scenario, the credit's influence ends in 2035, modeled as a single-year price jump to reflect the expiration of new project eligibility—a simplification based on the midpoint of the safe harbor period. This approach aligns with assumptions used in the DOE's *Pathways to Commercial Liftoff: Clean Hydrogen*.[vi] [77]

[vi] This approach is observable in Figure 12 of DOE's report, which includes an uncertainty bar with a shaded transition period from 2033 to 2035. We use a simplified representation, treating 2034 as the final year of federal credit impact.

Figure 11. Hydrogen fuel price scenarios with and without federal 45V tax credit



Notes: Both scenarios incorporate the maximum 45V tax credit. In the High-Price scenario, its retail price impact ends in 2035—a simplification representing the midpoint of the "safe harbor" window for projects starting construction by the end of 2032. In the Low-Price scenario, the effect of credits on retail price is modeled as continuing through the full 10-year payment term. Sources: ATB,[78] BNEF,[79] and EI-ICCT calculations.

Even after new facilities are no longer eligible, 45V tax credits could continue to influence retail prices if those prices are set by the lowest-cost marginal producer. This dynamic is reflected in the Low-Price scenario, which models tax credit impacts extending through the full time series (i.e., through 2044, given the five-year ownership period assumed).

Hydrogen Fuel Cell Vehicle Manufacturing Costs

Empirical data on fuel cell vehicle production costs and sales prices is even more limited than for battery electric HDVs. However, the available evidence suggests that fuel cell HDVs currently have significantly higher production costs. In late 2023, Nikola's manufacturing cost for its fuel cell Class 8 tractor was reported to be $679,000 per unit.[80] Earlier media reports estimated Nikola's direct manufacturing cost per fuel cell vehicles at $750,000 each.[81]

This study bases fuel cell stack and hydrogen tank specifications on the 2024 ATB. Retail prices for fuel cell stacks and hydrogen fuel tanks are based on 2024 research from the

EPA, which accounts for learning curve effects for both components.[vii][82] Future cost projections used in this analysis are shown in Table 2.

Table 2. Key component specifications and costs for fuell cell HDVs[viii]

Fuel Cell Stack	**2030**	**2035**	**2040**
Peak Power: Long-Haul Tractor	373 kW	371 kW	368 kW
Peak Power: Short-Haul Tractor	374 kW	371 kW	369 kW
Direct Manufacturing Cost	$170 per kW	$150 per kW	$136 per kW
Retail Price Estimate	$241 per kW	$213 per kW	$193 per kW
Hydrogen Fuel Tank	**2030**	**2035**	**2040**
Tank Size: Long-Haul Tractor	60 kg	54 kg	51 kg
Tank Size: Short-Haul Tractor	31 kg	28 kg	27 kg
Direct Manufacturing Cost	$659 per kg	$578 per kg	$524 per kg
Retail Price Estimate	$936 per kg	$821 per kg	$745 per kg

Sources: ATB[83] and EI-ICCT calculations.

We opt against using the ATB's manufacturing cost estimates for fuel cell HDV components, as we consider them overly optimistic.[84] The 2024 ATB's Mid scenario hinges on a rapid scale-up in fuel cell vehicle production, projecting 27,000 fuel cell HDVs in 2030 and 50,000 in 2035.[85] Such an assumption seems improbable for a central case. The 2024 ATB's low innovation – High-Price scenario for fuel cell stack and tank costs is based on fuel cell HDV sales levels under the Annual Energy Outlook's "reference case"—a baseline projection under current laws and policies, which seems better aligned conceptually with the Mid scenario.

To gauge the optimism of the ATB's Mid scenario, note that its direct manufacturing cost for hydrogen fuel tanks in 2030 is 4.5 times closer to the Advanced scenario than to the Conservative one. For the FC stack, the Mid scenario estimate is 1.7 times closer to the Advanced than to the Conservative scenario.[86]

[vii] Learning curve effects for hydrogen FC vehicle components are detailed in Table 3-2 of the EPA's Regulatory Impact Analysis for the Phase 3 HDV emissions standards.

[viii] For more about the source of these costs, see the EPA's final Regulatory Impact Assessment for its Phase 3 HDV pollution standards. Costs for 2027–2032 are given in Tables 2-70 and 2-71. This study's cost estimates for years 2033 and later are based on the learning curve for hydrogen fuel cell vehicles in Table 3-2.

A Clear TCO Advantage for Battery Electric vs. Fuel Cell HDVs

Findings indicate that battery electric versions hold a clear cost advantage over comparable fuel cell versions for both long-haul and short-haul tractors. Figure 12 displays the purchase cost for Class 8 tractors, equivalent to capex since we account for infrastructure in the levelized charging cost. Our estimates indicate that fuel cell HDV retail prices will remain significantly higher than both battery electric and diesel trucks through 2040, the latest year analyzed.

