Appendix G

Total Cost of Ownership Discussion Document

Advanced Clean Fleets Regulation

California Air Resources Board

Contents

This document was prepared by California Air Resources Board (CARB or Board) staff to document the preliminary cost inputs and assumptions to be used for the economic analysis of the proposed Advanced Clean Fleets (ACF) regulation currently under development, as well as display the total cost of ownership of selected vehicles. This document was originally released September 9, 2021 in advance of the Standardized Regulatory Impact Assessment (SRIA) and Initial Statement of Reasons (ISOR) for the proposed ACF regulation to support stakeholder input and to provide the opportunity for staff to make revisions prior to publication of the SRIA and ISOR.

A. Executive Summary

The zero-emission truck and bus market is growing rapidly, with over a hundred models commercially available today. Dozens of manufacturers, including established original equipment manufacturers and startups new to the heavy-duty market, have announced plans to release commercially available zero-emission vehicles (ZEVs). Zero-emission vehicles, including both battery-electric and fuel cell electric technologies, are the cleanest technology option and mass deployment is critical in achieving California's air quality and climate change goals.

This report assesses the total cost of ownership (TCO) of battery-electric and fuel cell electric vehicles versus their diesel, gasoline, and natural gas-powered counterparts. This report analyzes the key cost components that differ between these technology types including vehicle costs, fuel costs, maintenance costs, infrastructure investments, Low Carbon Fuel Standard (LCFS) revenue, and other costs. Six vehicle types were modeled in this analysis – a Class 2b cargo van, a Class 5 walk-in van, a Class 6 bucket truck, a Class 8 refuse packer, a Class 8 day cab tractor for use in drayage operations, and a Class 8 sleeper cab tractor. This analysis does not include any rebates, incentives, or grants to show how costs compare without the effect of subsidies.

In summary, the results show that battery-electric vehicles appear cost competitive with the established combustion technologies by 2025 in a variety of use cases. Significant savings are shown for battery-electric in the walk-in van, refuse truck, and day cab categories, even in the early years. Fuel cell electric vehicles also appear competitive with combustion-powered technologies in the 2025 to 2030 timeframe depending on the vehicle type. Despite the higher upfront costs associated with vehicle costs and infrastructure, cost savings from lower fuel costs and LCFS revenue result in a positive TCO. The TCO for ZEVs is expected to improve over time as costs continue to decline.

The following figures display the TCO for the six vehicle types in the three analysis periods.

Figure 1: Cargo Van TCO Comparison

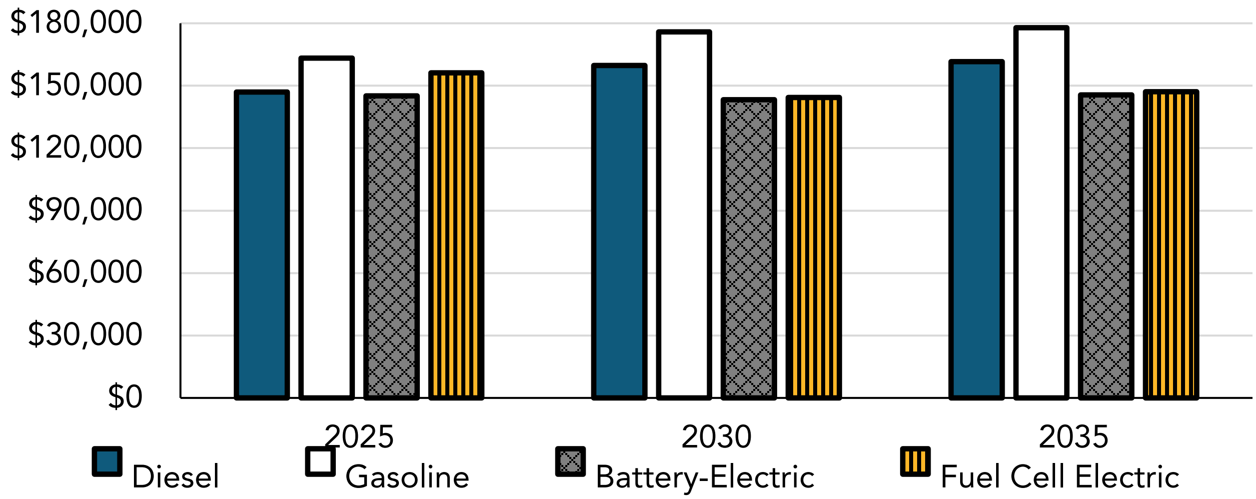


Figure 2: Walk-in Van TCO Comparison

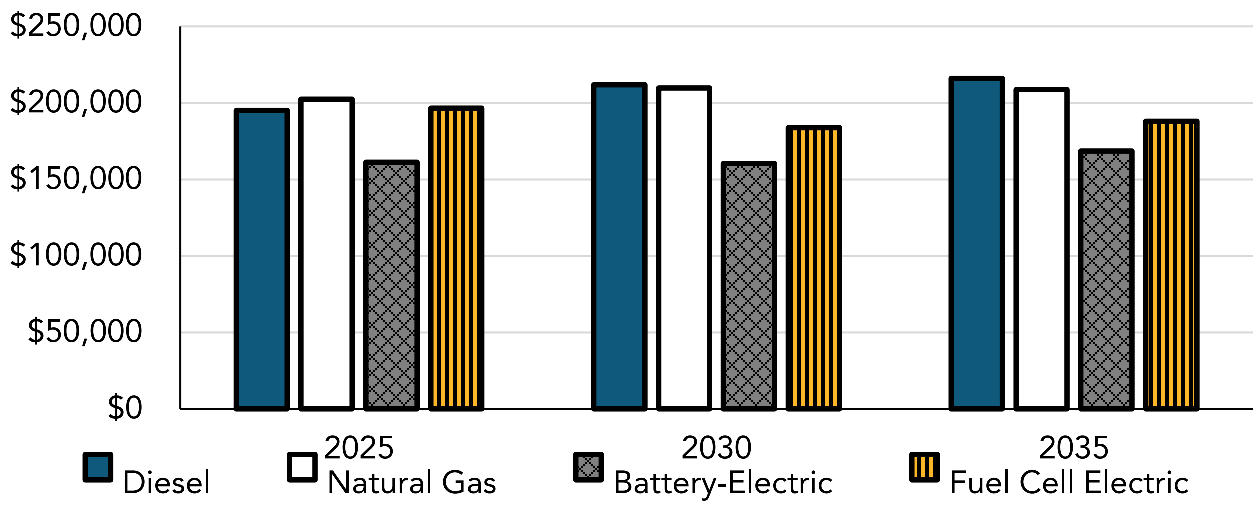


Figure 3: Bucket Truck TCO Comparison

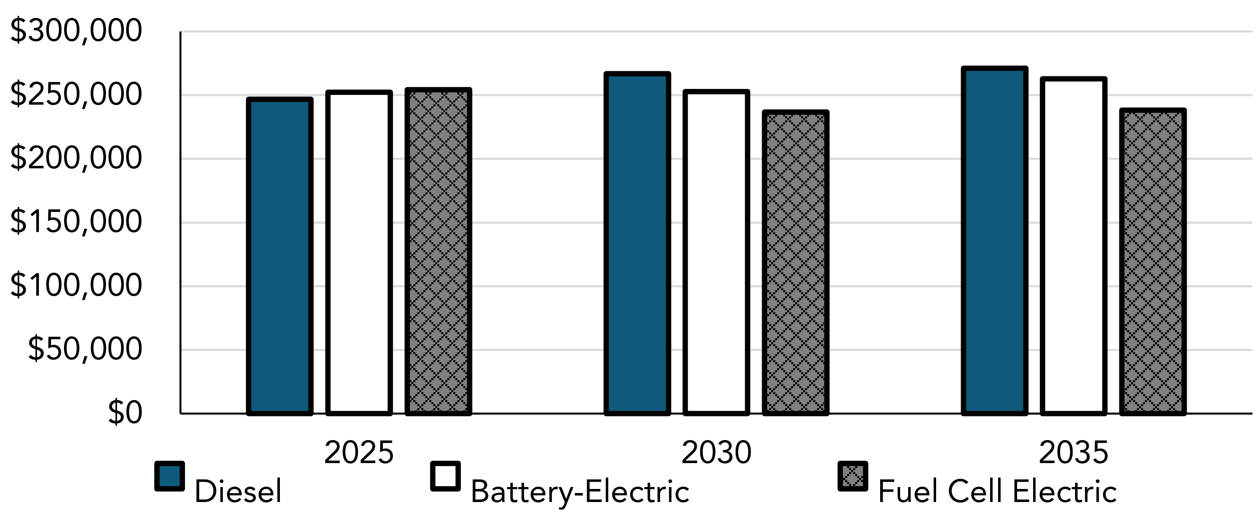


Figure 4: Refuse Truck TCO Comparison

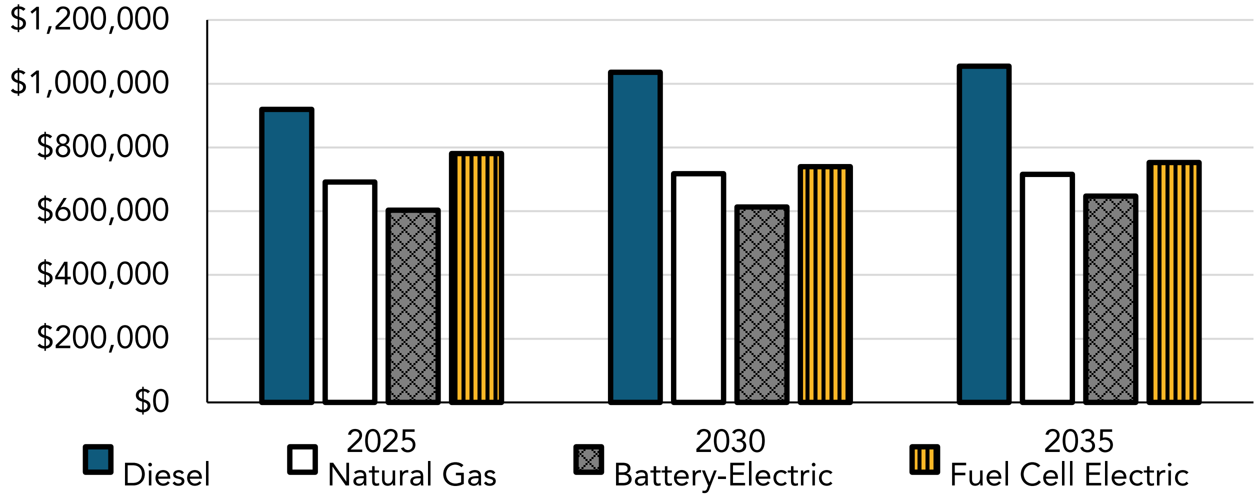


Figure 5: Day Cab Tractor TCO Comparison

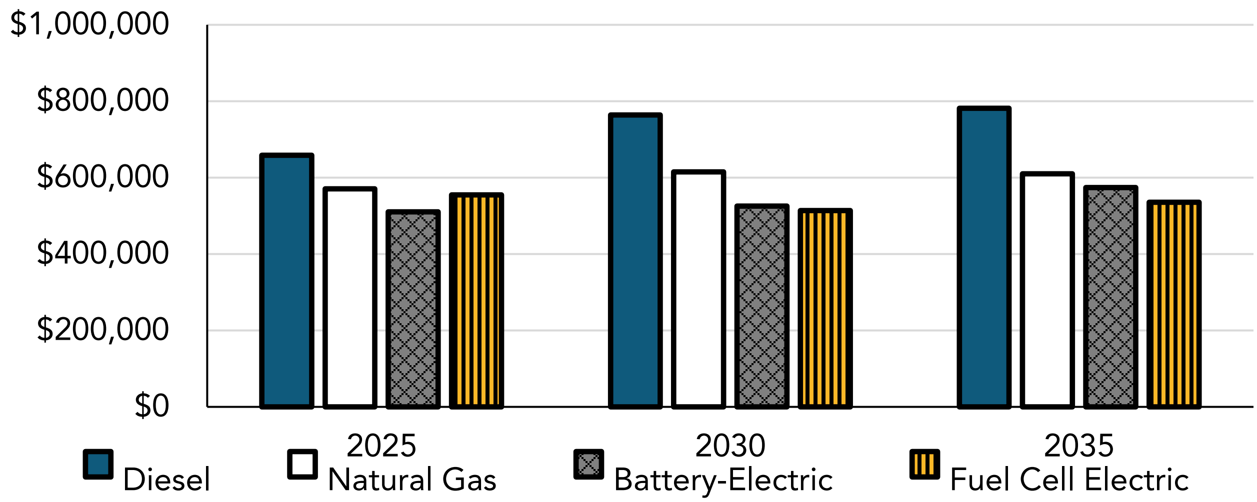
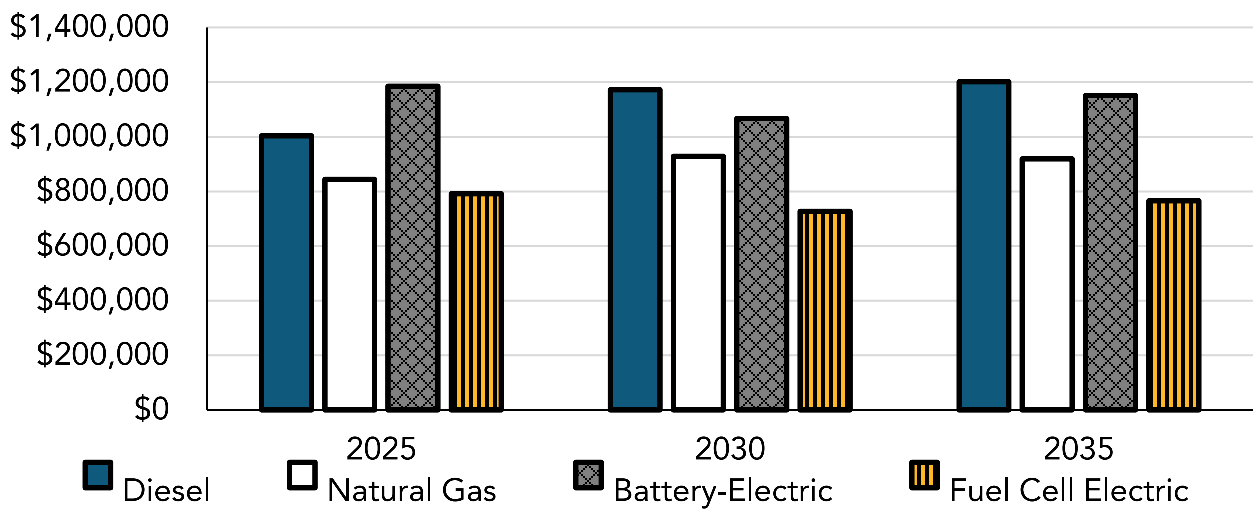


Figure 6: Sleeper Cab Tractor TCO Comparison



In addition to these TCO analysis, staff has analyzed the cashflow for vehicles over the expected operating lifetime

Figure 7: 2025 Cargo Van Cashflow Comparison

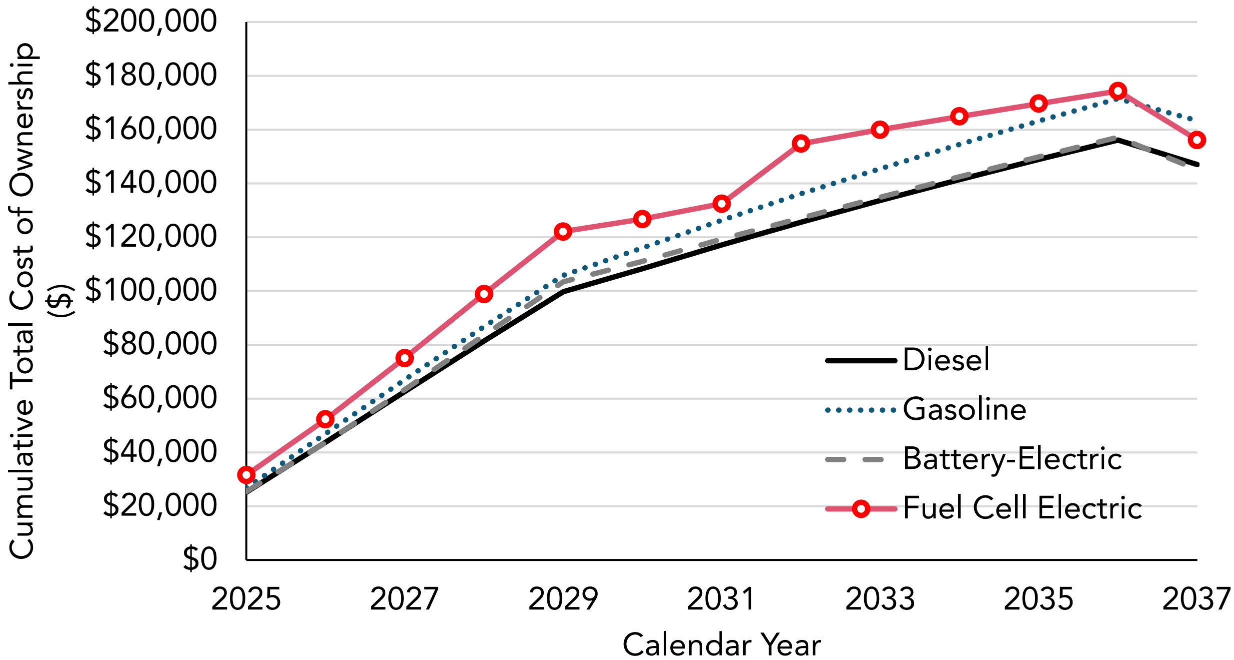
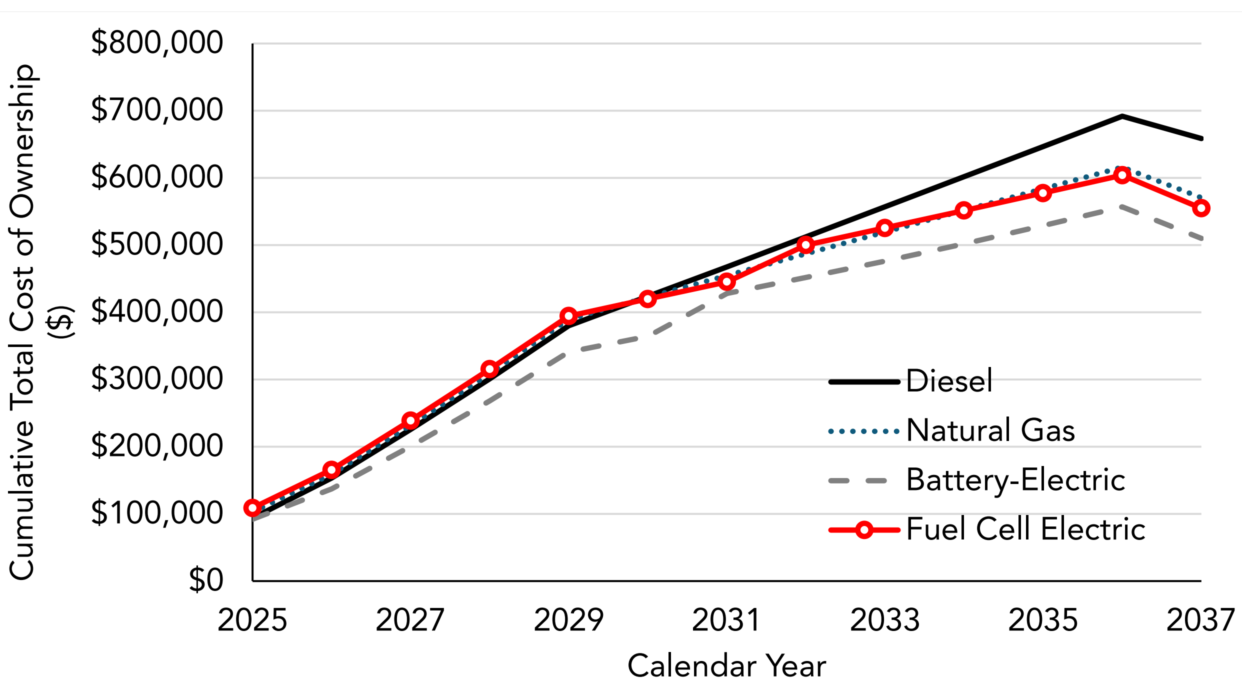


Figure 8: 2025 Day Cab Tractor Cashflow Comparison



The results of this analysis suggest the following:

- Costs of batteries and fuel cell components are expected to decline substantially over the next decade and will bring down the incremental capital costs of zero-emission trucks and buses. This will further improve their TCO compared to the combustion equivalents. Cost reductions beyond what is modeled are feasible and become more likely with large scale investment into ZEV technologies by manufacturers and fleets.
- Through a combination of lower fuel costs, decreased maintenance expenses, and revenue from California's LCFS program, ZEVs achieve lower operational costs versus their combustion counterparts. These savings typically outweigh higher upfront costs over the lifetime of the ZEV.
- Both battery-electric and fuel cell electric vehicles are projected to be cost competitive with combustion-powered vehicles over the course of this analysis. Battery-electric vehicles appear competitive in many categories beginning 2025, while fuel cell electric vehicles appear competitive in either 2025 or 2030 depending on the type of vehicle modeled.
- ZEVs can result in significantly lower TCO for fleets in specific scenarios. For example, by 2030, a battery-electric Class 5 walk-in van is expected to have a 22 percent lower TCO versus their diesel counterpart resulting in a savings of $47,000 per vehicle. A battery-electric and fuel cell electric day cab operating in a drayage duty cycle is expected to have a 31 and 33 percent lower TCO versus diesel day cabs, respectively, resulting in savings of $239,000 and $251,000, respectively.
- Further cost reductions may be feasible as this report does not model potentially reduced costs to fleets as a result of the Advanced Clean Trucks manufacturer ZEV sales requirement. Investments and action by manufacturers can lead to lower costs throughout the entire ZEV ecosystem including parts suppliers, infrastructure providers, service technicians, and others.
- Upfront costs are expected to be higher for ZEVs due to additional vehicle and infrastructure expenses. However, by financing these costs and allowing operational savings to accrue, fleets can operate ZEVs with minimal cashflow impact in the initial years. Once the vehicle is paid off, operational savings continue to accrue over time. This allows fleets to purchase and operate ZEVs without seeing the additional costs associated with ZEVs.
- The payback period for ZEVs versus their diesel counterpart varies among vehicles but ranges from five to ten years in the 2025 analysis. This drops to two to five years in the 2030 and 2035 analyses, indicating that ZEVs are able to recoup their additional costs in a reasonable timeframe.
- Revenue from LCFS credits significantly improves the TCO for battery-electric and fuel cell electric vehicles. LCFS credits can completely offset the cost of charging a battery-electric vehicle and significantly reduce the costs of refueling fuel cell electric vehicles.

- Although they are not included in this analysis, grants, incentives, and utility infrastructure programs can further reduce the upfront costs if fleet owners act early.

B. Introduction

Achieving California's aggressive greenhouse gas (GHG) and criteria pollutant emissions goals will require large-scale deployment of ZEVs everywhere feasible in all transportation sectors. This strategy is outlined in all of CARB's planning documents such as the Sustainable Freight Action Plan, the 2020 Mobile Source Strategy, the ZEV Action Plan, the Scoping Plan, and more. The proposed Advanced Clean Fleets (ACF) regulation provides a key solution to meeting the goals of these planning documents and the emissions reductions required under the Clean Air Act by supporting the transition of California's fleets to zero-emission technologies. The proposed ACF regulation is a component of the California Air Resources Board's (CARB's) strategy to clean up California's trucks through a combination of enhanced inspection and maintenance, sales mandates through the proposed ACF regulation, fleet phase-in requirements, incentives and recognition, and cleaner fuels and engines.

This purpose of this report is to evaluate the TCO of battery-electric and hydrogen fuel cell electric to combustion-powered technologies – diesel, gasoline, and natural gas. This report covers differences in upfront costs, operating costs, infrastructure installations, and other associated costs and savings resulting from a shift to these new technologies. This report follows analysis performed by the CARB over the prior years. In December 2020, CARB staff released the "Cost Data and Methodology Discussion Draft" to share data sources and general methodology to solicit feedback on what assumptions to make. The work performed here builds upon years of workshops, workgroups, and stakeholder analysis performed during development of the proposed ACF regulation. This report does not quantify potential reductions in cost due to expanded medium- and heavy-duty ZEV manufacturing as a result of the Advanced Clean Trucks regulation. As a result, costs may end up lower as regulated manufacturers will need to create products that meet consumer demands at an attractive price point in order to ensure they can meet their ZEV sales obligations.

Several representative vehicles have been modeled to illustrate the TCO across a variety of vocations and weight classes: a Class 2b cargo van, a Class 5 walk-in van, a Class 6 bucket truck, a Class 8 refuse truck, a Class 8 day cab tractor in drayage operations, and a Class 8 sleeper cab tractor. This report analyzes the cost of purchasing a new vehicle as ZEVs will not be available in the secondary market for a number of years.

This report is an assessment of key cost components that differ significantly between technologies including the purchase cost of the vehicle, ongoing fueling and maintenance costs, Low Carbon Fuel Standard (LCFS) revenue, infrastructure, and other assorted vehicle operating costs. The analysis does not include any vouchers, rebates, or grants for ZEVs to show how the costs compare without subsidies. The LCFS credit is a form of incentive, but is a market-based mechanism that is part of a regulation to increase the use of low carbon transportation fuels in California. Costs that are not expected to change among vehicle types, like overhead and driver wages are not included in the TCO analysis.

This report does not evaluate catenary electric systems, dynamic charging systems, hydrogen internal combustion, or other combustion fuels. This analysis follows Department of Finance guidelines and as a result uses 2020 constant dollars and does not use discount rates.

C. Duty Cycle

How fleets operate their vehicles affects many operating characteristics and varies between fleets. In the SRIA, staff will be using EMFAC projections to model duty cycles. This includes separately modelling vehicle categories, their fuel types, and vehicle accrual rates. EMFAC also models vehicle lifetimes and the rate that trucks enter and leave the California truck population. This report presents a simplified analysis to analyze one vehicle at a time in a typical use case to allow clear comparisons rather than the entire truck population as is necessary for the SRIA.

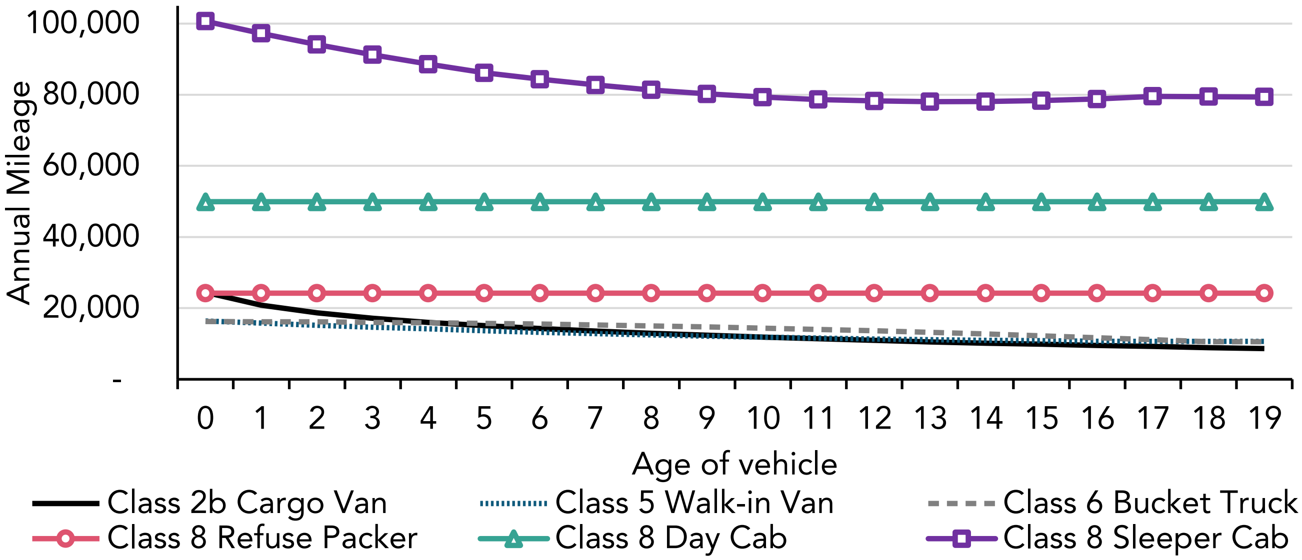
1. Annual Mileage

Annual mileage factors into a number of costs in this analysis including battery size, fuel costs, maintenance, and LCFS revenue. All annual mileage assumptions are based on EMFAC inventory estimates – for example day cab tractors, the T7 POLA category representing drayage trucks at the San Pedro Bay ports was used.[1,2] For most vehicle categories, annual mileage is the highest for newer vehicles and drops over time as the vehicle ages. EMFAC data was matched to the different representative vehicles. Figure 9 illustrates the accrual rates for a set of sample vehicles.

[1] California Air Resources Board, *EMFAC 2021*, 2021 (web link: https://arb.ca.gov/emfac/, last accessed September 2021).

[2] Eastern Research Group, *Heavy-Duty Vehicle Accrual Rates: Final Report*, 2019 (web link: https://ww2.arb.ca.gov/sites/default/files/2021-03/erg_finalreport_hdv_accruals_20190614_ada.pdf, last accessed August 2021).

Figure 9: Annual Mileage over Time for Modeled Vehicles



Staff assumes ZEVs will travel the same distance as their combustion-powered counterparts. As shown in Figure 9, the majority of single-unit trucks such as walk-in vans and refuse trucks travel under 25,000 miles per year which represents 100 miles per day. Most medium- and heavy-duty ZEVs available today can achieve this threshold and future product launches advertise higher range options. For tractors, the majority of in-state tractors travel below 200 miles per day based on sources such as CA-VIUS.[3] Manufacturers including Freightliner, Volvo, Tesla, and others have announced ZE tractor launches in 2021 and 2022 that are capable of meeting these needs. Long haul applications can be electrified through a combination of fuel cell technologies and battery-electric vehicles utilizing charging during rest breaks and in-between shifts.[4] As technology improves and publicly available infrastructure is built, staff anticipates all vehicle types will be able to perform similar duty cycles regardless of their powertrain technology.

2. Operating Years

Operating years indicate a reasonable representation of how long the vehicle is expected to stay in use. This discussion document assumes that a single fleet will own and operate a truck for a significant portion of its life in California. An operating life of 12 years will be used throughout this analysis to simplify the comparisons. This

[3] California Department of Transportation, *CalTrans Truck Survey*, 2018 (web link: http://www.scag.ca.gov/committees/CommitteeDocLibrary/mtf012319_CAVIUS.pdf, last accessed May 2021).

[4] Lawrence Berkeley National Laboratory, *Why Regional and Long-haul Trucks are Primed for Electrification Now*, 2021 (web link: https://eta-publications.lbl.gov/sites/default/files/updated_5_final_ehdv_report_033121.pdf, last accessed August 2021).

represents a middle ground between fleets who operate their trucks for five years before turning them over and those who operate their trucks for 20 or more years until the truck cannot operate. Most vehicles can last 20 or more years based on Department of Motor Vehicle (DMV) and EMFAC emission inventory survival rate data. For purposes of the SRIA analysis, staff will use vehicle lifetimes as modelled by EMFAC where the overall population for a given model declines over time as vehicles leave the California fleet.

D. Vehicle Costs

3. Vehicle Price

This section covers the cost to the fleet of purchasing a vehicle. Today and for the foreseeable future, battery-electric and fuel cell electric trucks will cost more upfront than their combustion-powered counterparts. Declining battery and component costs in addition to economies of scale are expected to lower the incremental costs of ZEVs as the market expands.

Base gasoline and diesel new vehicle prices are based on averages of prices taken from manufacturers' websites and online truck marketplaces such as TruckPaper and Commercial Truck Trader. [5] New natural gas vehicle prices are derived from sources which estimate the incremental cost of upfitting a gasoline or diesel-powered vehicle to run on natural gas.[6,7] Table 1 displays sample new vehicle prices for a variety of applications and technology types.

[5] California Air Resources Board, *New Vehicle Cost Analysis*, 2021 (web link: https://ww2.arb.ca.gov/sites/default/files/2021-08/210909costdoc_ADA.pdf, last accessed June 2022).
[6] National Renewable Energy Laboratory, *VICE 2.0: Vehicle and Infrastructure Cash-Flow Evaluation Model*, 2014 (web link: *https://www.afdc.energy.gov/files/u/publication/VICE_2_0_Jan_17_14.xlsx* last accessed June 2022).
[7] JB Hunt, *Natural Gas in Transportation*, 2014 (web link: https://jbhcdn001.azureedge.net/files/0001723_NATURAL_GAS_WHITE_PAPER_022014.pdf last accessed June 2022).

Table 1: New Combustion-Powered Vehicle Prices

Vehicle	Vehicle Price
Class 2b Cargo Van – Diesel	$39,000
Class 2b Cargo Van – Gasoline	$35,000
Class 5 Walk-in Van – Diesel	$87,000
Class 5 Walk-in Van – Natural Gas	$104,500
Class 6 Bucket Truck – Diesel	$126,000
Class 8 Refuse Packer – Diesel	$226,000
Class 8 Refuse Packer – Natural Gas	$256,295
Class 8 Day Cab – Diesel	$130,000
Class 8 Day Cab – Natural Gas	$180,000
Class 8 Sleeper Cab – Diesel	$140,000
Class 8 Sleeper Cab – Natural Gas	$230,000

The Federal and California Phase 2 GHG regulations require manufacturers to build trucks that have lower GHG emissions and are more fuel efficient. These requirements start in 2021 Model Year (MY) and ramp up through the 2027 MY. U.S. Environmental Protection Agency (U.S. EPA) estimated the cost per vehicle to comply with the regulation shown in Table 2.[8] These costs are added to the base cost of combustion-powered vehicles. Because ZEVs produce zero tailpipe emissions, they do not incur increased costs due to the Phase 2 GHG regulation.

Table 2: U.S. EPA Phase 2 GHG Estimated Incremental Compliance Costs

Phase 2 Category	2021-2023 MY	2024-2026 MY	2027+ MY
Class 2b-3 Pickup/Van	$524	$963	$1,364
Vocational Vehicles	$1,110	$2,022	$2,662
Tractors	$6,484	$10,101	$12,442

The Low-NOx Omnibus rulemaking is a multi-pronged, holistic approach to decrease emissions of new heavy-duty engines sold in California beginning in the 2024 MY. The regulation was approved by the Office of Administrative Law on December 22, 2021. That regulation lowers NOx emissions by lowering tailpipe NOx standards, establishing a new low-load test cycle to ensure emissions reductions are occurring in all modes of operation, strengthening durability, lengthening warranty and useful life, and in-use testing provisions, along with other measures. The costs to a typical fleet purchasing combustion-powered vehicles based on the certification type and the MY is shown in Table 3.

[8] United States Environmental Protection Agency, *Final Rule for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2*, 2016 (web link: https://www.govinfo.gov/content/pkg/FR-2016-10-25/pdf/2016-21203.pdf, last accessed May 2021).

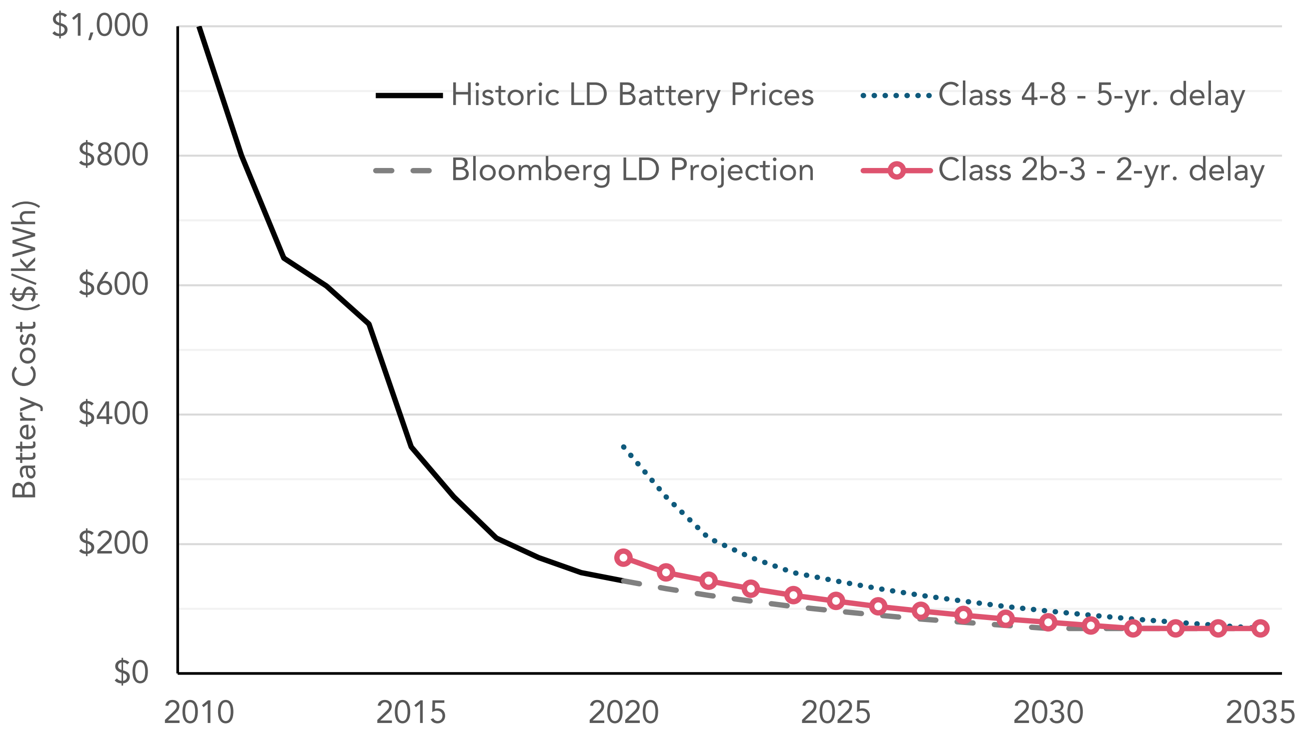
Table 3: CARB Low-NOx Omnibus Estimated Increase in Purchase Price

Vehicle Category	Corresponding Weight Class	2024-2026 MY	2027-2030 MY	2031+ MY
Medium-Duty Otto	Class 3	$412	$412	$412
Medium-Duty Diesel	Class 3	$1,554	$3,916	$4,354
Heavy-Duty Otto	Class 4-8	$506	$821	$1,015
Light-Heavy-Duty Diesel	Class 4-5	$1,687	$4,741	$6,041
Medium-Heavy-Duty Diesel	Class 6-7	$2,469	$6,063	$6,923
Heavy-Heavy-Duty Diesel	Class 8/Tractors	$3,761	$7,423	$8,478

Staff estimated the cost of medium- and heavy-duty ZEVs for battery-electric and fuel cell powered vehicles by adding electric components costs, fuel cell component costs, and energy storage costs to a conventional glider vehicle. The final retail price of the ZEV is the sum of the total component costs adjusted by an additional ten percent for other upfront costs such as research, development, retooling, and overhead. The calculated prices for battery-electric vehicles (BEV) are comparable to battery-electric trucks and vans that are available through the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) program today.

The cost of battery storage is the largest contributing factor associated with the price of BEVs. Battery pack costs have dropped nearly 90 percent since 2010 and are projected to continue declining. Battery pack cost for medium- and heavy-duty applications are higher than for light-duty cars due to smaller volumes and differing packaging requirements even though many use the same cells. At the December 4, 2018, ACT workgroup meeting, a number of manufacturers suggested we use light-duty battery prices with a 5-year delay to reflect battery price projections that are applicable to medium- and heavy-duty vehicles. Since that time, product announcements from manufacturers have indicated that smaller trucks and vans can share components with light-duty vehicles and as a result see lower component costs. Because these vehicles still need unique engineering and are built at lower scale than light-duty vehicles, staff is assuming Class 2b-3 vehicles will follow light-duty battery prices with a 2-year delay. Staff is using Bloomberg price projections as the basis for these battery price projections. Figure 10 shows the historic battery price trend and the battery price projections used in this analysis (shown in bold).

Figure 10: Historic Battery Price Trends and Battery Price Projections



The costs for BEVs are modelled using motors and electrical components in line with an existing diesel counterpart's power needs. Battery storage is estimated using the vehicle's average daily mileage based on EMFAC data and the energy efficiency of the electric vehicle in 2020. For vehicles which EMFAC models as driving below 100 miles per day, staff assumed the battery would have a minimum capability of driving 100 miles daily. Staff then modeled an additional 35 percent buffer to account for battery degradation and some operational variability. Table 4 lists the battery size specifications.

Table 4: Battery Size Calculation

Representative Vehicle	Daily Mileage	2020 Efficiency (kWh/mi)	Battery Size (kWh)
Class 2b Cargo Van	100	0.6	80
Class 5 Walk-in Van	100	1	135
Class 6 Bucket Truck	100	1.5	205
Class 8 Refuse Packer	100	3.0	405
Class 8 Day Cab	160	2.1	455
Class 8 Sleeper Cab	320	2.1	1,050

The hydrogen fuel cell vehicles are modeled using a 10 kWh battery and a fuel cell stack whose power output is half the vehicle's peak power needs. Hydrogen storage varies based on the vehicle: Class 2b-3 vehicles have 10 kg of storage, Class 4-6 vehicles have 20 kg of storage, Class 7-8 vehicles have 40 kg of storage, and Class 8 sleeper cab tractors have 80 kg of storage.

Generally, heavy-duty vehicles are manufactured in stages. A chassis manufacturer such as Ford or Freightliner installs a powertrain built by themselves or an outside supplier to produce a cab-and-chassis. This is then sent to a body manufacturer to install a body on the vehicle such as a box or bucket truck body. These body costs are modeled separately for ZEVs. The cost of a body can be estimated by measuring the difference between the price of a cab-and-chassis and the finished vehicle with a body. For this analysis, staff assumes bodies requiring power takeoff – in this case the bucket truck and refuse truck – will cost 10 percent extra up until 2030 to account for additional costs of electrifying the power takeoff. No increased costs are modeled for bodies without power takeoff.

The assumed vehicle prices for vehicles of all fuel types are shown in Table 5.

Table 5: New Vehicle Price Forecast

Vehicle	2025 MY	2030 MY	2035 MY
Class 2b Cargo Van – Diesel	$39,963	$40,364	$40,364
Class 2b Cargo Van – Gasoline	$35,963	$36,364	$36,364
Class 2b Cargo Van – Battery-Electric	$52,447	$48,001	$47,174
Class 2b Cargo Van – Fuel Cell Electric	$79,405	$67,592	$67,489
Class 5 Walk-in Van – Diesel	$90,709	$94,403	$95,703
Class 5 Walk-in Van – Natural Gas	$107,028	$107,983	$108,177
Class 5 Walk-in Van – Battery-Electric	$113,571	$105,167	$105,167
Class 5 Walk-in Van – Fuel Cell Electric	$129,422	$119,397	$119,397
Class 6 Bucket Truck – Diesel	$130,491	$134,725	$135,585
Class 6 Bucket Truck – Battery-Electric	$156,349	$144,073	$139,903
Class 6 Bucket Truck – Fuel Cell Electric	$176,695	$161,317	$157,147
Class 8 Refuse Packer – Diesel	$231,783	$236,085	$237,140
Class 8 Refuse Packer – Natural Gas	$258,823	$259,778	$259,972
Class 8 Refuse Packer – Battery-Electric	$299,932	$276,029	$266,929
Class 8 Refuse Packer – Fuel Cell Electric	$316,578	$294,380	$285,280
Class 8 Day Cab – Diesel	$143,862	$149,865	$150,920
Class 8 Day Cab – Natural Gas	$195,607	$198,263	$198,457
Class 8 Day Cab – Battery-Electric	$201,999	$176,028	$176,028
Class 8 Day Cab – Fuel Cell Electric	$212,353	$190,155	$190,155
Class 8 Sleeper Cab – Diesel	$153,862	$159,865	$160,920
Class 8 Sleeper Cab – Natural Gas	$240,607	$243,263	$243,457
Class 8 Sleeper Cab – Battery-Electric	$304,629	$247,638	$247,638
Class 8 Sleeper Cab – Fuel Cell Electric	$251,403	$226,272	$226,272

4. Taxes

Taxes are additional costs levied on the purchase of a vehicle. Because they are based on the purchase price of the vehicle, they are higher for ZEVs due to their higher upfront costs.

Vehicles purchased in California must pay a sales tax on top of the vehicle's purchase price. The sales tax varies across the state from a minimum of 7.25 percent up to 10.25 percent in some municipalities where 3.94 percent goes towards the State and the remaining portion goes towards local governments. A value of 8.5 percent was used for the sales tax rate based on a statewide population-weighted average.

Class 8 vehicles are subject to an additional federal excise tax which adds 12 percent to their purchase price.