Figure 12. Capex comparison: diesel, battery electric, and fuel cell

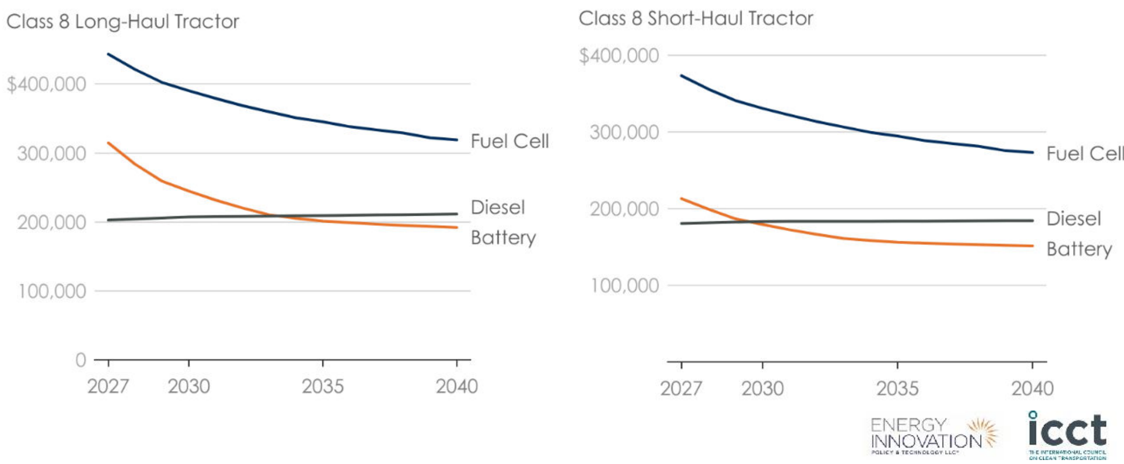


Figure 13, which presents opex results, shows an advantage for battery electric over fuel cell trucks across the full range in Texas and nearly the entire range in California—excluding only a narrow margin.

Figure 13.a. California opex for diesel, battery electric, and fuel cell HDVs

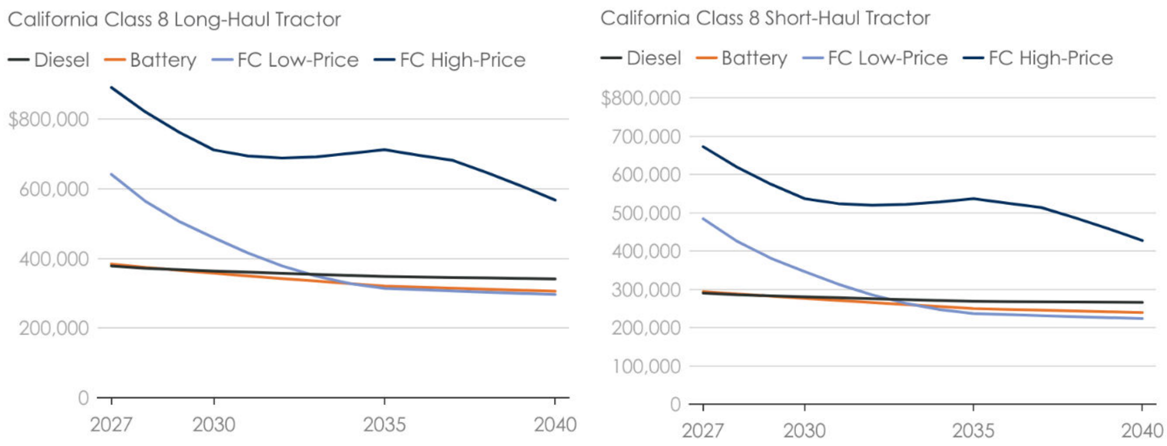
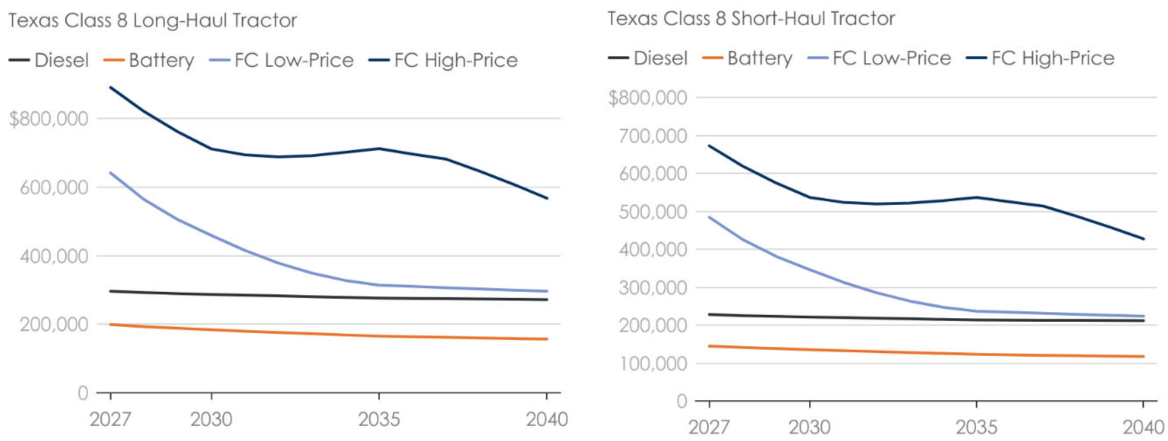


Figure 13.b. Texas opex for diesel, battery electric, and fuel cell HDVs



Notes: "FC Low-Price" and "FC High-Price" refer to fuel cell vehicle results under the low and high price scenarios, respectively.

The TCO comparison reveals an even clearer picture: due to the capex premium for FC trucks, BEVs have a lower TCO across the board—decisively so in Texas, and clearly in California, as shown in Figure 14.

While clean hydrogen is expected to play a key role in select industries, our TCO results and other evidence—such as deployment and sales levels—indicate that BE powertrains are set to become the preferred next-generation HDV technology, outperforming hydrogen FC HDVs.

Figure 14.a. California TCO for diesel, battery electric, and fuel cell HDVs

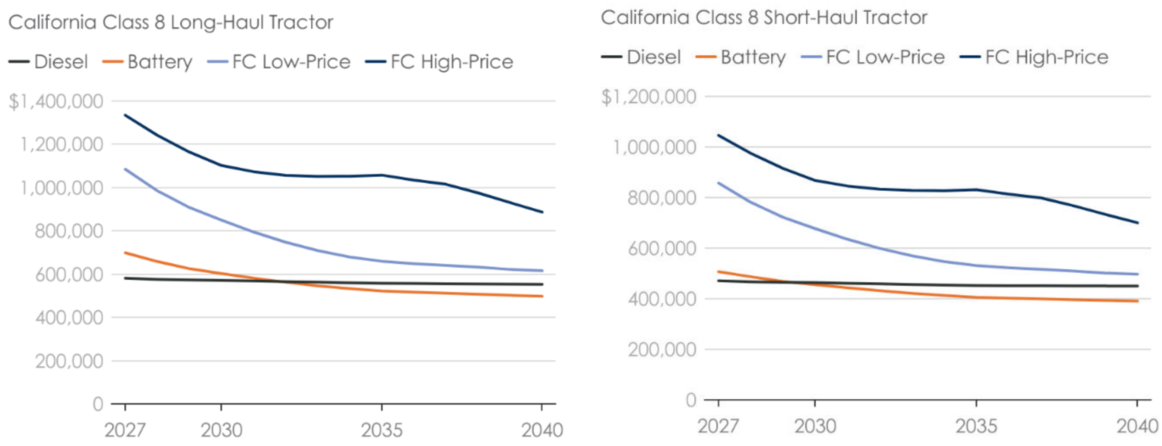
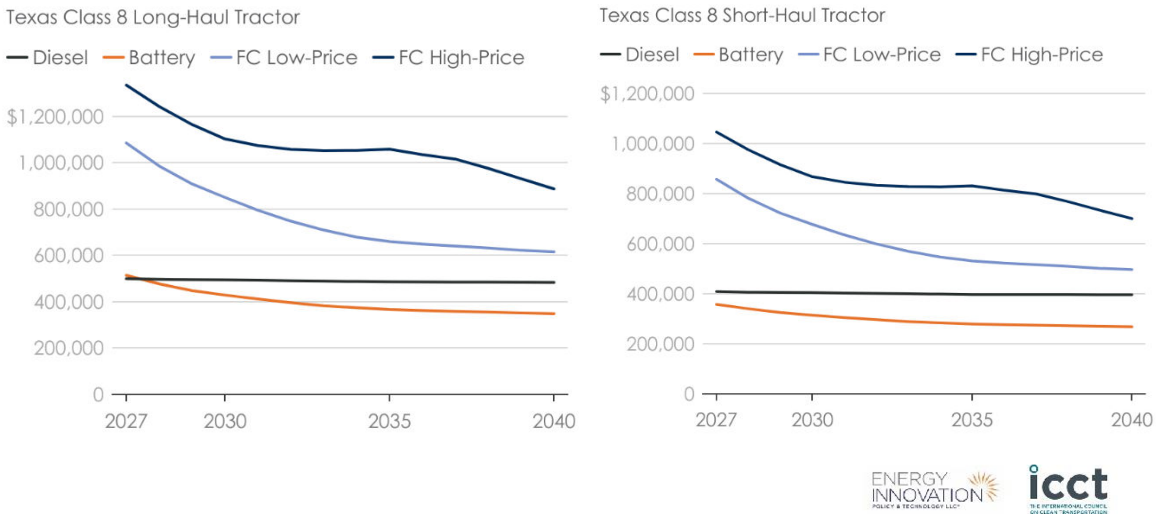


Figure 14.b. Texas TCO for diesel, battery electric, and fuel cell HDVs



Notes: "FC Low-Price" and "FC High-Price" refer to fuel cell vehicle results under the low and high price scenarios, respectively.

A similar conclusion was recently reached in a joint report by the Conseil d'Analyse Économique and the German Council of Economic Experts, official economic advisory bodies to the French and German governments.[87] They found that BE HDVs are already achieving TCO parity with diesel in both countries and represent the most viable path forward, while hydrogen fuel cell HDVs remain too expensive, too inefficient, and too far from market readiness.[88]

LEVELIZED COSTS OF CHARGING

Charging Cost by Station Type and State

This report models the levelized cost of charging (LCOC) using real-world utility rate data across six states. LCOC reflects the average cost per kilowatt-hour of delivered electricity over a station's lifetime, incorporating capital, energy, maintenance, and financing costs. As such, it is a critical aspect of battery electric HDV economics.

Charging economics vary significantly by place and infrastructure type—whether public stations, large depots, or small depots—making charger configuration and location central to TCO for battery electric HDVs.

We account for differences in infrastructure by modeling different charging station types. Charging assignments in our modeling are based on typical truck operations:

- Class 8 long-haul tractors rely exclusively on public stations.
- Class 8 short-haul tractors split charging between public and depot use.

- Class 4–7 trucks charge entirely at depots.