5. Financing

For the purpose of this analysis, vehicle purchases are assumed to be financed over a five-year period. Staff assumes most fleets will be able to finance at a lower interest rate while some less creditworthy fleets will have to finance for higher rates. To reflect this, staff modeled that 80 percent of fleets will finance at a 5 percent annual percentage rate and 20 percent of fleets will finance at 15 percent, resulting in an average financing rate of 7 percent.

E. Operating Costs

Operating costs are how many miles a vehicle drives annually and the per mile costs of the vehicle.

1. Fuel Costs

Fuel costs are calculated using total fuel used per year and the cost of fuel per unit. In general, ZEVs are two to five times as efficient as similar vehicles with internal combustion engine (ICE) technologies, they significantly reduce petroleum and other fossil fuel consumption, and they use less total energy.

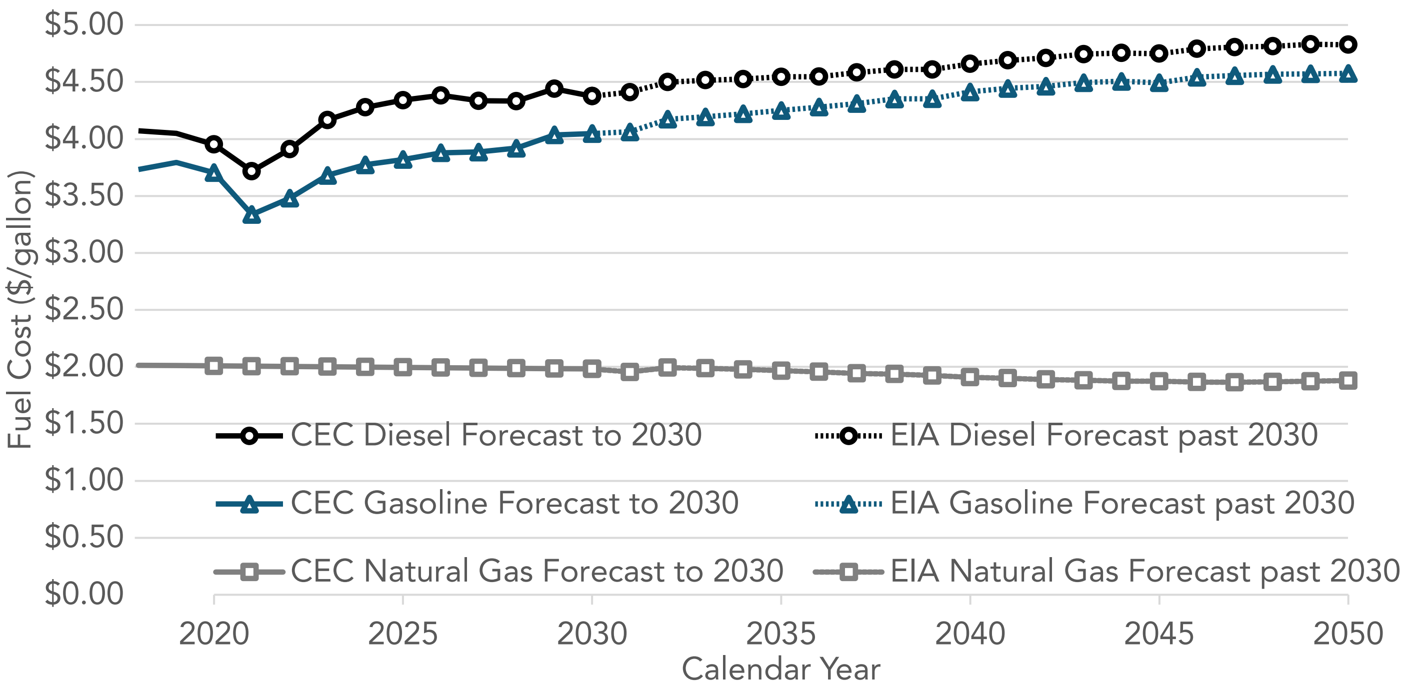
Gasoline and diesel fuel prices to 2030 are taken from the California Energy Commission's (CEC) "Fuel Price Forecasts" and are adjusted to 2021 dollars using the California consumer price index (CPI).[9] The "High Electricity Growth" scenario was used given the anticipated increase in electricity use due to this regulation and other upcoming CARB regulations. Gasoline and diesel fuel prices to 2030 are taken from CEC's "Fuel Price Forecasts" and adjusted to 2021 dollars using California consumer

[9] California Energy Commission, *Revised Transportation Energy Demand Forecast 2018-2030*, 2017 (web link: https://efiling.energy.ca.gov/getdocument.aspx?tn=235841, last accessed May 2021).

price index (CPI).[10] The annual percentage change in the U.S. Energy Information Administration (EIA) fuel prices past 2030 is applied to the 2030 CEC gasoline and diesel prices to estimate price changes past 2030.

Figure 11 shows the projected prices of gasoline, diesel, and natural gas out to 2050.

Figure 11: Gasoline, Diesel, and Natural Gas Price Forecasts



Electricity costs for battery-electric vehicles depend on the rate and on how they are charged, and include energy costs, fixed fees, and demand fees. Vehicles charged at high power or during peak periods will have higher electricity costs than if charging overnight or over an extended period. For this analysis, staff assumes most BEVs will primarily utilize depot charging while Class 8 sleeper cab tractors will primarily rely on retail charging.

Electricity prices for depot charging are calculated using CARB's Battery-Electric Truck and Bus Charging Calculator and assumes a fleet of 20 vehicles using a managed charging strategy with the applicable rate schedule.[11] Day cab tractors are assumed to be charged in a four-hour shift at night along with opportunity midday charging sessions at the depot. All other trucks are assumed to charge overnight. Charger efficiency losses and local electricity taxes are incorporated into these numbers. The

[10] California Energy Commission, *Revised Transportation Energy Demand Forecast 2018-2030*, 2017 (web link: https://efiling.energy.ca.gov/getdocument.aspx?tn=235841, last accessed May 2021).
[11] California Air Resources Board, *Battery-Electric Truck and Bus Charging Calculator*, 2021 (web link: https://ww2.arb.ca.gov/resources/documents/battery-electric-truck-and-bus-charging-cost-calculator, last accessed May 2021).

cost per kWh is calculated separately for each utility and a weighted average is used to determine the cost per kWh per vehicle in 2021. Table 6 shows the depot charging electricity price per kWh for each vehicle and major utility region as well as the weighted statewide average which was used in this report. In general, electricity costs are lower for larger vehicles because they tend to use more electricity which decreases the fixed costs per kWh and allows the use of lower cost rate schedules for larger utility customers. Note that Southern California Edison's (SCE) newly introduced electric vehicle rates, EV-8 and EV-9, have no demand fees from 2019 to 2023; these fees will phase back in over the following five years, with demand fees being fully reintroduced in 2029. However, to simplify the analysis, staff used the full cost of the SCE electricity rate including all demand charges from the beginning of the analysis period rather than discounting the price to reflect the transition period until the demand charges are fully reintroduced.[12]

Table 6: Electricity Cost Calculation for 2021

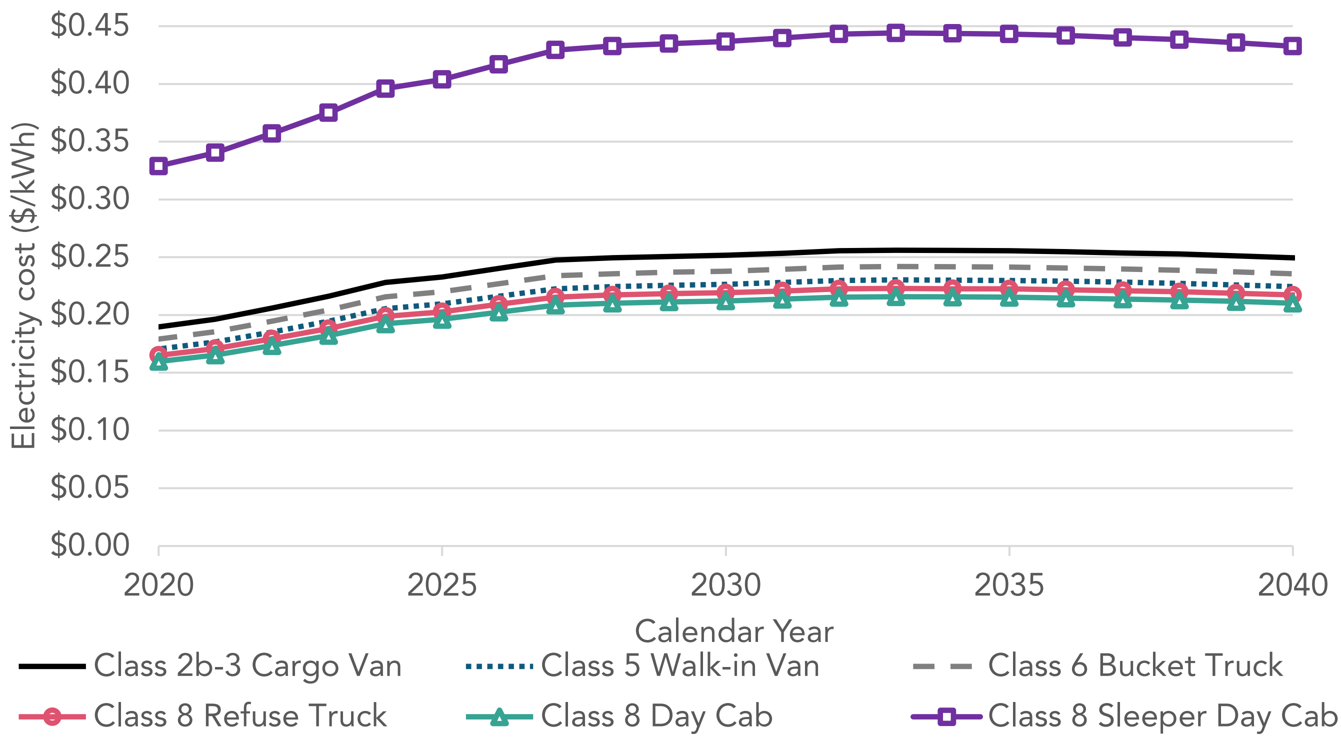
Utility Area	Cargo Van	Walk-in Van	Bucket Truck	Refuse Truck	Day Cab Tractor
Los Angeles Department of Water and Power	$0.11	$0.11	$0.13	$0.11	$0.17
Pacific Gas and Electric (PG&E)	$0.15	$0.15	$0.16	$0.15	$0.14
Sacramento Municipal Utility District	$0.17	$0.16	$0.16	$0.14	$0.14
San Diego Gas and Electric (SDG&E)	$0.21	$0.20	$0.22	$0.20	$0.15
Southern California Edison (SCE)*	$0.19	$0.15	$0.15	$0.14	$0.15
Weighted Statewide Average	$0.18	$0.16	$0.17	$0.16	$0.16

Sleeper cab tractors are assumed to require a retail charging network instead of utilizing depot charging. For retail charging, staff assumes the price for medium- and heavy-duty retail charging would be similar to current direct current fast charging costs for light-duty at $0.31/kWh.[13] This electricity cost includes all costs associated with building the publicly accessible station and its infrastructure.

Electricity price changes over time are modeled using CEC's "Revised Transportation Energy Demand Forecast, 2018-2030," adjusted to 2018 dollars using California consumer price index (CPI). Fuel prices after 2030 are calculated using the EIA 2018 Annual Energy Outlook for the Pacific region. The annual percentage changes in EIA gasoline and diesel fuel prices after 2030 are applied to the 2030 CEC gasoline and diesel prices to estimate future price changes. Results by vehicle type are shown in Figure 12.

[12] Southern California Edison, Communication via email with Alexander Echele in April 2019.
[13] Electrify America, *Pricing and Plans for EV Charging*, 2021 (web link: https://www.electrifyamerica.com/pricing/, last accessed May 2021).

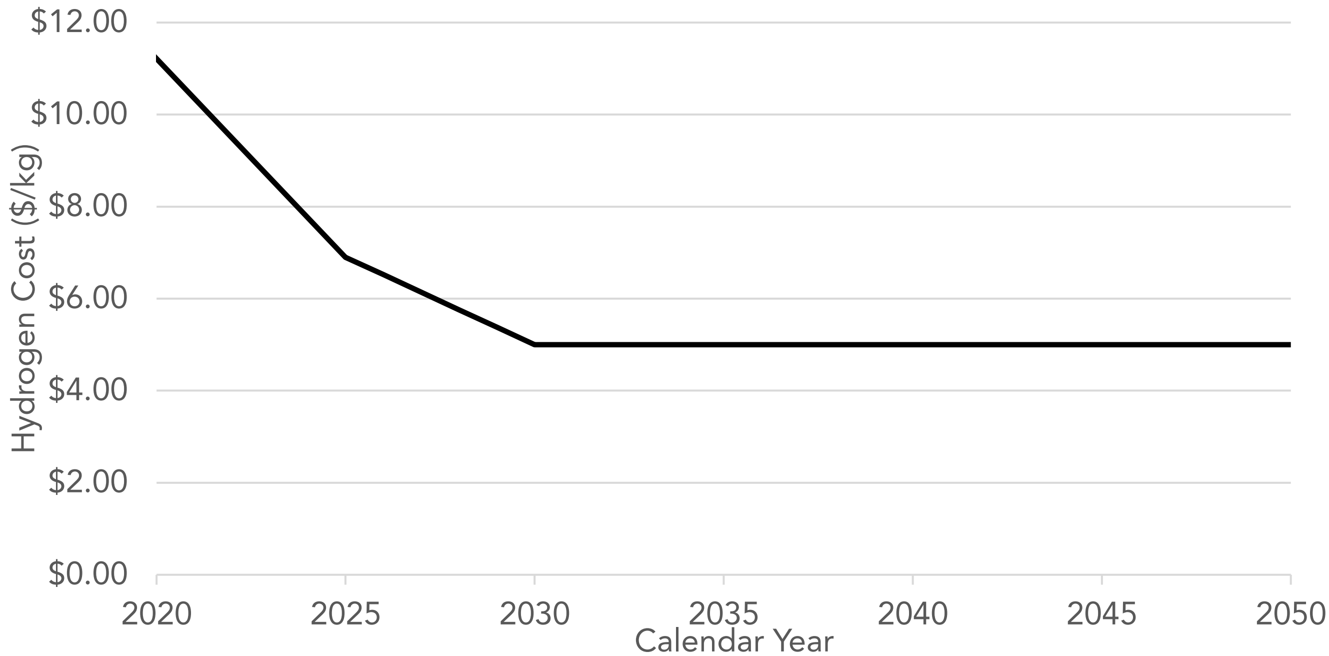
Figure 12: Electricity Price Forecasts



For this analysis, hydrogen stations were assumed to be available at strategic locations around seaports or major distribution hubs where the infrastructure costs are included in the hydrogen fuel price rather than reflecting costs for stations installed in a depot. This model is currently used for light-duty hydrogen stations and medium- and heavy-duty diesel sales and is based on stakeholder feedback; it appears to be most appropriate for medium- and heavy-duty hydrogen fueling. Hydrogen fuel costs are based on values provided by "Road Map to a U.S. Hydrogen Economy," a report released by a coalition of major hydrogen stakeholders including automotive, fuel cell, petroleum, and power companies.[14] Hydrogen costs over time are shown in Figure 13.

[14] Fuel Cell & Hydrogen Energy Association, "*Road Map to a US Hydrogen Economy*," 2021 (web link: https://www.fchea.org/us-hydrogen-study, last accessed May 2021).

Figure 13: Hydrogen Price Forecasts



Fuel economy is measured in miles per gallon for gasoline and diesel, miles per kWh for battery-electric, and miles per kg for fuel cell electric trucks. Gasoline, diesel, and natural gas fuel economy is derived from EMFAC inventory projections for each group. These projections incorporate the effects of the Phase 2 GHG regulation.

BEV fuel economy is derived from in-use data collected from a variety of vehicles and estimates made from similar vehicles.[15,16,17] For fuel cell efficiency, staff applied the LCFS program's Energy Efficiency Ratios (EER) of 2.5 and 1.9 for Class 2b-3 and Class 4-8 vehicles, respectively, to the diesel fuel economy to estimate the fuel cell fuel economy as there is limited information which measures the fuel efficiency of medium- and heavy-duty fuel cell electric vehicles (FCEV). Sleeper cab ZEV fuel economy is estimated to be 15 percent higher than the equivalent day cab tractor ZEV fuel economy values based on the relative difference between Phase 2 GHG standards for the two classes of vehicles.

Staff's modeling assumes that for both BEVs and FCEVs, the efficiency will improve at the same rate as the Phase 2 GHG regulation would require for combustion-powered vehicles until 2027 MY, then remain constant afterwards. This may be a conservative

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[15] California Air Resources Board, *Battery Electric Truck and Bus Efficiency Compared to Diesel Vehicles* (web link: https://ww2.arb.ca.gov/sites/default/files/2018-11/180124hdbevefficiency.pdf, last accessed May 2021).

[16] Penn State LTI Bus Research and Testing Center, *Motor Coach Industries D45 CRTeLE*, 2020 (web link: http://apps.altoonabustest.psu.edu/buses/reports/522.pdf?1608733416, last accessed May 2021).

[17] Penn State LTI Bus Research and Testing Center, *GreenPower Motor Company EV Star*, 2020 (web link: http://apps.altoonabustest.psu.edu/buses/reports/515.pdf?1603821665, last accessed May 2021).

estimate as both technologies are less developed than ICE powertrains and reports have shown improvements in the technology recently.

Table 7 outlines the fuel economy assumptions for the modeled vehicles over the modeled time period.

Table 7: Vehicle Fuel Economy Data

Vehicle	2025 MY	2030 MY	2035 MY	Unit
Class 2b Cargo Van – Gasoline	18.96	15.25	15.24	Mpg
Class 2b Cargo Van – Diesel	13.78	11.73	11.73	Mpg
Class 2b Cargo Van – Battery-Electric	1.89	2.00	2.00	mi./kWh
Class 2b Cargo Van – Fuel Cell Electric	44.60	47.24	47.24	mi./kg
Class 5 Walk-in Van – Diesel	9.10	8.05	8.33	Mpg
Class 5 Walk-in Van – Natural Gas	7.62	6.53	6.56	mpdge
Class 5 Walk-in Van – Battery-Electric	1.13	1.20	1.20	mi./kWh
Class 5 Walk-in Van – Fuel Cell Electric	16.06	17.01	17.01	mi./kg
Class 6 Bucket Truck – Diesel	8.58	7.58	7.84	Mpg
Class 6 Bucket Truck – Battery-Electric	0.76	0.80	0.80	mi./kWh
Class 6 Bucket Truck – Fuel Cell Electric	15.05	15.94	15.94	mi./kg
Class 8 Refuse Packer – Diesel	3.06	2.48	2.61	Mpg
Class 8 Refuse Packer – Natural Gas	6.27	4.83	4.88	mpdge
Class 8 Refuse Packer – Battery-Electric	0.38	0.40	0.40	mi./kWh
Class 8 Refuse Packer – Fuel Cell Electric	5.20	5.51	5.51	mi./kg
Class 8 Day Cab – Diesel	6.75	5.55	5.30	Mpg
Class 8 Day Cab – Natural Gas	6.54	5.25	5.01	Mpdge
Class 8 Day Cab – Battery-Electric	0.54	0.57	0.57	mi./kWh
Class 8 Day Cab – Fuel Cell Electric	10.93	11.58	11.58	mi./kg
Class 8 Sleeper Cab – Diesel	6.94	5.75	5.47	Mpg
Class 8 Sleeper Cab – Natural Gas	6.32	4.99	4.69	Mpdge
Class 8 Sleeper Cab – Battery-Electric	0.47	0.50	0.50	mi./kWh
Class 8 Sleeper Cab – Fuel Cell Electric	10.98	11.63	11.63	mi./kg

2. Diesel Exhaust Fluid Consumption

Diesel-powered vehicles equipped with modern emissions control devices require diesel exhaust fluid (DEF) to break down NOx in the exhaust stream. Argonne National Laboratory estimates DEF consumption as being 2 percent of total fuel usage in their online 2020 AFLEET tool.[18] This assumption will be applied to the fuel economy discussed previously to estimate the DEF consumption per mile. DEF is assumed to cost $2.80 per gallon per Argonne.

[18] Argonne National Laboratory, *Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool,* 2020 (web link: https://greet.es.anl.gov/afleet, last accessed May 2021).

3. Low Carbon Fuel Standard (LCFS) Revenue

The LCFS is a California regulation that creates a market mechanism that incentivizes low carbon fuels. The regulation requires the carbon intensity of California's transportation fuels to decrease by 20 percent through the 2030 timeframe and maintains the standard afterwards. Fleets using electricity and hydrogen are eligible to earn LCFS credits which can be sold to offset the costs of these fuels. Fossil gasoline and diesel are not eligible for LCFS credits.

Fleets that own and operate their infrastructure generate credits based on the amount of fuel or energy they dispense. The amount of revenue generated by LCFS credits depends on the credit price. For this analysis, staff is projecting an LCFS credit price of $200 until 2030, then declining linearly to $25 in 2045 and remaining constant thereafter. The amount of revenue generated for different fuel types is calculated using the LCFS Credit Price Calculator.[19] In 2025, an electric Class 2b-3 vehicle will earn $0.147/kWh using grid electricity while an electric Class 4-8 vehicle will earn roughly $0.249/kWh at this credit price. Staff assumes hydrogen is produced from 33 percent renewable feedstock as required by Senate Bill 1505 (2006).[20] This results in Class 2b-3 vehicles earning $3.034/kg and Class 4-8 vehicles earning $1.839/kg in 2025. LCFS credit revenue for a given fuel drops slightly over time as the program standards tighten and maintains upward pressure on the credit price.

For retail electricity refueling for sleeper cab tractors, staff conservatively assumes that retail refueling stations will not pass-through any LCFS credit revenue until 2030 due to limited competition and low utilization of early retail charging stations. Starting 2031, staff assumes ZEV charging station operators will pass-through LCFS credit revenue to fleets in order to remain competitive with other operators.

This analysis reflects that the LCFS value associated with natural gas is already included in the retail price to the fleet owner. Fossil natural gas is expected to be a deficit generator in the LCFS program for the majority of this analysis and will not generate revenue. While renewable natural gas does generate LCFS credits, the credits are typically claimed by the fuel producer and are used to offset the higher cost of renewable natural gas. Therefore, the net cost to the fleet owner using renewable natural gas is essentially the same as fossil-based natural gas.