Public station design follows national laboratory research by Bennett et al.[89] Depot stations are modeled to serve five vehicles with dedicated chargers in line with data showing that 95 percent of depots host five or fewer trucks.[90] Charging capacity is sized to ensure full overnight recharging during typical “dwell times”—periods when trucks are parked and available for charging.

Our one-to-one vehicle-to-charger ratio at depots is intentionally conservative. In practice, shared infrastructure and smarter scheduling can reduce costs—suggesting our estimates may understate future TCO savings potential.

LCOC is calculated by summing all relevant costs over the station’s lifespan, then dividing by total kilowatt-hours delivered. Costs include capital (e.g., equipment and installation), operational expenses (e.g., electricity rates, maintenance, and demand charges), and financing. We also account for land rent, transaction fees, taxes, and utilization rates, which significantly affect cost per kilowatt-hour—especially for public stations with high peak demand.

Grid electricity prices are the dominant factor in LCOC outcomes. To estimate these, we reviewed current rate sheets from major utilities in each state, focusing on tariffs most relevant to freight corridor locations and station power profiles. Rates were selected based on determinants such as peak power demand, following the ICCT’s methodology.[91]

Although most results are presented without subsidies, two federal incentives are reflected in the analysis: the 45V hydrogen production tax credit, discussed in the Hydrogen Fuel Price Scenario subsection, and the 30C tax credit for EV charging infrastructure, which reduces up-front capital costs by 17–29 percent.

The 30C credit’s impact on LCOC is modest, reducing costs by less than one cent per kilowatt-hour—ranging from $0.0035 to $0.0067 per kWh, depending on configuration. Though the modeled hydrogen tax credit is significant, incorporating the federal 30 C tax credit does not significantly change the relative economics across states or vehicle types.

LCOC Results: Power Prices Matter Most

A key policy implication of these results—explored further in the “Policy Strategies” section—is the critical role that electricity pricing and rate design play in battery electric HDV affordability. In Texas, low electricity rates drive battery electric TCO savings years earlier than in higher-cost states.

Figure 15 breaks down the components of LCOC, highlighting the outsized impact of electricity costs. Energy and demand charges for grid electricity account for 44 to 80 percent of state-level LCOC. Additional modeling details, including state-specific electricity rates, are provided in the appendix.

Figure 15.a. Public station levelized cost of charging by state

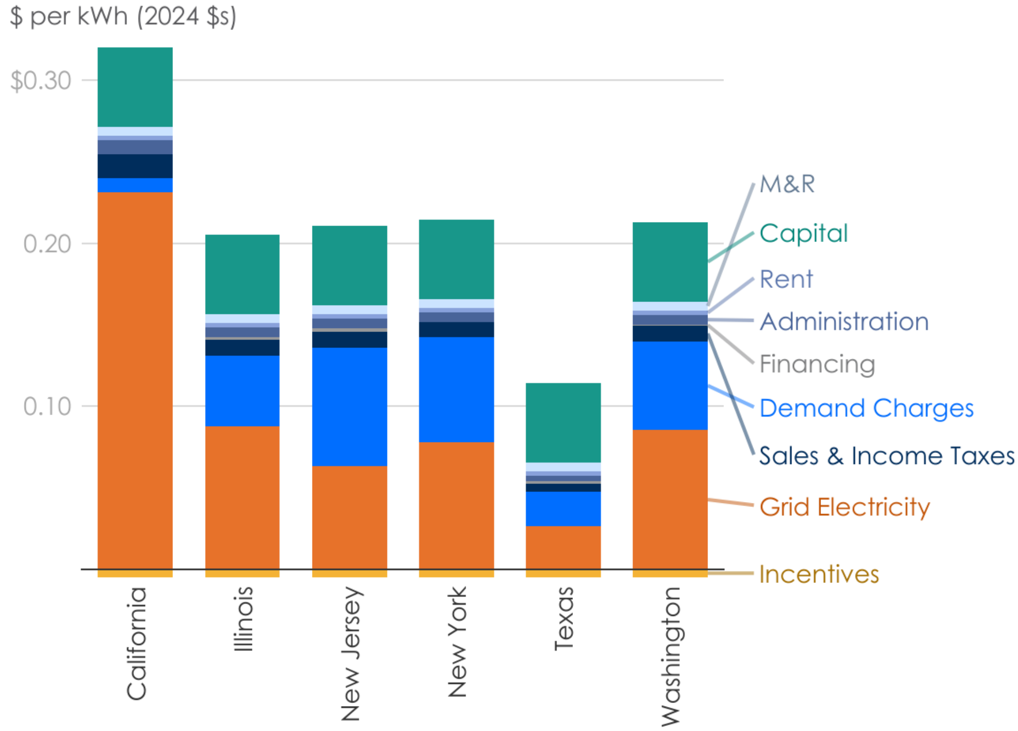


Figure 15.b. Large depot station levelized cost of charging by state

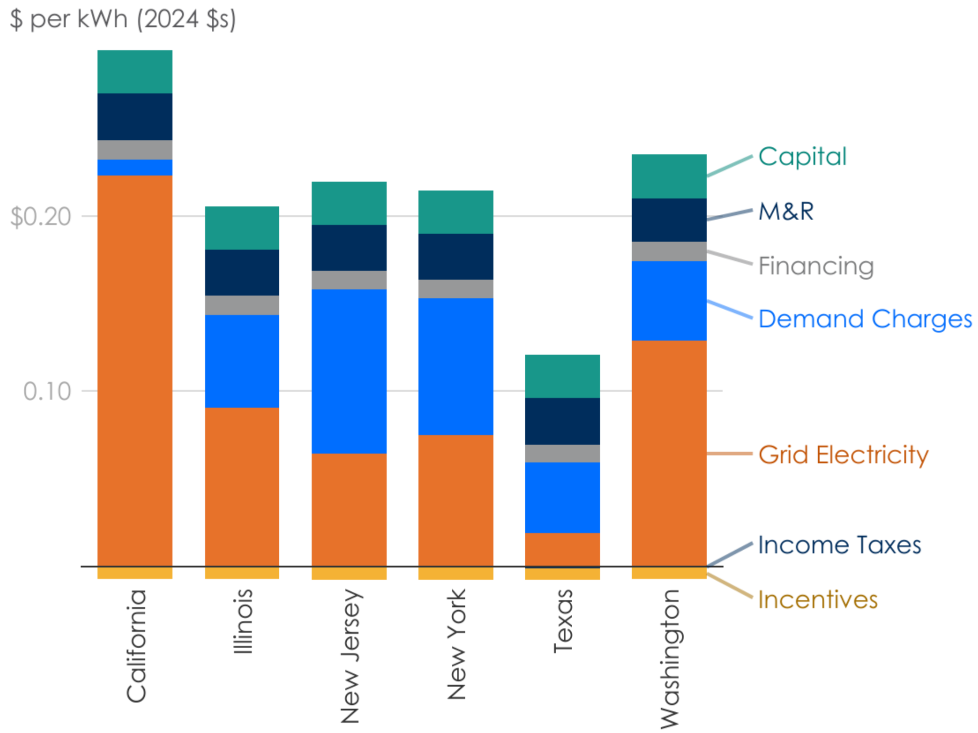
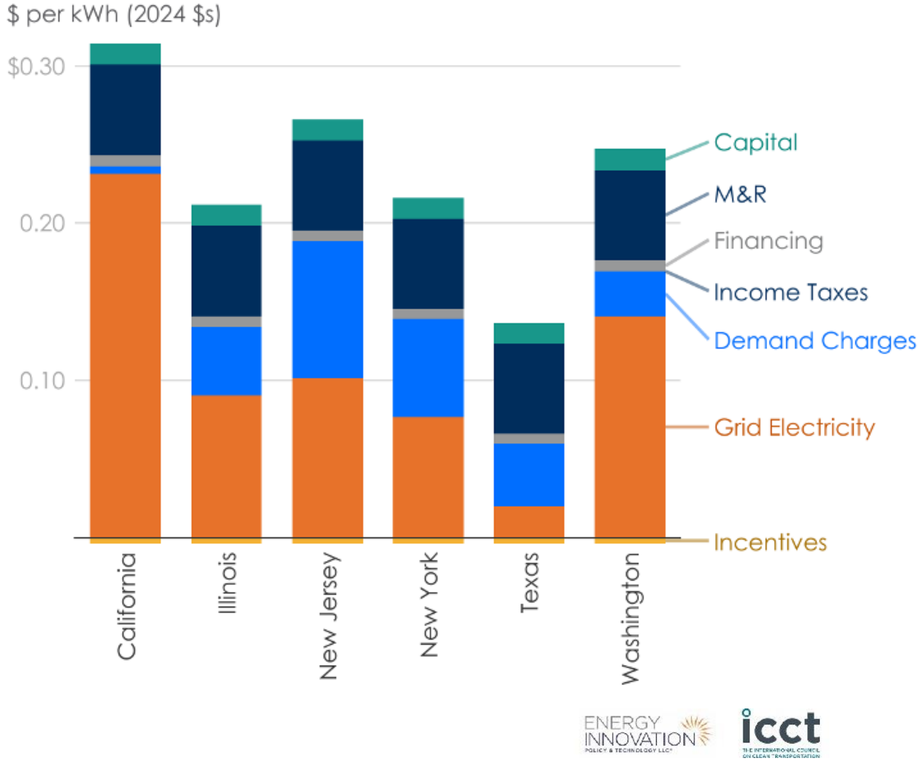


Figure 15.c. Small depot station levelized cost of charging by state



California LCFS: Charging Cost Impacts

Four U.S. states have implemented a low-carbon fuel standard (LCFS): California, Oregon, Washington, and New Mexico. This case study evaluates the impact of California's updated LCFS on LCOC. In 2024, the program was reformed to provide stronger incentives for vehicle charging infrastructure and now includes heavy-duty-specific provisions designed to create a valuable revenue stream through a "capacity" credit mechanism for both charging and hydrogen infrastructure.[92] This analysis examines its potential effects.

To conduct this assessment, we collaborated with O'Malley and Pavlenko of the ICCT, who have developed a new model to evaluate the LCFS's impact on HDV charging infrastructure.[93] Their model accounts for energy and capacity credit formulas. We applied the model using a future LCFS compliance credit price of $100 per credit in constant 2024 dollars, a level within its historical range, along with the engineering and operational specifications for the three charging station types analyzed in this study.[94] The estimated monetary value of LCFS credits for each charging station was incorporated as an ancillary revenue stream in our LCOC modeling.