4. Maintenance Costs

Maintenance costs reflect the cost of labor and parts for routine maintenance, preventative maintenance, and repairing broken components but do not include costs reflected in the next section "Midlife Costs" where engine rebuilds, battery

[19] California Air Resources Board, *LCFS Credit Price Calculator*, 2021(web link: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/dashboard/creditvaluecalculator.xlsx, last accessed May 2021).

[20] SB 1505 (Lowenthal, Stats. 2006, ch.877). Health and Saf. Code sections 43868 and 43869.

replacements, or fuel cell stack refurbishments are described. Maintenance costs for electric vehicles are generally assumed to be lower than for diesel vehicles, in part due to their simpler design and fewer moving components.

Maintenance costs for combustion-powered vehicles are based on numerous published studies assessing maintenance costs for vehicles over a representative timeframe.[21, 22, 23, 24, 25, 26, 27] The maintenance cost for the selected representative vehicles was calculated by identifying all sources where the maintenance cost appeared for the representative vehicles and averaging the values. Maintenance costs for different combustion technologies are assumed to be the same due to a lack of data on the differences between technologies.

ZEVs are assumed to have 25 percent lower vehicle maintenance costs compared to gasoline and diesel, based on an aggregation of sources and data.[28, 29, 30, 31] While numerous reports assume ZEVs can achieve maintenance costs of 50 percent or greater, the lack of long-term data on maintenance costs presents uncertainty for modeling purposes; therefore, the staff analysis uses the lower estimate.

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[21] Argonne National Laboratory, *AFLEET Tool*, 2020 (web link: https://greet.es.anl.gov/afleet_tool, last accessed May 2021).
[22] National Renewable Energy Laboratory, *FedEx Express Gasoline Hybrid Electric Delivery Truck Evaluation: 12-Month Report*, 2011 (web link: https://www.nrel.gov/docs/fy11osti/48896.pdf, last accessed May 2021).
[23] National Renewable Energy Laboratory, *Thirty-Six Month Evaluation of UPS Diesel Hybrid-Electric Delivery Vans*, 2012 (web link: https://www.nrel.gov/docs/fy12osti/53503.pdf, last accessed May 2021).
[24] National Renewable Energy Laboratory, *Eighteen-Month Final Evaluation of UPS Second Generation Diesel Hybrid-Electric Delivery Vans*, 2012 (web link: https://www.nrel.gov/docs/fy12osti/55658.pdf, last accessed May 2021).
[25] Bloomberg, *What Tesla's Big Rig Must Do to Seduce Truckers*, 2017 (web link: https://www.bloomberg.com/news/articles/2017-11-15/what-tesla-s-semi-truck-must-do-to-seduce-truckers, last accessed May 2021).
[26] American Truck Research Institute, *An Analysis of the Operational Costs of Trucking: 2018 Update*, 2018. (web link: https://truckingresearch.org/wp-content/uploads/2018/10/ATRI-Operational-Costs-of-Trucking-2018.pdf, last accessed May 2021).
[27] Fleet Advantage, *Mitigating Rising M&R Costs for Class-8 Truck Fleets*, 2018 (web link: http://info.fleetadvantage.com/mitigating-rising-fleet-maintenance-and-repair-costs-for-class-8-trucks, last accessed May 2021).
[28] California Air Resources Board, *Literature Review on Transit Bus Maintenance Cost* 2018 (web link: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2018/ict2018/appg.pdf, last accessed May 2021).
[29] Electrification Coalition, *State of the Plug-in Electric Vehicle Market*, 2013 (web link: https://www.pwc.com/gx/en/automotive/industry-publications-and-thought-leadership/assets/pwc-ec-state-of-pev-market-final.pdf, last accessed May 2021).
[30] Propfe, B. et.al. *Cost analysis of Plug-in Hybrid Electric Vehicles including Maintenance & Repair Costs and Resale Values,* 2012 (web link: http://www.mdpi.com/2032-6653/5/4/886, last accessed May 2021).
[31] Taefi, T. et.al. *Comparative Analysis of European examples of Freight Electric Vehicle Schemes*, 2016 (web link: http://nrl.northumbria.ac.uk/15185/1/Bremen_final_paperShoter.pdf, last accessed May 2021).

Table 8 illustrates the maintenance costs for the modeled vehicles.

Table 8: Vehicle Maintenance Costs per Mile

Vehicle	Maintenance Cost ($/mi.)
Class 2b Cargo Van – Diesel	$0.337
Class 2b Cargo Van – Gasoline	$0.337
Class 2b Cargo Van – Battery-Electric	$0.253
Class 2b Cargo Van – Fuel Cell Electric	$0.253
Class 5 Walk-in Van – Diesel	$0.210
Class 5 Walk-in Van – Natural Gas	$0.210
Class 5 Walk-in Van – Battery-Electric	$0.158
Class 5 Walk-in Van – Fuel Cell Electric	$0.158
Class 6 Bucket Truck – Diesel	$0.700
Class 6 Bucket Truck – Battery-Electric	$0.525
Class 6 Bucket Truck – Fuel Cell Electric	$0.525
Class 8 Refuse Packer – Diesel	$0.943
Class 8 Refuse Packer – Natural Gas	$0.943
Class 8 Refuse Packer – Battery-Electric	$0.708
Class 8 Refuse Packer – Fuel Cell Electric	$0.708
Class 8 Day Cab – Diesel	$0.198
Class 8 Day Cab – Natural Gas	$0.198
Class 8 Day Cab – Battery-Electric	$0.149
Class 8 Day Cab – Fuel Cell Electric	$0.149
Class 8 Sleeper Cab – Diesel	$0.159
Class 8 Sleeper Cab – Natural Gas	$0.159
Class 8 Sleeper Cab – Battery-Electric	$0.119
Class 8 Sleeper Cab – Fuel Cell Electric	$0.119

5. Midlife Costs

Midlife costs are the cost of rebuilding or replacing major propulsion components due to wear or deterioration. These costs do not include general maintenance on vehicles – these are included in the "Maintenance Costs" section. The frequency and cost of a midlife rebuild across varies across the different technologies. For combustion-powered vehicles, this would be a midlife rebuild, for BEVs this would be a battery replacement, and for a hydrogen FCEV this would be a fuel cell stack refurbishment.

Combustion-powered vehicles are expected to need a midlife rebuild at the end of their engine's useful life. The useful life periods were determined in the Low-NOx Omnibus rulemaking based on the vehicle's weight class and are shown in Table 9.[32]

[32] California Air Resources Board, *Public Hearing to Consider the Proposed Heavy-Duty Engine And Vehicle Omnibus Regulation and Assocated Regulatory Amendments – Staff Report: Initial Statement of Reasons*, 2020 (web link:

Once the vehicle's engine reaches the end of its useful life, the vehicle will require an engine rebuild. The cost of this rebuild is estimated at 25 percent of the total vehicle price minus body costs.

Table 9: Useful Life of Diesel Engines

Vehicle/Engine Category	Useful Life (Years/Miles)
Class 4-5 (Light-Heavy-Duty)	15/270,000
Class 6-7 (Medium-Heavy-Duty)	12/350,000
Class 8 (Heavy-Heavy-Duty)	12/800,000

BEVs are expected to need battery replacements as battery's health degrades over time. Long-term battery performance is limited for heavy-duty BEVs today, but today's ZEV manufacturers are offering vehicles with warranties of eight or more years and up to 300,000 miles on their products. [33,34,35] Staff anticipates battery durability will continue to improve as manufacturers strive to meet fleet needs. Based on this, staff estimates that the battery will be replaced every 300,000 miles prior to 2030 and every 500,000 miles afterwards. The cost of the battery replacement is assumed to be the size of the battery in kWh multiplied by the price per kWh at the time of the replacement.

For FCEVs, the consulting firm Ricardo has estimated that a fuel cell stack refurbishment is necessary every seven years and costs one third the cost of a new fuel cell stack at the time of refurbishment.[36]

To provide an example, the midlife costs of a 2025 MY day cab tractor of four different fuel types would be:

- Diesel and natural gas: The tractor engine will need to be overhauled after 12 years in 2037 the overhaul is expected to cost $35,966.
- Battery-electric: The vehicle is expected to reach 300,000 miles after 7 years and the battery replacements in 2031 is expected to cost $31,275.

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https://ww2.arb.ca.gov/sites/default/files/classic/regact/2020/hdomnibuslownox/isor.pdf, last accessed May 2021).

[33] BYD, *The BYD K9,* 2019 (web link: https://en.byd.com/wp-content/uploads/2019/07/4504-byd-transit-cut-sheets_k9-40_lr.pdf, last accessed May 2021).

[34] New Flyer, *Xcelsior Charge*, 2019 (web link: https://www.newflyer.com/site-content/uploads/2019/06/Xcelsior-CHARGE-web.pdf, last accessed May 2021).

[35] Proterra, *Catalyst: 40 Foot Bus – Performance Specifications*, 2019 (web link: https://mk0proterra6iwx7rkkj.kinstacdn.com/wp-content/uploads/2019/06/Proterra-Catalyst-40-ft-Spec-Sheet.pdf, last accessed May 2021).

[36] Ricardo, *Economics of Truck TCO and Hydrogen Refueling Stations*, 2016 (web link: https://cafcp.org/sites/default/files/8_Economics-of-Hydrogen-Refueling-Stations-Ricardo_CaFCP-Bus-Team-meeting-Aug2016.pdf, last accessed May 2021).

- Fuel cell electric: A fuel cell stack refurbishments would occur after 7 years in 2031at a cost of $9,917 for the refurbishment.

6. Registration Fees

Vehicles operating and registered in California must pay an annual registration fee. The registration fee varies based on the vehicle's cost, age, and weight. These calculations are different for combustion-powered vehicles and ZEVs.

Combustion-powered vehicles and ZEVs are subject to the following fixed fees based on the DMV online calculator.[37] These are constant annual fees for every vehicle and are shown in Table 10 and Table 11.

Table 10: Fixed Registration Fees for ICE Vehicles

Diesel Fee Name	Amount
Current Registration	$61
Commercial Vehicle Registration Act (CVRA) Registration Fee	$122
CVRA Service Authority for Freeway Emergencies Fee	$3
CVRA Fingerprint ID Fee	$3
CVRA Abandoned Vehicle Fee	$3
CVRA California Highway Patrol Fee	$46
Current Air Quality Management District	$6
Current Cargo Theft Interdiction Program Fee	$3
CVRA Weight Decal Fee	$3
Alt Fuel/Tech Registration Fee	$3
CVRA Auto Theft Deterrence/DUI Fee	$4
Reflectorized License Plate Fee	$1
Total	$258

[37] California Department of Motor Vehicles, *California New Vehicle Fees*, 2021 (web link: https://www.dmv.ca.gov/portal/dmv/detail/portal/feecalculatorweb, last accessed May 2021).

Table 11: Fixed Registration Fees for ZEVs

ZEV Fee Name	Amount
Current Registration	$61
Current California Highway Patrol	$28
CVRA Service Authority for Freeway Emergencies Fee	$1
CVRA Fingerprint ID Fee	$1
CVRA Abandoned Vehicle Fee	$1
Current Air Quality Management District	$6
Alt Fuel/Tech Registration Fee	$3
CVRA Auto Theft Deterrence/DUI Fee	$2
Reflectorized License Plate Fee	$1
Road Improvement Fee	$100
Total	$204

All vehicles registered in California must pay a Transportation Improvement Fee based on the price of the vehicle. As of 2021, the fee is $171 for vehicles priced between $35,000 and $60,000, and $192 for vehicles priced above $60,000.

All registered vehicles are assessed a Vehicle License Fee which is equal to the vehicle price multiplied by 0.65 percent and a separate percentage schedule. This separate schedule is shown in Table 12.

Table 12: Vehicle License Fees Decline over Time

Year	1	2	3	4	5	6	7	8	9	10	11+
Percentage	100%	90%	80%	70%	60%	50%	40%	30%	25%	20%	15%

For commercial ICE vehicles, vehicle owners are assessed an annual weight fee based on the vehicle's potential maximum loaded weight. For electric vehicles, the weight fee is based on its unladen weight. The estimated weight fees are shown in Table 13.

Table 13: Weight Fees for ICE Vehicles and ZEVs

Weight Class	Diesel Weight Fee	ZEV Weight Fee
Class 2b-3	$210	$266
Class 4-5	$447	$358
Class 6-7	$546	$358
Class 8	$1,270	$358
Class 7-8 Tractor	$2,064	$358

Overall, a ZEV requires lower registration fees over the vehicle's life although it may be higher in the initial years of registration. This difference is greater for heavier vehicles due to the large difference in annual weight fees.

F. Infrastructure

Infrastructure is necessary to refuel or recharge vehicles. All vehicles need either dedicated refueling infrastructure onsite or publicly available retail stations in order to operate. There are numerous ways infrastructure expenses can be accounted for which will affect the cost to California businesses in different ways. Infrastructure expenses are generally an upfront capital investment needed prior to vehicles being deployed, but infrastructure can last multiple vehicle lifetimes and generally is amortized over its life.

In this report, staff assumes gasoline, diesel, and hydrogen vehicles are either using existing infrastructure or publicly accessible stations and as a result have no separate infrastructure costs. Battery-electric and natural gas vehicle deployments will generally require the fleet making infrastructure upgrades to support their vehicles.

1. Natural Gas Vehicle Infrastructure

Natural gas infrastructure costs are derived from two sources. For Class 8 refuse packers and Class 8 tractors, infrastructure costs are assumed to be $40,000 per vehicle. This is based on the value used in the Innovative Clean Transit rulemaking of a 100 bus compressed natural gas (CNG) refueling station costing $4,000,000.[38] For Class 4-7 vehicles, a cost value of $18,000 per vehicle is used. This was calculated using the National Renewable Energy Laboratory's Vehicle Infrastructure and Cash-Flow Evaluation 2.0 CNG model in a scenario where a fleet deploys 150 CNG delivery trucks with an average vehicle lifetime of 15 years.[39]

2. Battery-Electric Vehicle Infrastructure

All vehicles in this analysis other than the Class 8 sleeper cab are assumed to use depot charging. Fleets utilizing depot charging for their battery-electric vehicles will need to install chargers to recharge the vehicles as well as perform upgrades to the site to support the increased level of electricity demand. Charger costs are derived from the International Council on Clean Transportation working paper, “Estimating Electric Vehicle Charging Infrastructure Costs Across Major U.S. Metropolitan Areas.”[40] Generally, smaller trucks can use Level 2 chargers similar to what light-duty vehicles use. Class 6 and heavier vehicles are assumed to require higher power direct current

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[38] California Air Resources Board, *Appendix K: Transit Fleet Cost Model*, 2017 (web link: https://www.arb.ca.gov/regact/2018/ict2018/appk-transitfleetcostmodel.xlsx, last accessed July 2021).
[39] National Renewable Energy Laboratory, *VICE 2.0: Vehicle Infrastructure and Cash-Flow Evaluation Model*, 2014 (web link: https://afdc.energy.gov/files/u/publication/VICE_2_0_Jan_17_14.xlsx, last accessed July 2021).
[40] International Council on Clean Transportation, *Estimating Electric Vehicle Charging Infrastructure Costs Across Major U.S. Metropolitan Areas*, 2019. (web link: https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf, last accessed May 2021).

chargers. Class 8 single-unit vehicles are assumed to have two vehicles share a 150 kW charger while each Class 8 day cab will have its own charger.

Infrastructure upgrade costs represent costs on the customer side of the meter associated with setting up charging infrastructure at a facility and include trenching, cabling, laying conduit, potential transformer upgrades, and more. Infrastructure costs are derived from an analysis of BEV deployments conducted by CARB. The data was analyzed to calculate the cost per port and then results were broken into three groups: below 50 kW, between 50 and 250 kW, and above 250 kW. The results are shown in Figure 14 in a box-and-whisker plot.

Figure 14: Infrastructure Upgrade Cost per Charger Port and Power level

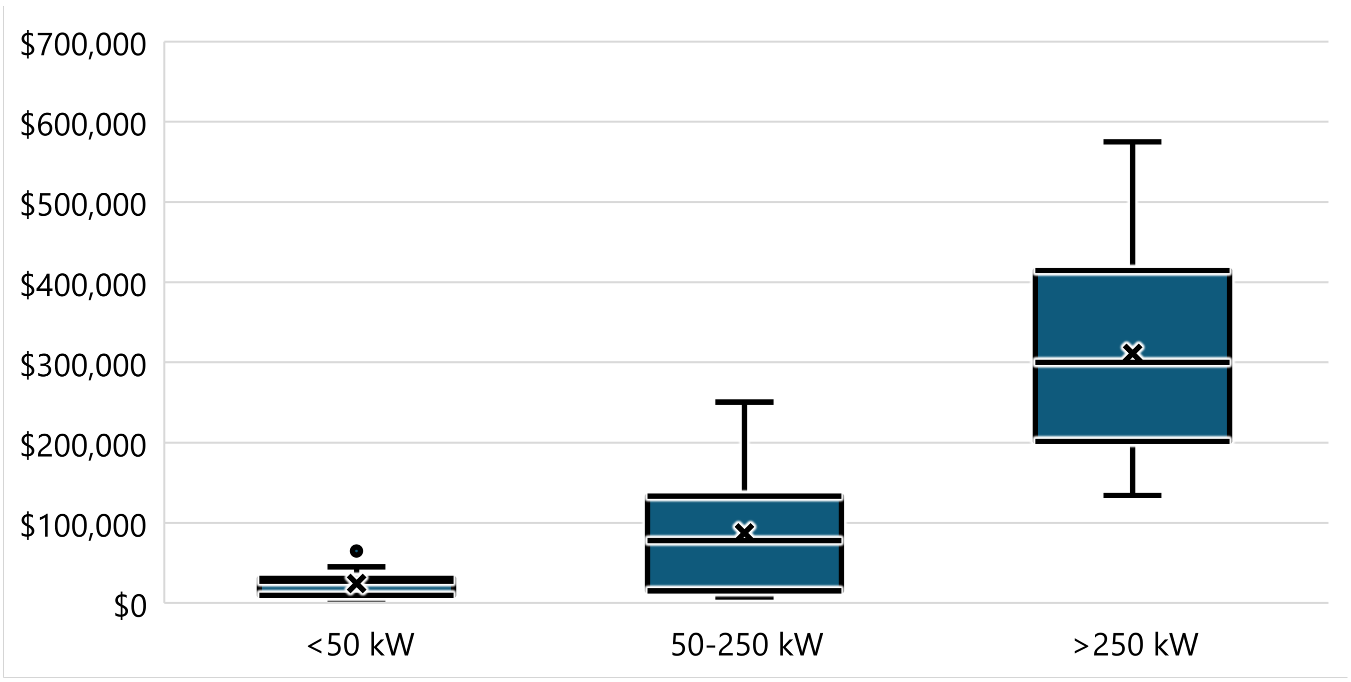


Table 14 outlines the assumptions for charger power, charger cost, and infrastructure upgrade costs. Because sleeper cab tractors are assumed to use publicly accessible retail charging, no infrastructure costs are modelled.

Table 14: Charger Power Ratings and Infrastructure Costs Per Vehicle

Vehicle	Charger Power (kW)	Charger Cost	Infrastructure Upgrade Cost
Class 2b Cargo Van	19	$5,000	$25,000
Class 5 Walk-in Van	19	$5,000	$25,000
Class 6 Bucket Truck	50	$25,000	$44,000
Class 8 Refuse Packer	150 kW for 2 vehicles	$37,500	$44,000
Class 7-8 Day Cab Tractor	150 kW	$75,000	$88,000

Fleets are assumed to amortize their infrastructure costs over a 20 year period with an interest rate of seven percent.

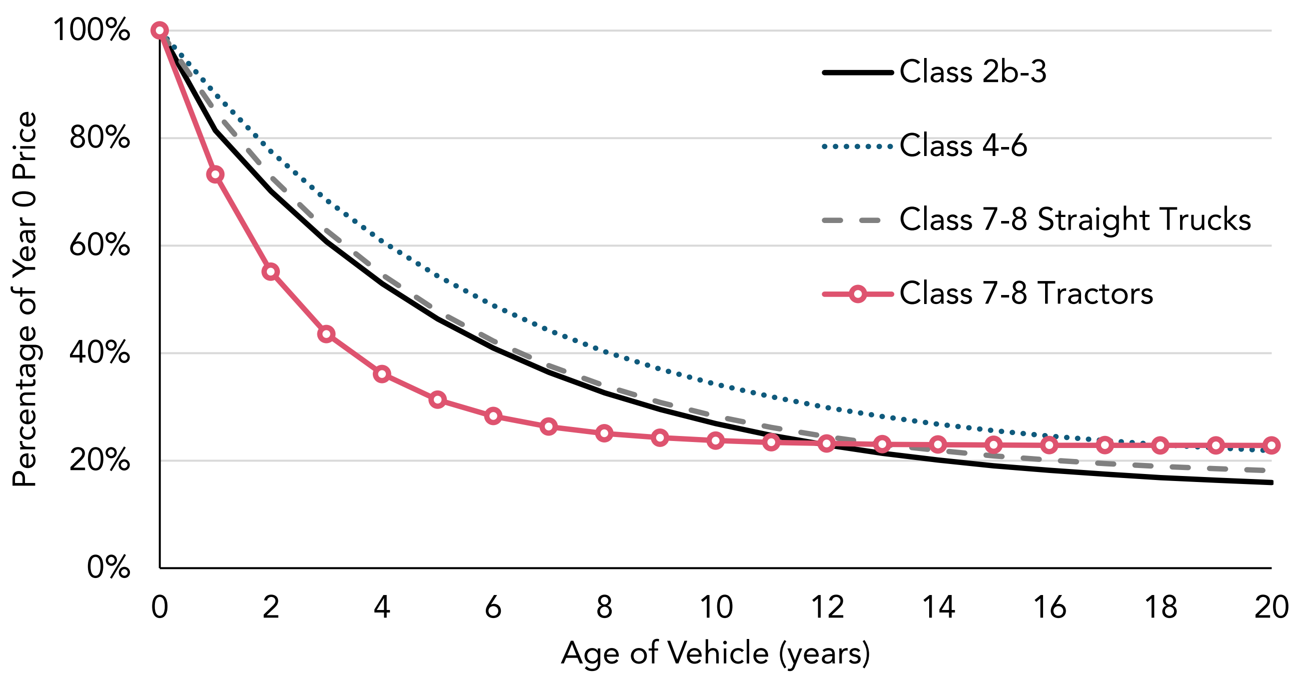
G. Other Assorted Costs

1. Residual Values

The residual value represents the value of the vehicle at the point where the initial purchaser sells the vehicle to another party. This value depends on numerous factors including the type of vehicle, its age, and the vehicle's propulsion technology and it becomes more significant when modeling vehicle replacement cycles that are less than 12 years.