The results indicate a substantial impact on charging costs. We estimate that the combined value of capacity and energy credits lowers the LCOC for public stations by approximately 6 cents per kWh—a reduction of about 18 percent—when averaged over the station's 40-year lifetime. Because the LCFS policy limits capacity crediting to a maximum of 10 years per station, credit values are front-loaded. When averaged over the first 10 years of public station charger sales, the estimated LCFS credit value rises to nearly 14 cents per kWh.

Table 3. LCFS effects on public charging station finances in California

Variable	Estimate (real 2024 $s)
LCSF credit value (total over 10 years)	$21,445,069
Levelized LCFS credit value over project lifetime (40 years)	$0.023 per kWh
LCFS credit value per kWh considering sales in first 10 years	$0.136 per kWh
Levelized price without LCFS credit value	$0.315 per kWh
Levelized price with LCFS credit value	$0.258 per kWh

INDUSTRY PERSPECTIVES

Industry statements reinforce our findings: electric trucks are becoming more affordable and, in some cases, already offer a compelling financial case.

Adam Buttgenbach, Director of Fleet Engineering at PepsiCo, underscores this shift with operational insights: "We've seen in certain duty cycles and in certain asset classes that the economics already make sense—from fuel savings, from maintenance savings, from driver turnover, and the positive impact on our employees operating the vehicles. We see electric vehicles in certain asset classes making fiscal sense today without grants and initiatives."[95]

PepsiCo's Dejan Antunovic, Electrification Program Manager, adds: "What's very important for us is to have demonstrated that heavy-duty EVs should and can mirror and replicate diesel operations [for regional and long-haul applications]. And, for us, cost is a big factor. We have seen and are seeing electrification and electricity provide a lower-cost solution over time."[96]

Titan Freight System's Keith Wilson reports that his company's BE Class 8 truck fuel costs per mile are about 63 percent lower than for comparable diesel models, with maintenance costs down by 25 percent.[97] Factoring in available grants and incentives, the company has found that operating an electric Class 8 truck costs 7 percent less than a diesel equivalent. Wilson notes: "And that's just for the first truck. Once we've made the up-front investment in the infrastructure, we're saving 30 percent per EV." [98]

Jonathan Colbert of the fleet charging company Voltera highlights both economic and strategic drivers of battery electric HDV adoption: "The economics already make sense for many use cases, and many forward-thinking companies with ambitious sustainability goals are investing in electrification even for use cases where the economic case for battery electric vehicles is still not on par with [internal combustion engine] vehicles. Even among those fleets who take a slower approach to electrification, there is consensus that transportation will be decarbonized, and it will be beneficial—economically and environmentally."[99]

These examples offer evidence that BE HDVs are already outperforming diesel trucks on a TCO basis in some duty cycles and asset classes. As battery prices fall and charging infrastructure grows, an expanding range of BE HDV applications is expected to offer TCO savings compared to diesel counterparts.

POLICY STRATEGIES TO BOOST AFFORDABILITY

Battery electric trucks are on track to become the most cost-effective powertrain for heavy-duty freight. But realizing that potential and ensuring that modeled savings translate to real-world outcomes will require smart policy support. Despite favorable TCO projections, challenges remain, including up-front price differences, weak resale markets, and the need for more widespread charging infrastructure. The challenges posed by the federal policymaking landscape merit mention. With Washington moving to undo recent progress, sustained state leadership remains critical.

This section outlines five priority strategies to close these gaps and improve market functioning—followed by a menu of complementary tools.

1. Target purchase incentives to drive affordability

Purchase incentives remain essential to accelerating early adoption by narrowing the up-front cost gap with diesel trucks. Smaller fleets in particular face higher financing barriers and lack leverage in pricing negotiations.

However, incentives can also inadvertently increase buyers' willingness to pay, potentially reducing pricing pressure on manufacturers. Intelligent incentive policy design can mitigate this risk and strengthen cost discipline. Well-structured incentives help ensure that public spending supports both widespread deployment and downward pressure on new vehicle prices.

Key approaches include:

- **Capping vehicle price for incentive eligibility** to encourage manufacturers to lower or keep MSRP below defined thresholds.
- **Requiring public MSRP disclosure by manufacturers as a condition of eligibility,** enhancing price transparency.
- **Creating self-funding mechanisms** to minimize reliance on public funding, pairing fees on higher-emission vehicles with rebates for cleaner ones.

- **Using a reverse auction approach** to direct incentives to the lowest-cost trucks.

How would a reverse auction for incentives work? Assuming battery electric HDV buyers are required to disclose MSRPs, prospective purchasers would bid for the smallest rebate they would need to complete a purchase. Incentives would then be awarded to those requiring the least public support—reducing program costs and limiting upward pressure on vehicle prices. Reverse auctions have been found to lower costs when used to award guaranteed revenue contracts to new solar and wind projects.[100]

2. Strengthen supply-side policies, such as vehicle standards

Vehicle performance standards are among the most powerful tools for transforming transportation markets. They accelerate clean technology deployment, encourage innovation, and enhance competitiveness in emerging technology. By gradually ramping up requirements over time, standards encourage manufacturers to scale production, diversify model offerings, and bring down prices through volume and innovation.