The used vehicle prices for combustion-powered trucks are calculated using online truck marketplaces such as TruckPaper by measuring the price of a given body type over several body types, MYs, and weight classes. The trend is calculated by grouping similar trucks, performing a weighted average, then calculating an exponential curve fit for the different groups. Figure 15 displays the four residual value curves calculated for combustion-powered vehicles over a 20-year period.

Figure 15: Residual Values over Time by Weight Class



ZEVs are assumed to depreciate at the same rate as diesel powered vehicles.

2. Insurance

Fleets purchase insurance policies to protect against financial loss and a variety of unexpected events including damaging other property, damage to the vehicle, medical coverage in the event of an accident, and others. Because ZEVs are anticipated to cost more than their combustion-powered counterparts, vehicle coverage is anticipated to be more costly as well. Currently, this analysis only reflects the physical damage component of insurance costs because that is the only aspect of insurance we expect to change.

Table 15 shows the estimated cost of various insurance coverage components based on several sources staff identified. [41,42,43]

Table 15: Estimated Annual Semi Truck Insurance Policy Costs

Types of Insurance Coverage	Policy Cost
Primary Liability	$6,000
General Liability	$550
Umbrella Policy	$600
Physical Damage	$2,000
Bobtail Insurance	$375
Uninsured/Underinsured Motorist	$75
Occupational Accident	$1,900

Physical damage is the only coverage element that depends on the cost of the vehicle being operated. The other coverage types are not dependent on the cost of the vehicle. For example, if truck were to crash into a signpost, the cost of the truck would not affect the cost of paying to replace the signpost.

Based on the data shown, the "Physical Damage" coverage costs 1/70th of the price of a new semi-truck; for the purpose of this analysis, staff assumes the "Physical Damage" insurance cost is proportional to 1/70th the cost of the vehicle when new. Insurance costs for a vehicle decline over time as the value of the vehicle decreases. Staff assumes the insurance costs decline at the same rate as shown in the "Residual Values" section.

3. Depreciation

Depreciation represents an asset's loss in value over time. This loss can be claimed as an expense and used to decrease a business's tax burden. Vehicles owned and used by businesses can have their depreciation quantified using values provided by the

[41] Forerunner Insurance Group, *What does Average semi truck insurance costs for owner operators?*, 2018 (web link: https://www.forerunnerinsurance.com/what-does-average-semi-truck-insurance-costs-for-owner-operators/, last accessed May 2021).
[42] Commercial Truck Insurance HQ, *Average Semi Truck Insurance Cost*, 2019 (web link: https://www.commercialtruckinsurancehq.com/average-semi-truck-insurance-cost, last accessed May 2021).
[43] Strong Tie Insurance, *Why You Need a Commercial Semi Truck Insurance Coverage*, 2021 (web link: https://www.strongtieinsurance.com/semi-truck-insurance/, last accessed May 2021).

Internal Revenue Service (IRS) Publication 946 regarding property depreciation which may be recovered when itemizing deductions from taxes.[44] These deductions are referred to as the Modified Accelerated Cost Recovery System (MACRS) and are considered to be cost-savings.

The cost-savings from depreciation can be calculated by multiplying the vehicle's purchase price by the MACRS depreciation rate and the corporate tax rate. Per the IRS publication, most trucks follow a five-year depreciation schedule while tractors follow a three-year depreciation schedule. The amount of deprecation year-over-year is shown in Table 16.

Table 16: Depreciation Rate by Age

Age	0	1	2	3	4	5	6+
Truck	20.00%	32.00%	19.20%	11.52%	11.52%	5.76%	0%
Tractor	33.33%	44.45%	14.81%	7.41%	0%	0%	0%

The vehicle value depreciated per year is multiplied by the corporate tax rate to determine the amount of tax savings per year. The California corporate tax rate is 8.84 percent and the federal corporate tax rate is 21 percent.[45,46]

H. Total Cost of Ownership Analysis

Based on the inputs listed above, the total cost of ownership is calculated for each vehicle. The following TCO elements have been lumped together in the below graphs:

- Vehicle Costs
  - Vehicle Price
  - Taxes
  - Financing
- Net fuel costs
  - The cost of the fuel
  - DEF consumption
  - LCFS credit revenue
- Infrastructure
- Other costs, including
  - Maintenance costs
  - Midlife costs

[44] Internal Revenue Service, *Publication 946 (2020), How To Depreciate Property*, 2020 (web link: https://www.irs.gov/pub/irs-pdf/p946.pdf, last accessed May 2021).
[45] Franchise Tax Board, *Business Tax Rates*, 2021 (web link: https://www.ftb.ca.gov/file/business/tax-rates.html, last accessed May 2021).
[46] Internal Revenue Service, *Publication 542, Corporation*, 2021 (web link: https://www.irs.gov/publications/p542, last accessed May 2021).

- Registration fees
- Residual values
- Insurance
- Depreciation

All TCO analyses are performed in 2025, 2030, and 2035 except for the Class 8 sleeper cab tractor. Sleeper cab tractors do not face a requirement in the current Advanced Clean Fleets proposal until 2030 so no 2025 analysis is included.

The cumulative TCO over time has been plotted for the different fuel types to illustrate how the fleet's cashflow may differ. The simple payback period for each year and vehicle has been calculated between the ZEV and diesel models. This is done by dividing the ZEV's additional upfront vehicle and infrastructure costs by the difference in operating costs including fuel costs, LCFS revenue, maintenance, and average midlife costs.

4. 2025 Cargo Van

Figure 16: 2025 Cargo Van Total Cost of Ownership Comparison

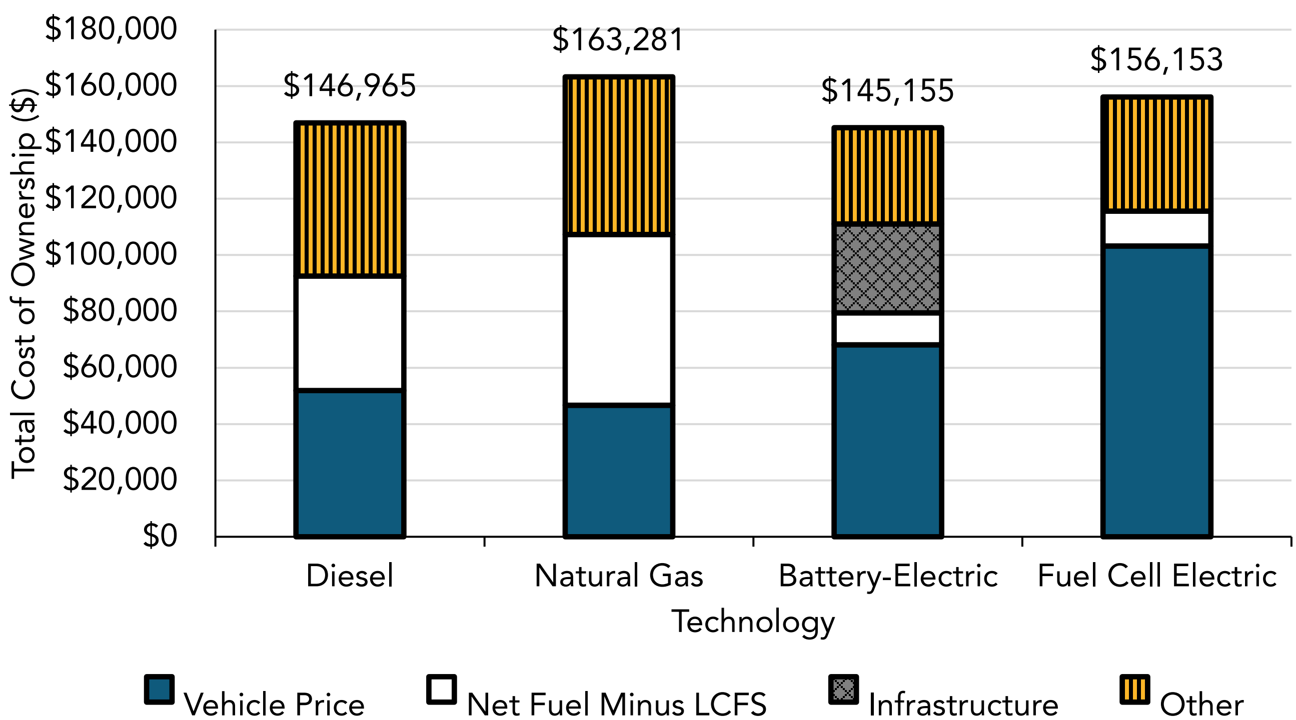


Figure 17: 2025 Cargo Van Cashflow Comparison

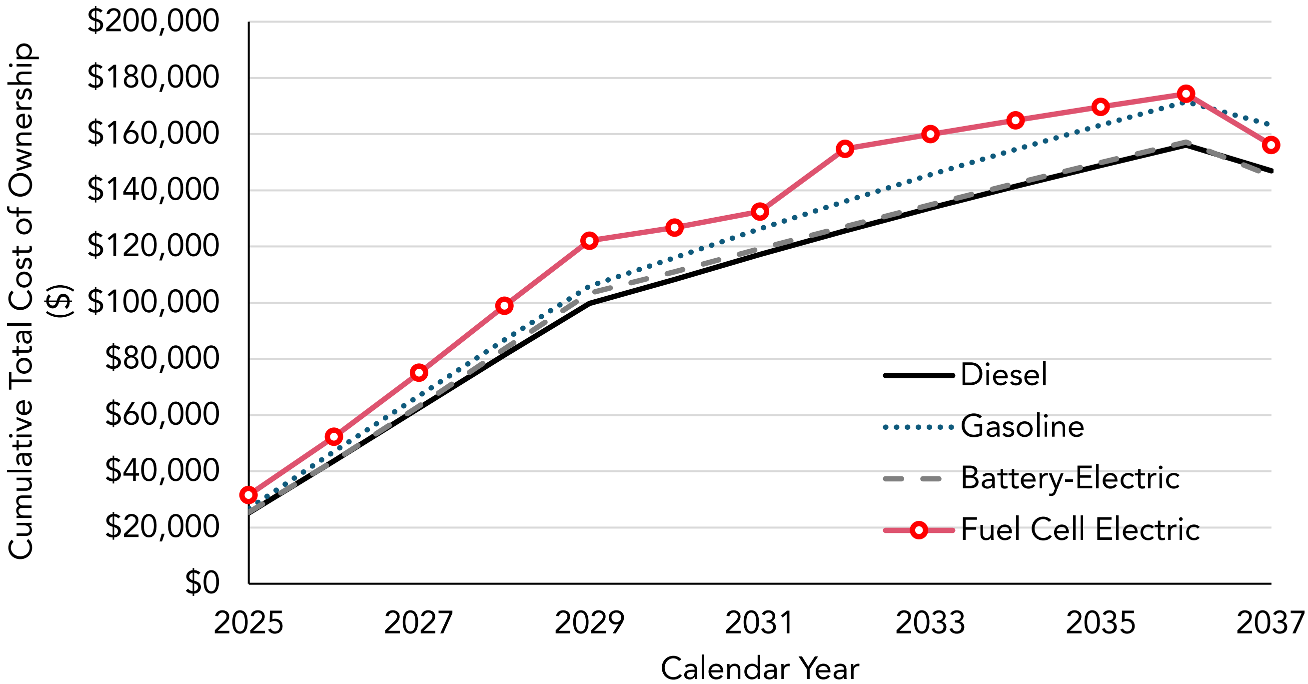


Table 17: 2025 Cargo Van Cost Breakdown

Cost Component	Diesel	Gasoline	Battery-Electric	Fuel Cell Electric
Total Miles	188,600	188,600	188,600	188,600
Operating Years	12	12	12	12
Energy Storage	-	-	80 kWh	10 kWh/10 kg H2
Vehicle Power	-	-	200 kW	200 kW/100 kWFC
Vehicle Price	$39,963	$35,963	$52,447	$79,405
Taxes	$3,197	$2,877	$4,196	$6,352
Financing Costs	$8,770	$7,892	$11,510	$17,426
Total Vehicle Cost	$51,930	$46,732	$68,152	$103,183
Fuel Economy	19 mpg	13.8 mpg	1.89 mi./kWh	44.6 mi./kg
Unit Fuel Cost	$4.03/gal	$4.42/gal	$0.25/kWh	$5.63/kg
Fuel Cost	$40,068	$60,522	$24,838	$23,801
DEF Consumption	$557	$0	$0	$0
LCFS Revenue	$0	$0	-$13,495	-$11,361
Total Fuel Cost	$40,625	$60,522	$11,342	$12,440
Maintenance Cost	$63,563	$63,563	$47,672	$47,672
Midlife Costs	$0	$0	$0	$17,000
Registration Fee	$8,542	$8,387	$9,720	$11,015
Depreciation	-$11,989	-$10,789	-$15,734	-$23,821
Residual Value	-$9,145	-$8,230	-$12,002	-$18,171
Insurance Costs	$3,440	$3,096	$4,515	$6,835
Total Other Costs	$54,410	$56,027	$34,171	$40,530
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$0	$28,318	$0
Total Infrastructure Cost	$0	$0	$31,489	$0
TOTAL	$146,965	$163,281	$145,155	$156,153
Payback Period vs Diesel (yr)	-	-	8.0	10.4

5. 2030 Cargo Van

Figure 18: 2030 Cargo Van Total Cost of Ownership Comparison

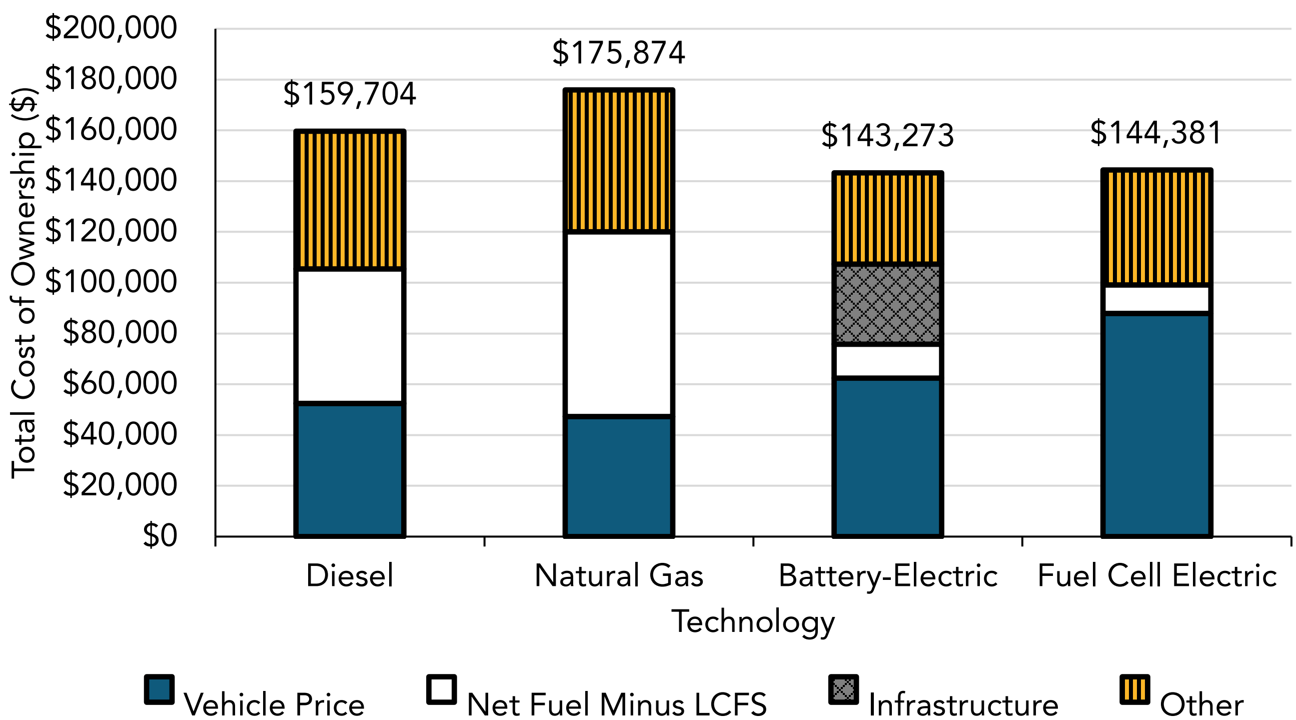


Figure 19: 2030 Cargo Van Cashflow Comparison

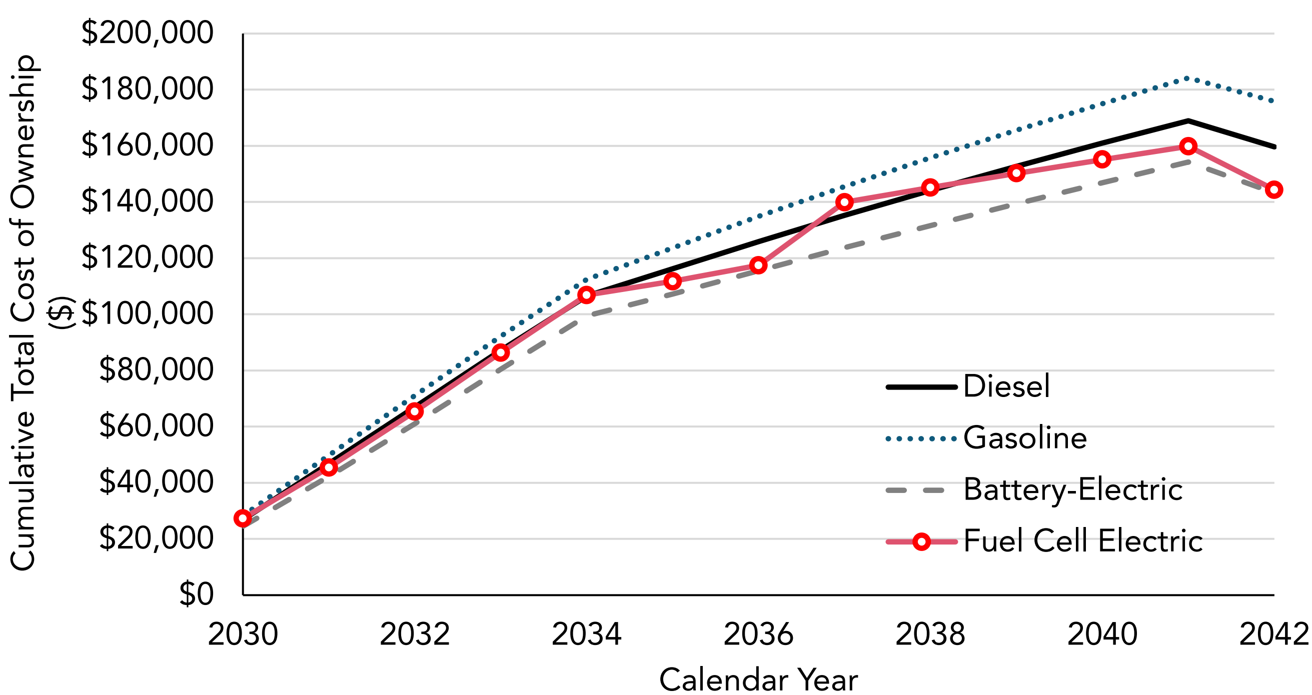


Table 18: 2030 Cargo Van Cost Breakdown

Cost Component	Diesel	Gasoline	Battery-Electric	Fuel Cell Electric
Total Miles	188,600	188,600	188,600	188,600
Operating Years	12	12	12	12
Energy Storage	-	-	80 kWh	10 kWh/10 kg H2
Vehicle Power	-	-	200 kW	200 kW/100 kWFC
Vehicle Price	$40,364	$36,364	$48,001	$67,592
Taxes	$3,229	$2,909	$3,840	$5,407
Financing Costs	$8,858	$7,980	$10,534	$14,833
Total Vehicle Cost	$52,451	$47,253	$62,375	$87,833
Fuel Economy	15.3 mpg	11.7 mpg	2 mi./kWh	47.2 mi./kg
Unit Fuel Cost	$4.23/gal	$4.53/gal	$0.25/kWh	$5/kg
Fuel Cost	$52,312	$72,756	$23,889	$19,961
DEF Consumption	$693	$0	$0	$0
LCFS Revenue	$0	$0	-$10,448	-$8,717
Total Fuel Cost	$53,005	$72,756	$13,441	$11,245
Maintenance Cost	$63,563	$63,563	$47,672	$47,672
Midlife Costs	$0	$0	$0	$17,000
Registration Fee	$8,557	$8,402	$9,548	$10,558
Depreciation	-$12,109	-$10,909	-$14,400	-$20,278
Residual Value	-$9,237	-$8,321	-$10,984	-$15,467
Insurance Costs	$3,475	$3,130	$4,132	$5,818
Total Other Costs	$54,248	$55,865	$35,968	$45,303
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$0	$28,318	$0
Total Infrastructure Cost	$0	$0	$31,489	$0
TOTAL	$159,704	$175,874	$143,273	$144,381
Payback Period vs Diesel (yr)	-	-	5.7	4.8