California's **Advanced Clean Trucks (ACT)** policy is an example of a vehicle standard. The ACT sets gradually rising zero emission sales targets for truck manufacturers, measured as a percentage of total sales.[101] It includes credit trading and banking, allowing manufacturers flexibility in how they meet their targets. Rather than mandating specific technologies, the policy uses performance-based, technology-neutral criteria to shift the overall sales mix.[102]

Vehicle standards are a target in federal repeal efforts—both in proposals to weaken national tailpipe rules and in challenges to state authority. Under the Clean Air Act, California retains the right to go beyond federal policy, and other states may follow its lead.[103] That legal authority underpins ACT—and it is now under threat, with legislative efforts to revoke it still unfolding as of this writing.[104]

A successful legislative rollback would be unprecedented and almost certainly face legal challenge—meaning uncertainty around the ACT is likely to linger. Even so, the strength of vehicle standards as a policy tool makes ACT adoption a path still well worth pursuing for states not already doing so.

3. Build confidence in resale value

Resale value is a hidden but pivotal factor in TCO. Fleets and lenders often apply conservative assumptions, especially for technologies lacking a long track record. For battery electric HDVs, this translates into higher financing costs and fewer lease options—barriers that slow adoption, particularly among small fleets. Yet second-life uses for electric truck components, especially batteries, are growing. Companies like

Zenobe and Connected Energy are already buying used batteries for stationary storage.[105] Policy can accelerate this trend and stabilize resale values.

Tools include:

- **Residual value guarantees** with public backing and manufacturer risk-sharing.
- **Battery repurposing incentives** to strengthen secondary markets.
- **A price clearinghouse** to publish anonymized resale price data.

Stronger resale confidence lowers risk for lenders, reduces lease payments, and expands access to capital—especially vital for operators who can't self-finance.

4. Improve price transparency and market discipline

In the U.S., battery electric HDV prices remain unusually high and opaque. Class 8 tractor prices, in particular, show sharp divergence from global trends. In this seller-dominated market, a lack of pricing transparency limits competition and opens the door to inflated margins.

Policy tools to generate additional downward price pressure include:

- **Mandatory MSRP disclosure** for incentive-eligible vehicles.
- **Aggregated reporting** of transaction prices from fleets receiving incentives.
- **Providing reference price data**—which could be aggregated and offered as ranges to protect proprietary information—to help purchasers assess whether vehicles are competitively priced.

These steps would support more rational pricing, help fleet owners make informed decisions, and protect public investments. Over time, greater transparency could align U.S. battery electric HDV prices with global cost trends and accelerate broader adoption.

5. Support cost-effective charging infrastructure deployment

Early-stage public charging infrastructure faces a "utilization trap." Low initial demand makes stations expensive on a per-kilowatt-hour basis—undermining the operating cost advantage of battery electric trucks. Our modeling finds that California's updated LCFS provides an effective solution, lowering the levelized cost of public megawatt-scale charging from $0.315 to $0.258 per kWh over a projected 40 year lifetime. LCFS credits are paid out over the first 10 years of operation. When levelized across charging sales at a megawatt-scale public charging station during that period, LCFS credits are worth $0.136 per kWh.

Key policies include:

- **Revenue enhancement and stabilization mechanisms** like LCFS-style credits.
- **Time-of-use electricity tariffs** that reward off-peak charging.
- **Targeted corridor investments** that prioritize high-traffic freight routes.

Another promising revenue stabilization approach is being pioneered by Canada's Charging and Hydrogen Refueling Infrastructure Initiative, which de-risks early investment by offering flexible repayment terms.[106] Borrowers can delay repayments until revenue begins, with payments scaled to actual income.

These measures reduce per-mile fueling costs, accelerate station viability, and de-risk investment. A strong infrastructure foundation not only supports deployment but reinforces the TCO advantage of battery electric trucks—turning modeled savings into real-world margins.

6. Consider additional policy tools

A comprehensive, detailed overview of policies is beyond the scope of this report, but before moving on, we survey a broader menu of complementary actions helpful for achieving affordability and accelerating adoption:

- **Pay close attention to electricity rate affordability**, especially in regions like California facing wildfire-driven cost increases. Consider using non-ratepayer funding to reduce grid infrastructure costs, helping to lower electricity rates and, in turn, the cost of charging.
- **Improve grid readiness** by streamlining interconnection processes, aligning planning with key freight corridors.
- **Expand access to affordable financing** through tools such as green bank lending, loan guarantees, and interest rate buy-downs that reduce the cost of capital for fleets.
- **Adopt indirect source rules** for large logistics hubs to accelerate fleet turnover and create demand for lower-cost clean vehicle options.
- **Invest in workforce development** to address labor shortages, from vehicle maintenance to charging infrastructure construction and maintenance, particularly for high-capacity freight applications.
- **Support fleet aggregation models** that enable smaller operators to pool purchasing power and access lower-cost vehicles and infrastructure.

Together, these policy approaches can help transform the current market—improving transparency, aligning U.S. prices with global trends, and delivering the full economic benefit of battery electric HDVs.

CONCLUSION

Battery electric HDVs are approaching broad cost superiority, with modeled results showing net TCO savings over diesel by 2030 and thousands to tens of thousands of dollars in five-year TCO savings compared to diesel by 2035. While hydrogen fuel cell trucks may serve niche roles, battery electric HDVs are expected to be the preferred choice for most applications due to their lower capital, fuel, and maintenance costs. Ongoing advancements in battery range, charging speed, and energy density are poised to sustain—and even enhance—battery electric vehicles' competitive advantage over hydrogen FC trucks.

With rising manufacturing investment and proven technology leadership, the U.S. is well positioned to compete globally in battery electric vehicle markets and capitalize on affordability gains at home. But U.S. deployment still lags. Without a robust domestic market, the U.S. risks losing ground—even as battery factories open at record pace. Strategic, coordinated policy is the missing piece.

Well-designed incentives, smart regulatory frameworks, and targeted infrastructure support can accelerate cost reductions and ensure modeled savings become real-world outcomes. If implemented effectively, these actions can reduce freight costs, improve fleet economics, ease cost pressures for American households, and strengthen the nation's competitive position in global transportation markets.

APPENDIX: CHARGING COST METHODOLOGY

The appendix begins with rate structure details for each charging station type. These are important inputs because energy costs are the main determinant of charging costs.

Table A1. Service plans by state and charging station types

	Small Depot	Large Depot	Public Station
California (Pacific Gas & Electric)			
Service plan	BEV-1	BEV-2, Secondary	BEV-2, Primary-Transmission
Energy ($/kWh)	$0.186	$0.179	$0.188
Demand ($/kW per month)	$119	$478	$17,196
Fixed ($/month)	0	0	0
Illinois (Commonwealth Edison)			
Service plan	Small Load, Secondary	Medium Load, Secondary	Extra Large Load, Primary
Energy ($/kWh)	$0.081	$0.081	$0.081
Demand ($/kW per month)	$11.53	$11.81	$10.06
Fixed ($/month)	$25	$39	$1,906
New Jersey (Public Service Gas & Electric)			
Service plan	General Light & Power, Secondary	Large Light & Power, Secondary	High Tension Service
Energy ($/kWh)	$0.085	$0.054	$0.053
Demand ($/kW per month)	$22.01	$18.44	$15.30
Fixed ($/month)	$8	$371	$1,843
New York (National Grid)			
Service plan	SC-2, Secondary	SC-3, Secondary	SC-3, Primary
Energy ($/kWh)	$0.063	$0.061	$0.058
Demand ($/kW per month)	$15.00	$13.49	$12.29
Fixed ($/month)	$54	$675	$700
Texas (Oncor Electric)			
Service plan	Secondary > 10 kW	Primary > 10 kW, Distribution Line	Primary > 10 kW, Substation
Energy ($/kWh)	$0.018	$0.018	$0.025
Demand ($/kW per month)	$10.66	$8.90	$5.02
Fixed ($/month)	$32	$62	$525
Washington (Puget Sound Energy)			
Service plan	Schedule 26	Schedule 26	Schedule 31
Energy ($/kWh)	$0.117	$0.107	$0.070
Demand ($/kW per month)	$6.66	$9.37	$11.37
Fixed ($/month)	$54	$54	$358

HDVs charging at depots are assumed to accomplish their charging overnight. In states where energy rate plans modeled are time dependent, like California and Texas, this allows depots to avoid the highest-priced time for consumption of grid electricity—the peak period from 4pm to 9pm. In these states, the public station electricity rate is calculated as a weighted average of 10 percent peak, 30 percent daytime (9am – 4pm), and 60 percent nighttime (9pm – 9am).

Having estimated grid electricity costs by state, we employ the H2FAST modeling framework, an open-source tool for fiscal analysis of infrastructure investments, to estimate the LCOC for each station.[107] Investments with differing lifespans—essential for capturing the replacement cycles of EV supply equipment versus grid infrastructure—prompted a switch to the more flexible H2FAST model. H2FAST's capital refurbishment feature models a 10-year lifespan for charging equipment alongside a 40-year lifespan for distribution upgrades.

Charger equipment purchase price, installation cost, and most variables reference national laboratory research.[108] Energy efficiency from the charging unit to vehicle battery is 85 percent for all charger types modeled.[109] Future inflation is forecast to be 2.51 percent annually based on a recent Federal Reserve 30-year forecast.[110]

Table A2. Charging station specification for LCOC modeling

Input	Public Megawatt Charging Station	Large Truck Depot	Small Truck Depot
Project Duration	40 years	10 years	10 years
Equipment Lifetime	40 years (grid) 10 years (chargers)	10 years (chargers)	10 years (chargers)
Construction Time	2 years	1 year	1 year
Operations Begin	2027	2026	2026
Utilization Rate	15%	30%	35%
Ramp Rate	9 years	Year 1 of operation	Year 1 of operation
Peak Demand	10,000 kW	250 kW	96 kW
Grid Upgrade Cost	$5.1 million	None	None
Capital Depreciation Method	MACRS (5-year accelerated depreciation)	Standard straight-line (10-year)	Standard straight-line (10-year)
Land Rent	$67,300 per year (2.5 acres)	None (existing site)	None (existing site)
Loan Term	15 years	10 years	10 years
Loan Rate	6% annual	12% annual	12% annual
Credit Card Fees	2.5% of sales	None	None
Sales Taxes	5% of sales	None	None
Federal Incentive (30C Tax Credit) [111]	29% installed cost reduction	17% installed cost reduction	17% installed cost reduction

In Table A2, "peak demand" refers to the maximum power demand when operating at full utilization. This variable directly impacts the scale of demand charges. The term "ramp rate" refers to the time required to reach full utilization. In our model, depots achieve full utilization the year after completion. Public charging station utilization ramps up linearly, reaching full 15 percent utilization in 2035, following Basma et al.[112]

We entered the foregoing electricity charges and other inputs into the H2FAST model, producing LCOC results for each of the three charging station types by state.[113]

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