6. 2035 Cargo Van

Figure 20: 2035 Cargo Van Total Cost of Ownership Comparison

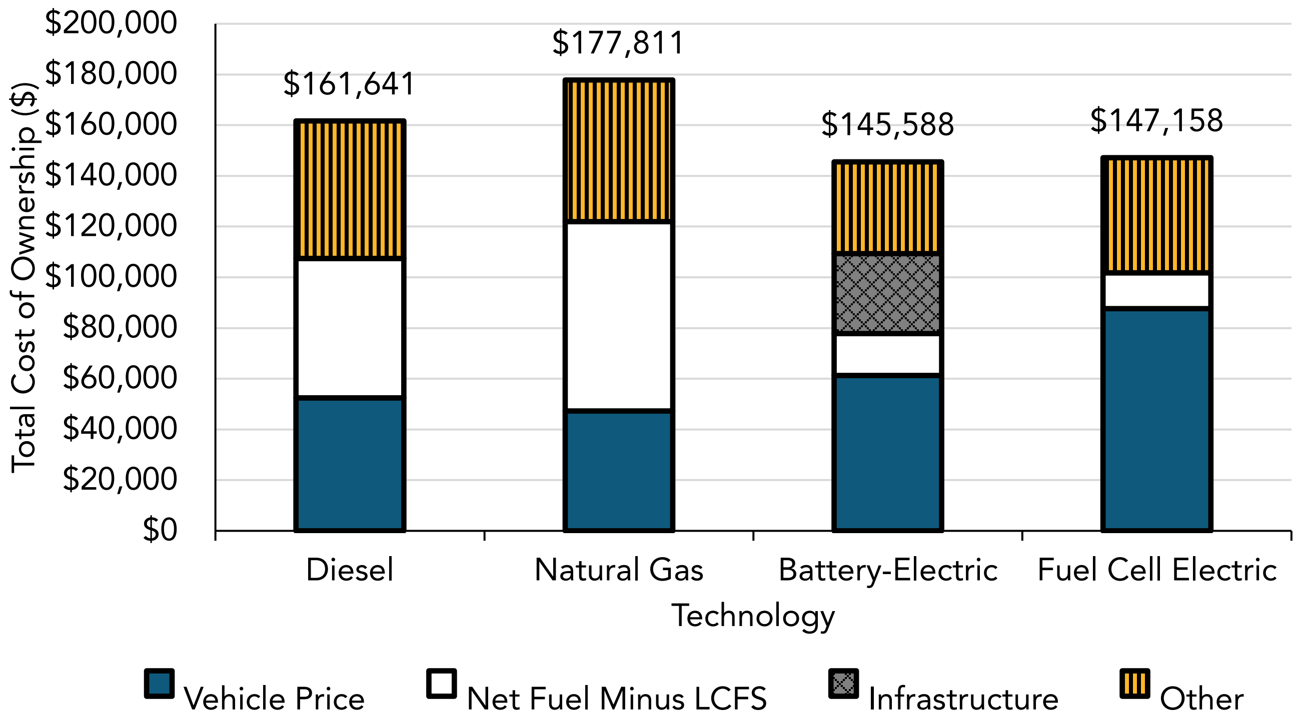


Figure 21: 2035 Cargo Van Cashflow Comparison

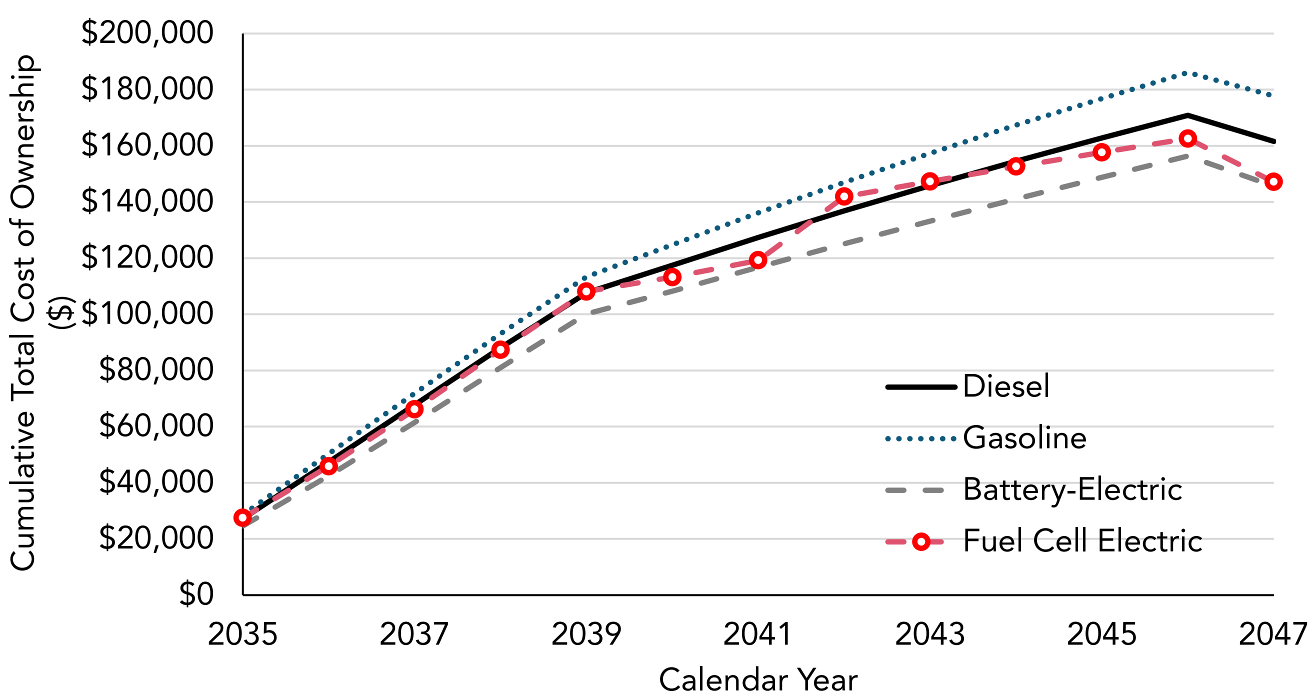


Table 19: 2035 Cargo Van Cost Breakdown

Cost Component	Diesel	Gasoline	Battery-Electric	Fuel Cell Electric
Total Miles	188,600	188,600	188,600	188,600
Operating Years	12	12	12	12
Energy Storage	-	-	80 kWh	10 kWh/10 kg H2
Vehicle Power	-	-	200 kW	200 kW/100 kWFC
Vehicle Price	$40,364	$36,364	$47,174	$67,489
Taxes	$3,229	$2,909	$3,774	$5,399
Financing Costs	$8,858	$7,980	$10,352	$14,811
Total Vehicle Cost	$52,451	$47,253	$61,300	$87,698
Fuel Economy	15.3 mpg	11.7 mpg	2 mi./kWh	47.2 mi./kg
Unit Fuel Cost	$4.39/gal	$4.65/gal	$0.25/kWh	$5/kg
Fuel Cost	$54,249	$74,693	$23,505	$19,961
DEF Consumption	$693	$0	$0	$0
LCFS Revenue	$0	$0	-$7,009	-$5,847
Total Fuel Cost	$54,942	$74,693	$16,497	$14,114
Maintenance Cost	$63,563	$63,563	$47,672	$47,672
Midlife Costs	$0	$0	$0	$17,000
Registration Fee	$8,557	$8,402	$9,516	$10,554
Depreciation	-$12,109	-$10,909	-$14,152	-$20,247
Residual Value	-$9,237	-$8,321	-$10,795	-$15,444
Insurance Costs	$3,475	$3,130	$4,061	$5,809
Total Other Costs	$54,248	$55,865	$36,302	$45,345
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$0	$28,318	$0
Total Infrastructure Cost	$0	$0	$31,489	$0
TOTAL	$161,641	$177,811	$145,588	$147,158
Payback Period vs Diesel (yr)	-	-	5.6	4.7

7. 2025 Walk-in Van

Figure 22: 2025 Walk-in Van Total Cost of Ownership Comparison

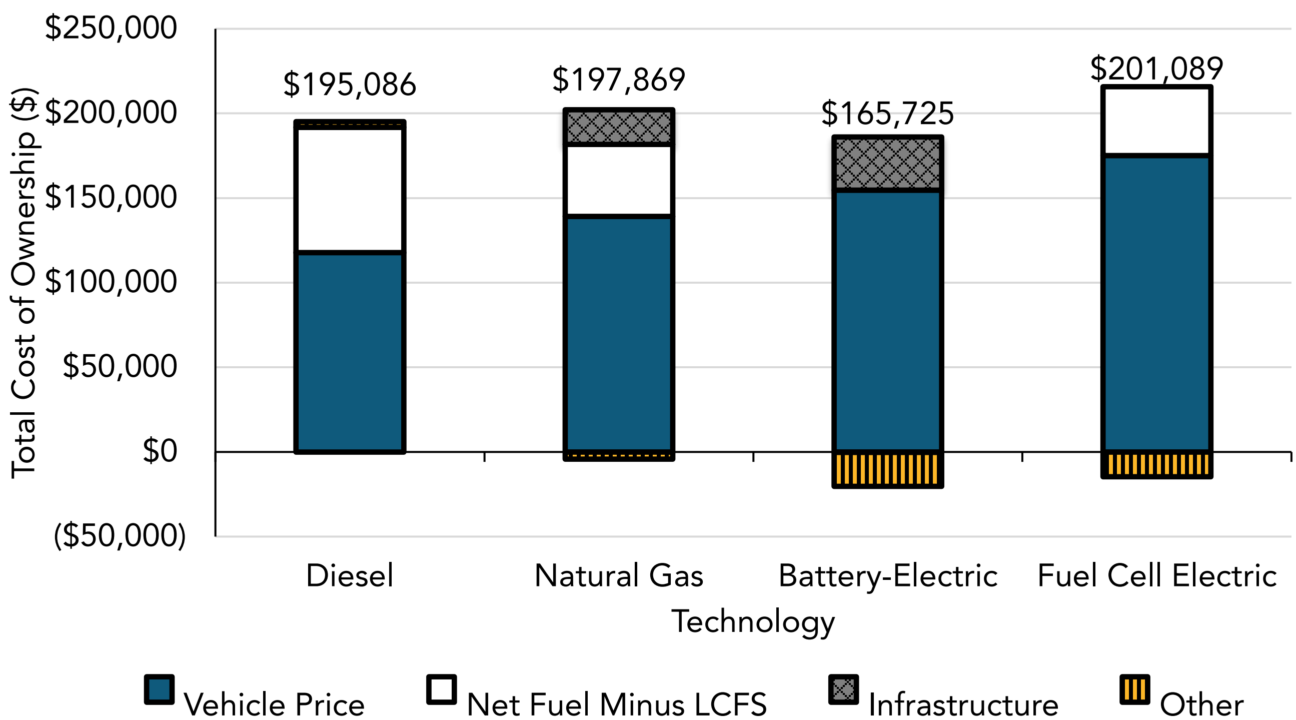


Figure 23: 2025 Walk-in Van Cashflow Comparison

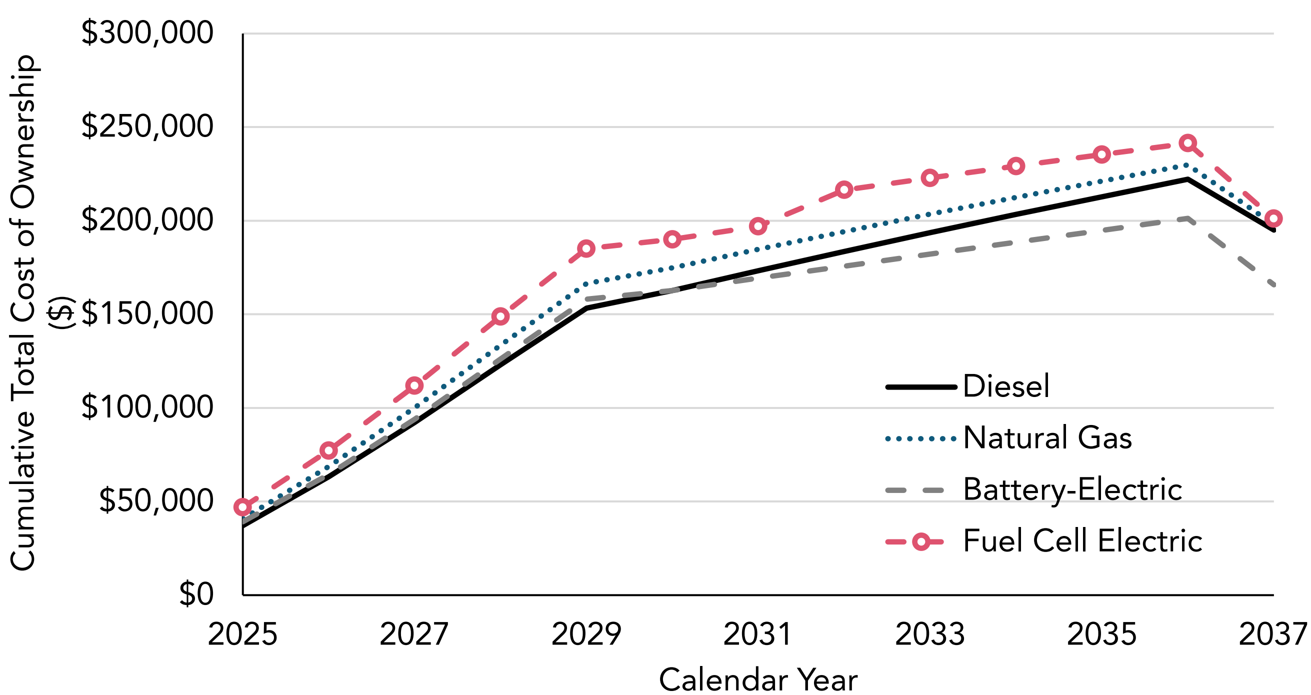


Table 20: 2025 Walk-in Van Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	163,979	163,979	163,979	163,979
Operating Years	12	12	12	12
Energy Storage	-	-	140 kWh	10 kWh/20 kg H2
Vehicle Power	-	-	150 kW	150 kW/75 kWFC
Vehicle Price	$90,709	$107,028	$118,971	$134,822
Taxes	$7,257	$8,562	$9,518	$10,786
Financing Costs	$19,906	$23,488	$26,108	$29,587
Total Vehicle Cost	$117,872	$139,078	$154,597	$175,194
Fuel Economy	9.1 mpg	7.6 mpg	1.13 mi./kWh	16.1 mi./kg
Unit Fuel Cost	$4.05/gal	$1.98/gal	$0.22/kWh	$5.54/kg
Fuel Cost	$72,923	$42,663	$32,510	$56,598
DEF Consumption	$1,009	$0	$0	$0
LCFS Revenue	$0	$0	-$32,764	-$16,019
Total Fuel Cost	$73,932	$42,663	-$253	$40,579
Maintenance Cost	$34,444	$34,444	$25,833	$25,833
Midlife Costs	$0	$0	$0	$12,750
Registration Fee	$14,272	$14,903	$13,649	$14,262
Depreciation	-$27,213	-$32,108	-$35,691	-$40,446
Residual Value	-$27,108	-$31,985	-$35,554	-$40,292
Insurance Costs	$8,886	$10,485	$11,655	$13,208
Total Other Costs	$3,282	-$4,261	-$20,108	-$14,684
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$20,389	$28,318	$0
Total Infrastructure Cost	$0	$20,389	$31,489	$0
TOTAL	$195,086	$197,869	$165,725	$201,089
Payback Period vs Diesel (yr)	-	-	8.1	21.4

8. 2030 Walk-in Van

Figure 24: 2030 Walk-in Van Total Cost of Ownership Comparison

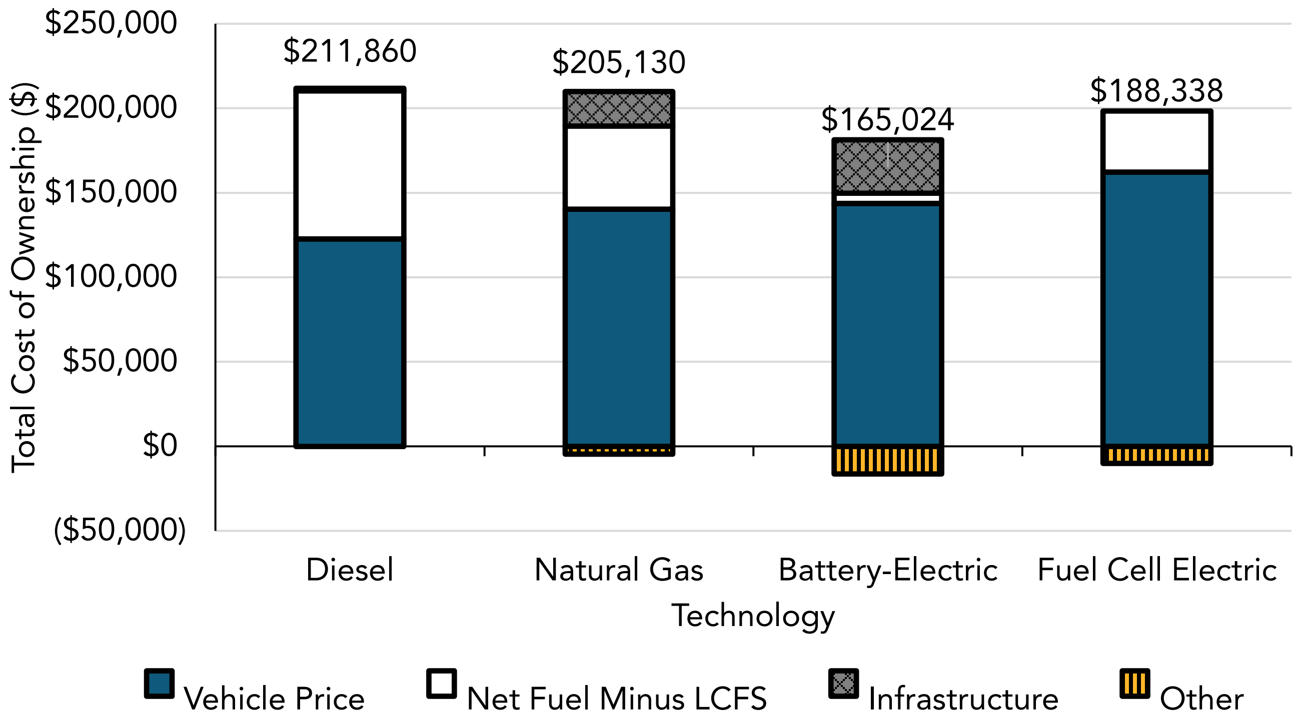


Figure 25: 2030 Walk-in Van Cashflow Comparison

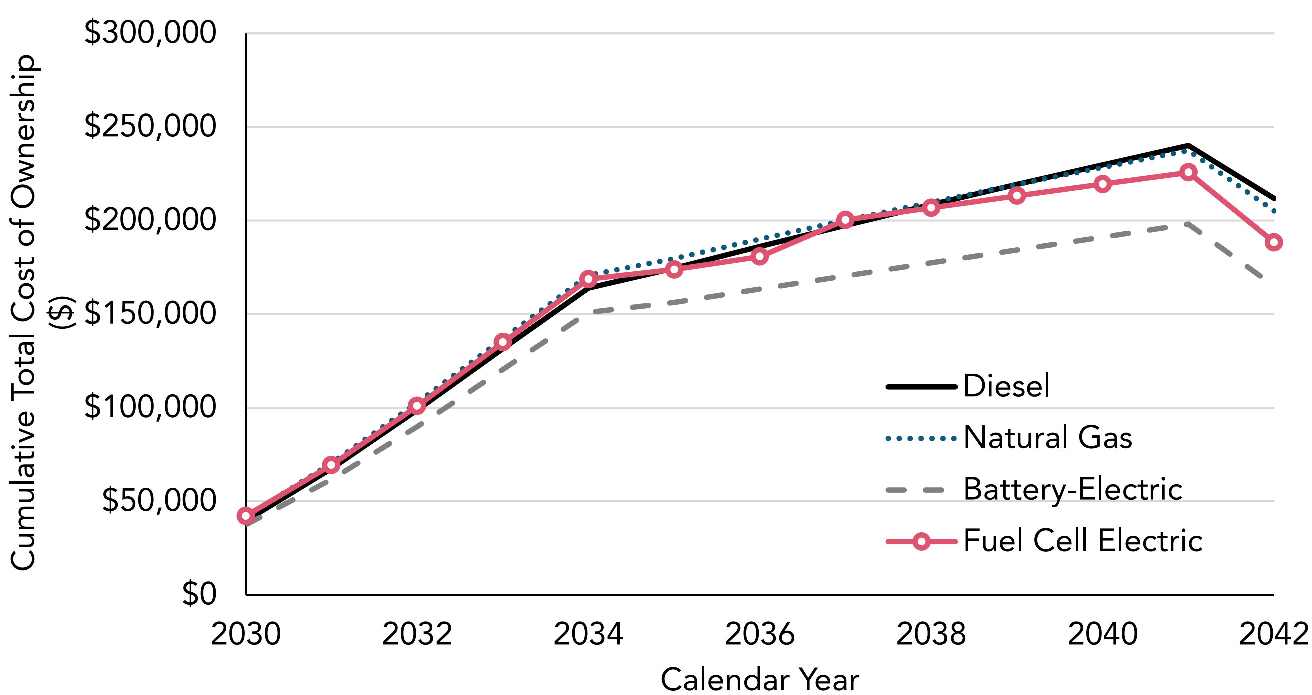


Table 21: 2030 Walk-in Van Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	163,979	163,979	163,979	163,979
Operating Years	12	12	12	12
Energy Storage	-	-	140 kWh	10 kWh/20 kg H2
Vehicle Power	-	-	150 kW	150 kW/75 kWFC
Vehicle Price	$94,403	$107,983	$110,644	$124,802
Taxes	$7,552	$8,639	$8,851	$9,984
Financing Costs	$20,717	$23,697	$24,281	$27,388
Total Vehicle Cost	$122,672	$140,319	$143,776	$162,175
Fuel Economy	8.1 mpg	6.5 mpg	1.2 mi./kWh	17 mi./kg
Average Unit Fuel Cost	$4.25/gal	$1.95/gal	$0.23/kWh	$5/kg
Fuel Cost	$86,473	$49,125	$31,145	$48,204
DEF Consumption	$1,141	$0	$0	$0
LCFS Revenue	$0	$0	-$25,128	-$11,987
Total Fuel Cost	$87,614	$49,125	$6,017	$36,217
Maintenance Cost	$34,444	$34,444	$25,833	$25,833
Midlife Costs	$0	$0	$0	$12,750
Registration Fee	$14,415	$14,940	$13,327	$13,875
Depreciation	-$28,321	-$32,395	-$33,193	-$37,441
Residual Value	-$28,212	-$32,271	-$33,066	-$37,297
Insurance Costs	$9,248	$10,579	$10,839	$12,226
Total Other Costs	$1,575	-$4,702	-$16,259	-$10,053
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$20,389	$28,318	$0
Total Infrastructure Cost	$0	$20,389	$31,489	$0
TOTAL	$211,860	$205,130	$165,024	$188,338
Payback Period vs Diesel (yr)	-	-	5.7	6.7

9. 2035 Walk-in Van

Figure 26: 2035 Walk-in Van Total Cost of Ownership Comparison

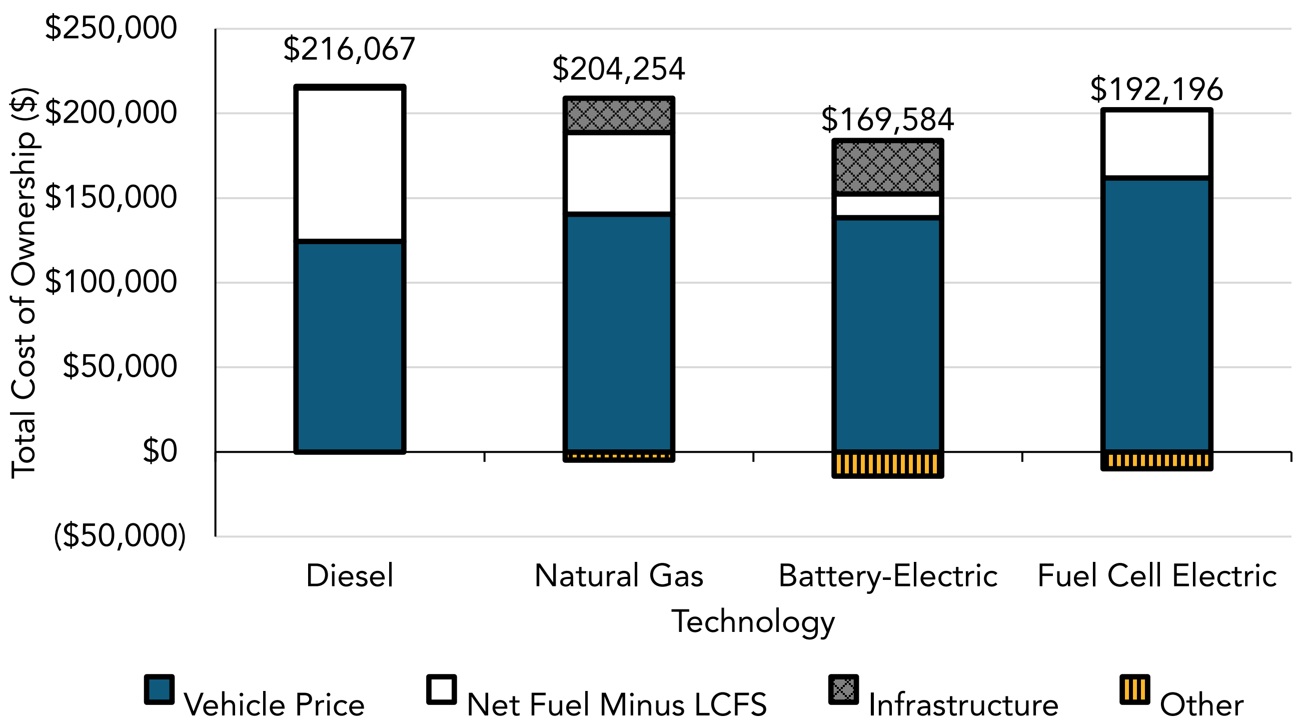


Figure 27: 2035 Walk-in Van Cashflow Comparison

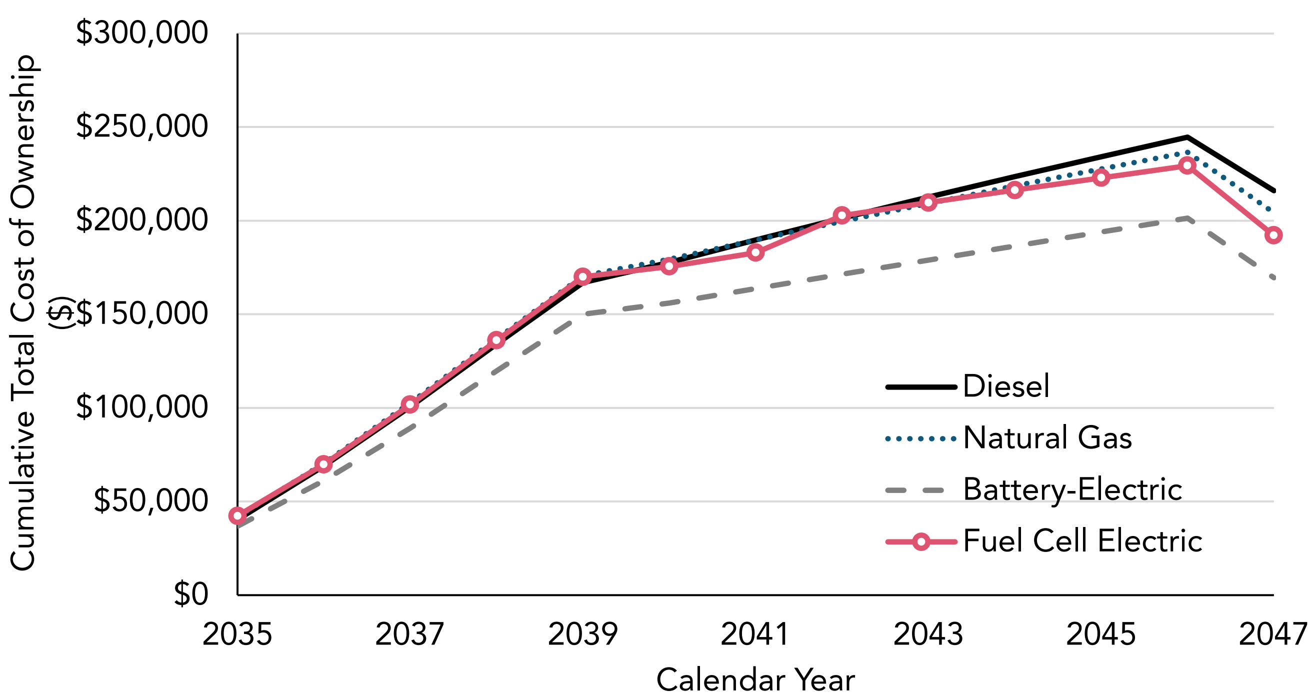


Table 22: 2035 Walk-in Van Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	163,979	163,979	163,979	163,979
Operating Years	12	12	12	12
Energy Storage	-	-	140 kWh	10 kWh/20 kg H2
Vehicle Power	-	-	150 kW	150 kW/75 kWFC
Vehicle Price	$95,703	$108,177	$106,486	$124,505
Taxes	$7,656	$8,654	$8,519	$9,960
Financing Costs	$21,002	$23,740	$23,369	$27,323
Total Vehicle Cost	$124,362	$140,571	$138,373	$161,789
Fuel Economy	8.1 mpg	6.5 mpg	1.2 mi./kWh	17 mi./kg
Average Unit Fuel Cost	$4.4/gal	$1.91/gal	$0.22/kWh	$5/kg
Fuel Cost	$89,591	$48,086	$30,579	$48,204
DEF Consumption	$1,141	$0	$0	$0
LCFS Revenue	$0	$0	-$16,520	-$7,881
Total Fuel Cost	$90,732	$48,086	$14,059	$40,324
Maintenance Cost	$34,444	$34,444	$25,833	$25,833
Midlife Costs	$0	$0	$0	$12,750
Registration Fee	$14,465	$14,948	$13,166	$13,863
Depreciation	-$28,711	-$32,453	-$31,946	-$37,352
Residual Value	-$28,601	-$32,329	-$31,823	-$37,209
Insurance Costs	$9,376	$10,598	$10,432	$12,197
Total Other Costs	$974	-$4,792	-$14,337	-$9,916
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$20,389	$28,318	$0
Total Infrastructure Cost	$0	$20,389	$31,489	$0
TOTAL	$216,067	$204,254	$169,584	$192,196
Payback Period vs Diesel (yr)	-	-	5.0	6.2

10. 2025 Bucket Truck

Figure 28: 2025 Bucket Truck Total Cost of Ownership Comparison

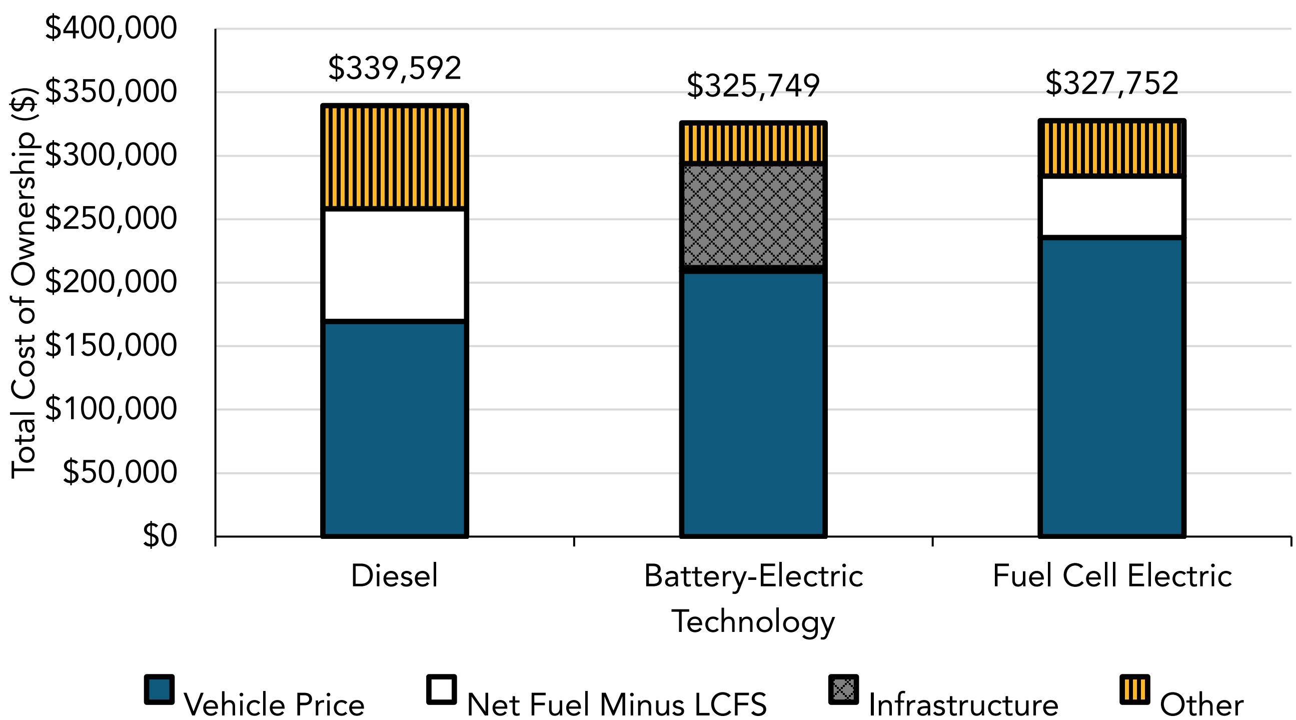


Figure 29: 2025 Bucket Truck Cashflow Comparison

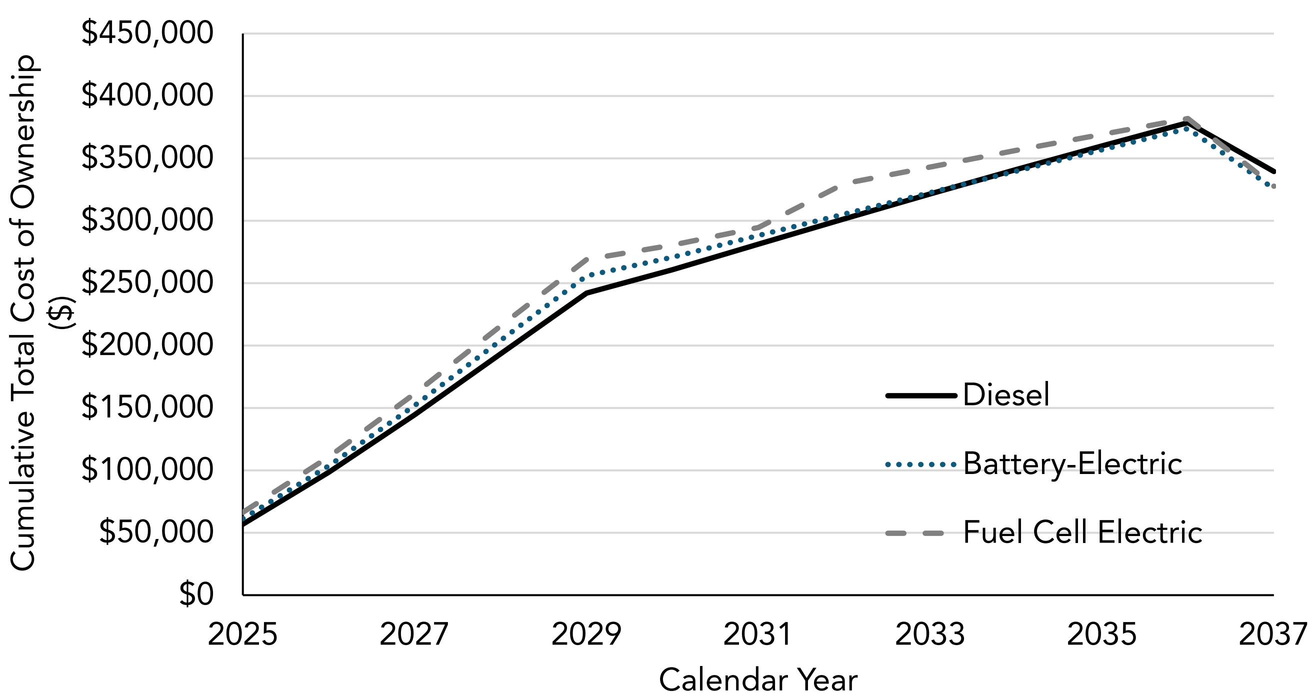


Table 23: 2025 Bucket Truck Cost Breakdown

Cost Component	Diesel	Battery-Electric	Fuel Cell Electric
Total Miles	185,153	185,153	185,153
Operating Years	12	12	12
Energy Storage	-	200 kWh	10 kWh/20 kg H2
Vehicle Power	-	250 kW	250 kW/125 kWFC
Vehicle Price	$130,491	$160,936	$181,282
Taxes	$10,439	$12,875	$14,503
Financing Costs	$28,637	$35,318	$39,783
Total Vehicle Cost	$169,567	$209,128	$235,567
Fuel Economy	8.6 mpg	0.76 mi./kWh	15.1 mi./kg
Average Unit Fuel Cost	$4.06/gal	$0.24/kWh	$5.5/kg
Fuel Cost	$87,571	$57,929	$67,626
DEF Consumption	$1,209	$0	$0
LCFS Revenue	$0	-$55,184	-$19,154
Total Fuel Cost	$88,780	$2,745	$48,472
Maintenance Cost	$129,607	$97,205	$97,205
Midlife Costs	$0	$0	$21,250
Registration Fee	$16,999	$15,272	$16,059
Depreciation	-$39,147	-$48,281	-$54,385
Residual Value	-$38,997	-$48,096	-$54,176
Insurance Costs	$12,784	$15,766	$17,760
Total Other Costs	$81,245	$31,867	$43,713
EVSE Cost	$0	$32,169	$0
Infrastructure Upgrade Cost	$0	$49,839	$0
Total Infrastructure Cost	$0	$82,009	$0
TOTAL	$339,592	$325,749	$327,752
Payback Period vs Diesel (yr)	-	11.2	14.0

11. 2030 Bucket Truck

Figure 30: 2030 Bucket Truck Total Cost of Ownership Comparison

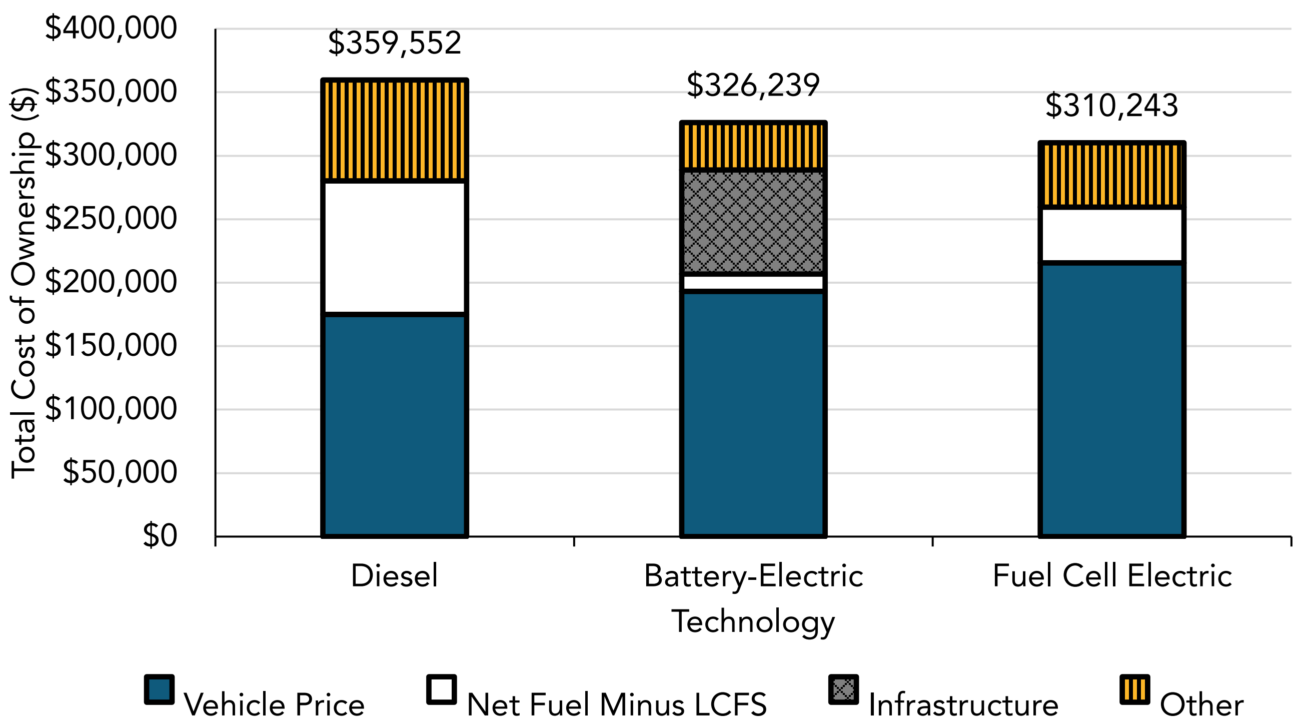


Figure 31: 2030 Bucket Truck Cashflow Comparison

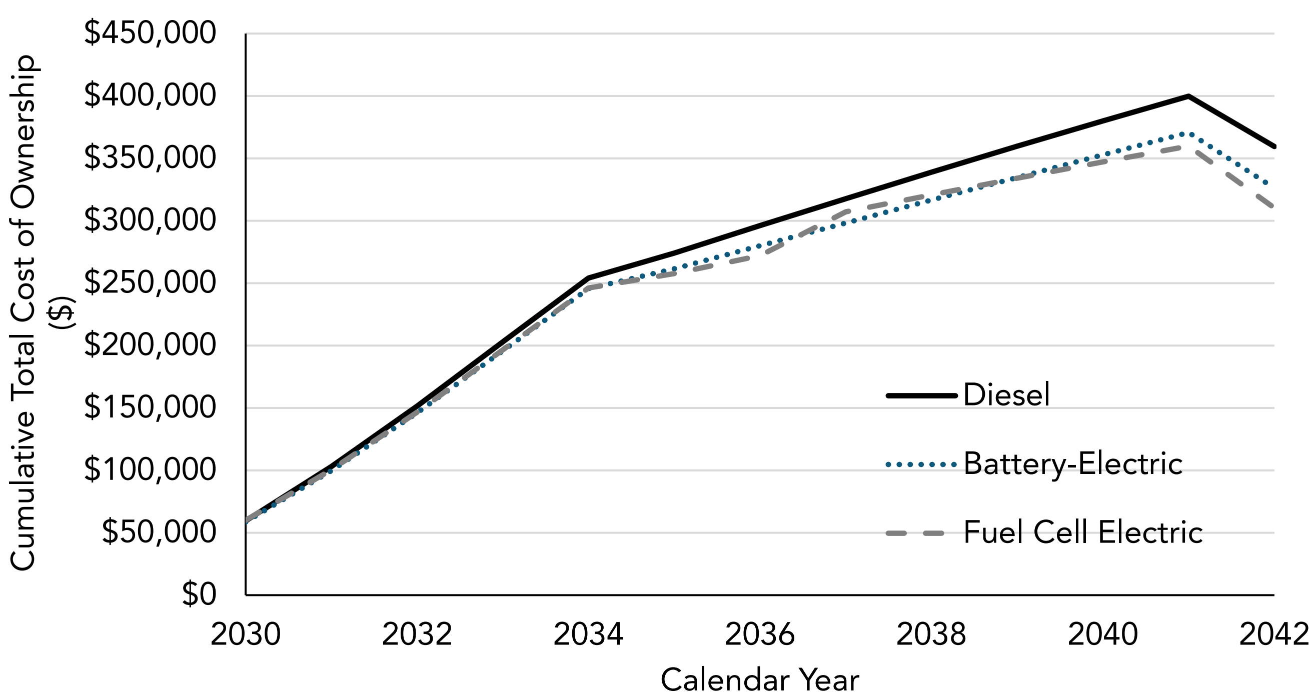


Table 24: 2030 Bucket Truck Cost Breakdown

Cost Component	Diesel	Battery-Electric	Fuel Cell Electric
Total Miles	185,153	185,153	185,153
Operating Years	12	12	12
Energy Storage	-	200 kWh	10 kWh/20 kg H2
Vehicle Power	-	250 kW	250 kW/125 kWFC
Vehicle Price	$134,725	$148,770	$165,909
Taxes	$10,778	$11,902	$13,273
Financing Costs	$29,566	$32,648	$36,409
Total Vehicle Cost	$175,069	$193,319	$215,591
Fuel Economy	7.6 mpg	0.8 mi./kWh	15.9 mi./kg
Average Unit Fuel Cost	$4.25/gal	$0.24/kWh	$5/kg
Fuel Cost	$103,828	$55,380	$58,071
DEF Consumption	$1,367	$0	$0
LCFS Revenue	$0	-$41,960	-$14,237
Total Fuel Cost	$105,195	$13,420	$43,834
Maintenance Cost	$129,607	$97,205	$97,205
Midlife Costs	$0	$0	$21,250
Registration Fee	$17,162	$14,802	$15,465
Depreciation	-$40,418	-$44,631	-$49,773
Residual Value	-$40,263	-$44,460	-$49,582
Insurance Costs	$13,199	$14,574	$16,254
Total Other Costs	$79,288	$37,491	$50,818
EVSE Cost	$0	$32,169	$0
Infrastructure Upgrade Cost	$0	$49,839	$0
Total Infrastructure Cost	$0	$82,009	$0
TOTAL	$359,552	$326,239	$310,243
Payback Period vs Diesel (yr)	-	8.7	5.0

12. 2035 Bucket Truck

Figure 32: 2035 Bucket Truck Total Cost of Ownership Comparison

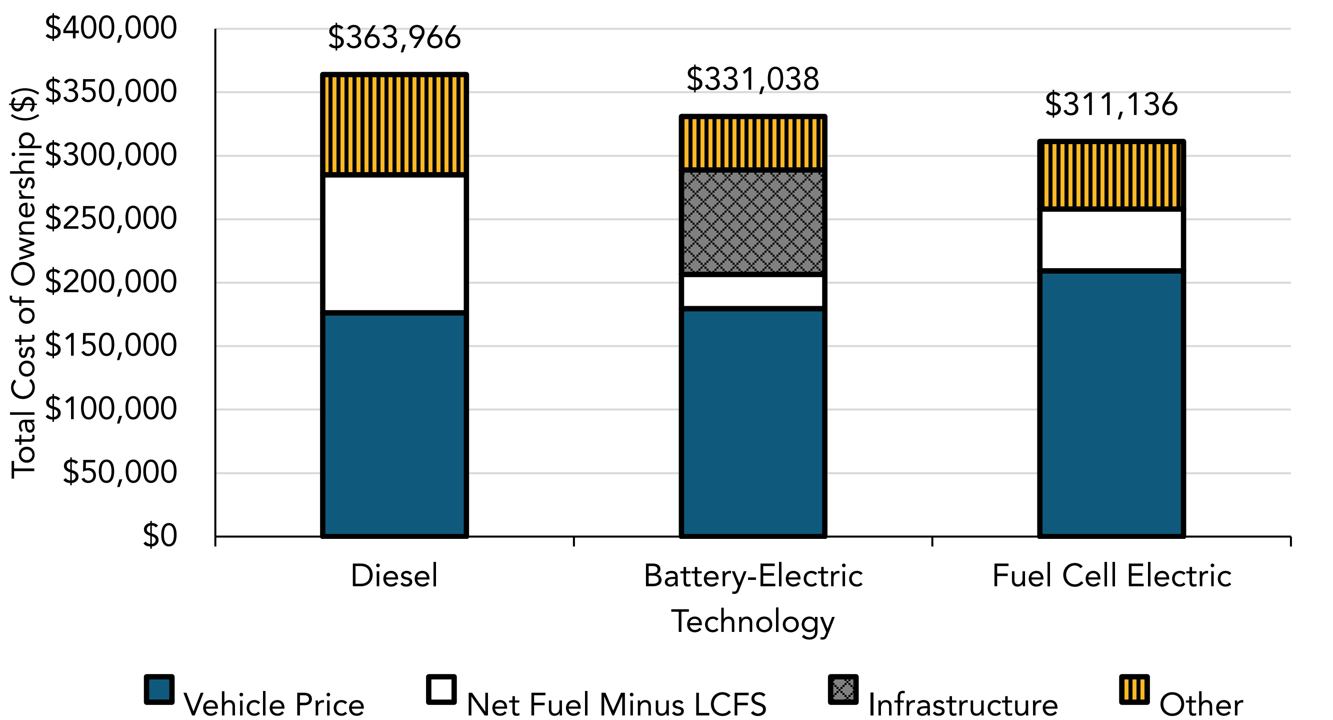


Figure 33: 2035 Bucket Truck Cashflow Comparison

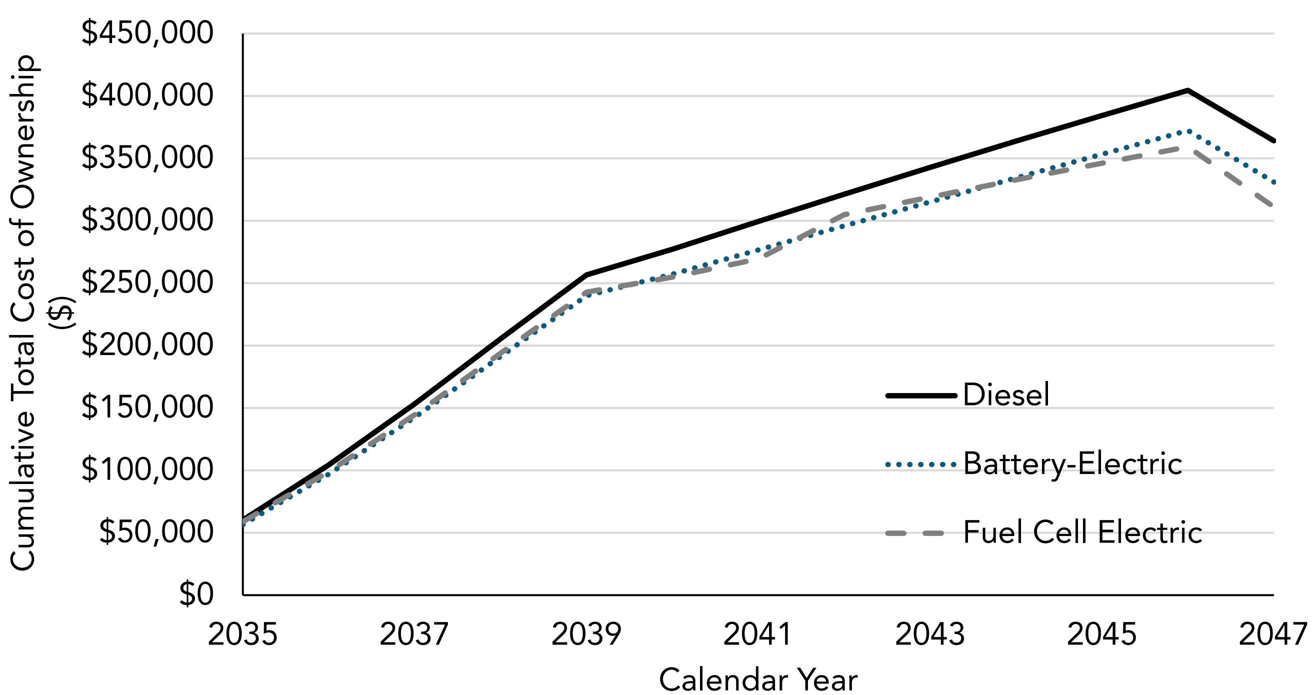


Table 25: 2035 Bucket Truck Cost Breakdown

Cost Component	Diesel	Battery-Electric	Fuel Cell Electric
Total Miles	185,153	185,153	185,153
Operating Years	12	12	12
Energy Storage	-	200 kWh	10 kWh/20 kg H2
Vehicle Power	-	250 kW	250 kW/125 kWFC
Vehicle Price	$135,585	$138,243	$161,025
Taxes	$10,847	$11,059	$12,882
Financing Costs	$29,755	$30,338	$35,338
Total Vehicle Cost	$176,186	$179,640	$209,245
Fuel Economy	7.6 mpg	0.8 mi./kWh	15.9 mi./kg
Average Unit Fuel Cost	$4.4/gal	$0.23/kWh	$5/kg
Fuel Cost	$107,522	$54,310	$58,071
DEF Consumption	$1,367	$0	$0
LCFS Revenue	$0	-$27,277	-$9,255
Total Fuel Cost	$108,889	$27,033	$48,816
Maintenance Cost	$129,607	$97,205	$97,205
Midlife Costs	$0	$0	$21,250
Registration Fee	$17,196	$14,395	$15,276
Depreciation	-$40,676	-$41,473	-$48,308
Residual Value	-$40,520	-$41,314	-$48,123
Insurance Costs	$13,283	$13,543	$15,775
Total Other Costs	$78,890	$42,356	$53,076
EVSE Cost	$0	$32,169	$0
Infrastructure Upgrade Cost	$0	$49,839	$0
Total Infrastructure Cost	$0	$82,009	$0
TOTAL	$363,966	$331,038	$311,136
Payback Period vs Diesel (yr)	-	7.8	4.0

13. 2025 Refuse Packer

Figure 34: 2025 Refuse Packer Total Cost of Ownership Comparison

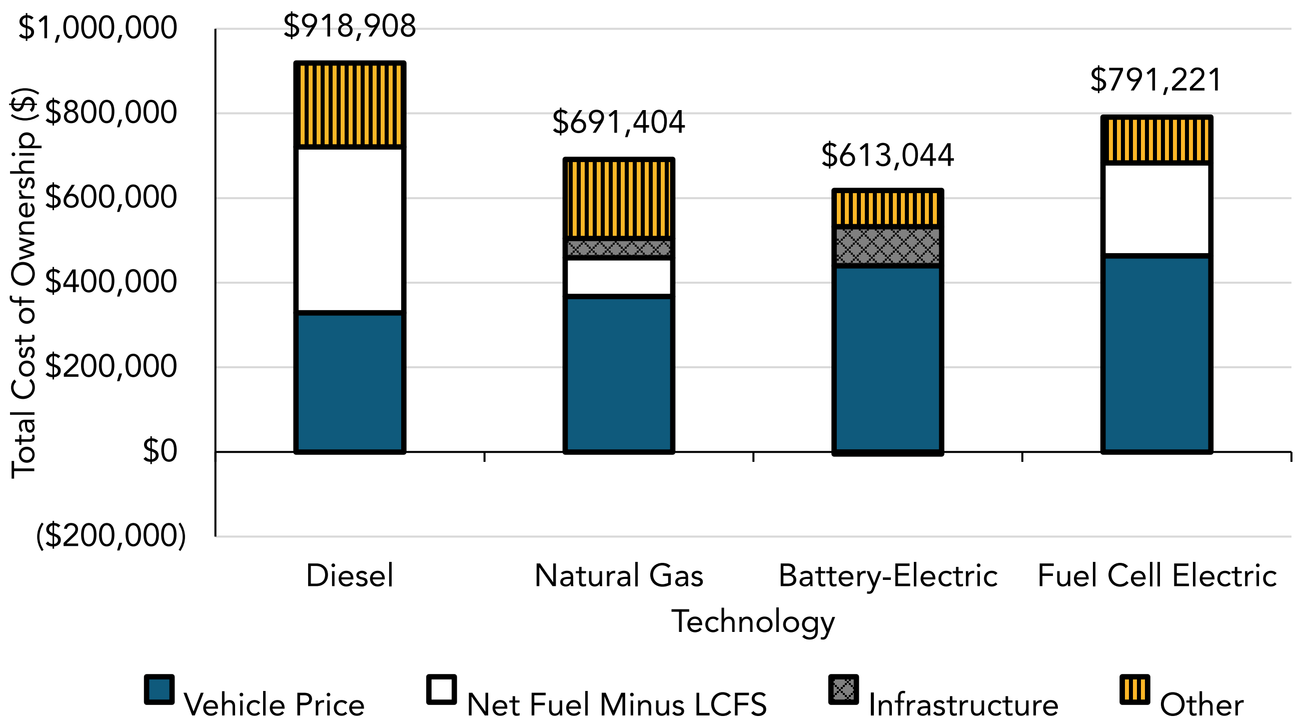


Figure 35: 2025 Refuse Packer Cashflow Comparison

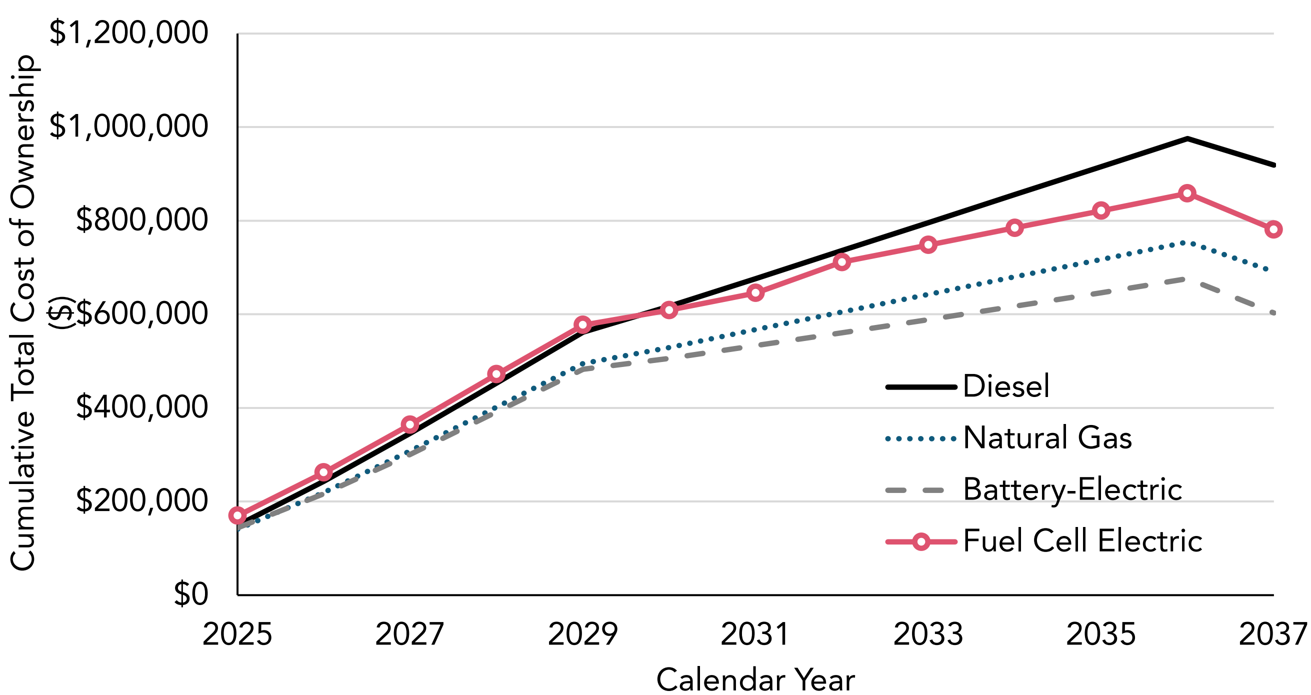


Table 26: 2025 Refuse Packer Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	290,640	290,640	290,640	290,640
Operating Years	12	12	12	12
Energy Storage	-	-	410 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$231,783	$258,823	$299,932	$316,578
Taxes	$46,357	$51,765	$59,986	$63,316
Financing Costs	$50,866	$56,800	$65,821	$69,474
Total Vehicle Cost	$329,005	$367,387	$425,739	$449,368
Fuel Economy	3.1 mpg	6.3 mpg	0.38 mi./kWh	5.2 mi./kg
Average Unit Fuel Cost	$4.06/gal	$1.98/gal	$0.22/kWh	$5.48/kg
Fuel Cost	$386,373	$91,777	$167,757	$305,878
DEF Consumption	$5,324	$0	$0	$0
LCFS Revenue	$0	$0	-$172,447	-$86,513
Total Fuel Cost	$391,697	$91,777	-$4,690	$219,365
Maintenance Cost	$274,213	$274,213	$205,660	$205,660
Midlife Costs	$0	$0	$0	$29,750
Registration Fee	$29,604	$30,650	$20,648	$21,292
Depreciation	-$69,535	-$77,647	-$89,979	-$94,973
Residual Value	-$56,674	-$63,285	-$73,337	-$77,407
Insurance Costs	$20,597	$23,000	$26,653	$28,132
Total Other Costs	$198,206	$186,931	$89,645	$112,453
EVSE Cost	$0	$0	$42,477	$0
Infrastructure Upgrade Cost	$0	$45,309	$49,839	$0
Total Infrastructure Cost	$0	$45,309	$92,316	$0
TOTAL	$918,908	$691,404	$603,009	$781,186
Payback Period vs Diesel (yr)	-	-	4.8	9.4

14. 2030 Refuse Packer

Figure 36: 2030 Refuse Packer Total Cost of Ownership Comparison

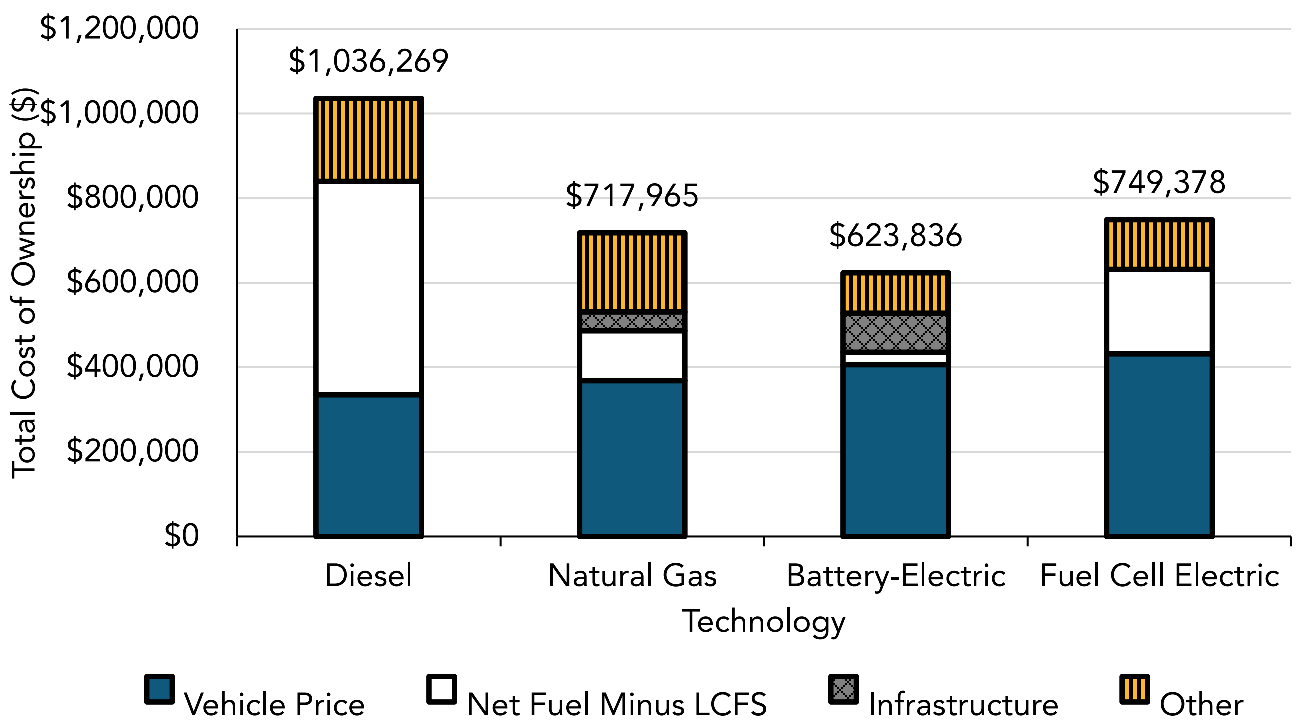


Figure 37: 2030 Refuse Packer Cashflow Comparison

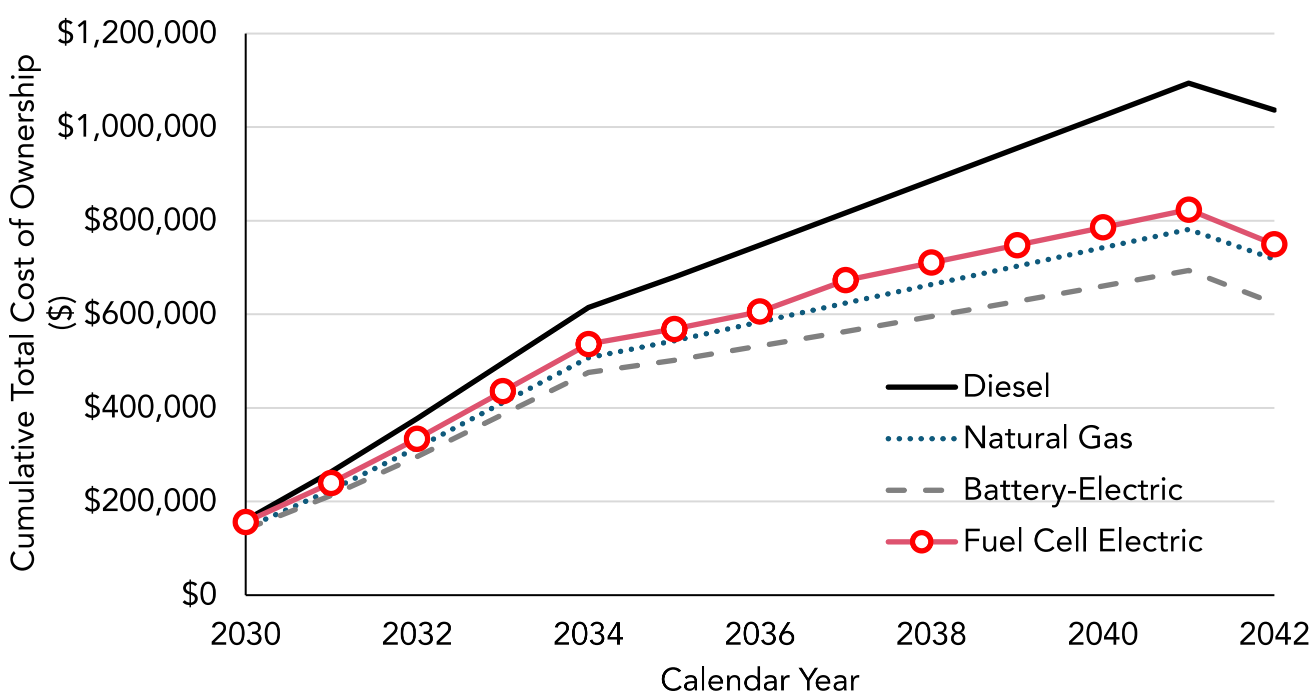


Table 27: 2030 Refuse Packer Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	290,640	290,640	290,640	290,640
Operating Years	12	12	12	12
Energy Storage	-	-	410 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$236,085	$259,778	$286,264	$304,396
Taxes	$47,217	$51,956	$57,253	$60,879
Financing Costs	$51,810	$57,009	$62,822	$66,801
Total Vehicle Cost	$335,112	$368,743	$406,338	$432,075
Fuel Economy	2.5 mpg	4.8 mpg	0.4 mi./kWh	5.5 mi./kg
Average Unit Fuel Cost	$4.26/gal	$1.95/gal	$0.22/kWh	$5/kg
Fuel Cost	$498,194	$117,381	$160,168	$263,744
DEF Consumption	$6,551	$0	$0	$0
LCFS Revenue	$0	$0	-$130,330	-$63,975
Total Fuel Cost	$504,745	$117,381	$29,838	$199,769
Maintenance Cost	$274,213	$274,213	$205,660	$205,660
Midlife Costs	$0	$0	$0	$29,750
Registration Fee	$29,771	$30,687	$20,119	$20,821
Depreciation	-$70,826	-$77,933	-$85,879	-$91,319
Residual Value	-$57,726	-$63,519	-$69,995	-$74,428
Insurance Costs	$20,979	$23,085	$25,438	$27,050
Total Other Costs	$196,412	$186,533	$95,344	$117,533
EVSE Cost	$0	$0	$42,477	$0
Infrastructure Upgrade Cost	$0	$45,309	$49,839	$0
Total Infrastructure Cost	$0	$45,309	$92,316	$0
TOTAL	$1,036,269	$717,965	$623,836	$749,378
Payback Period vs Diesel (yr)	-	-	3.5	3.2

15. 2035 Refuse Packer

Figure 38: 2035 Refuse Packer Total Cost of Ownership Comparison

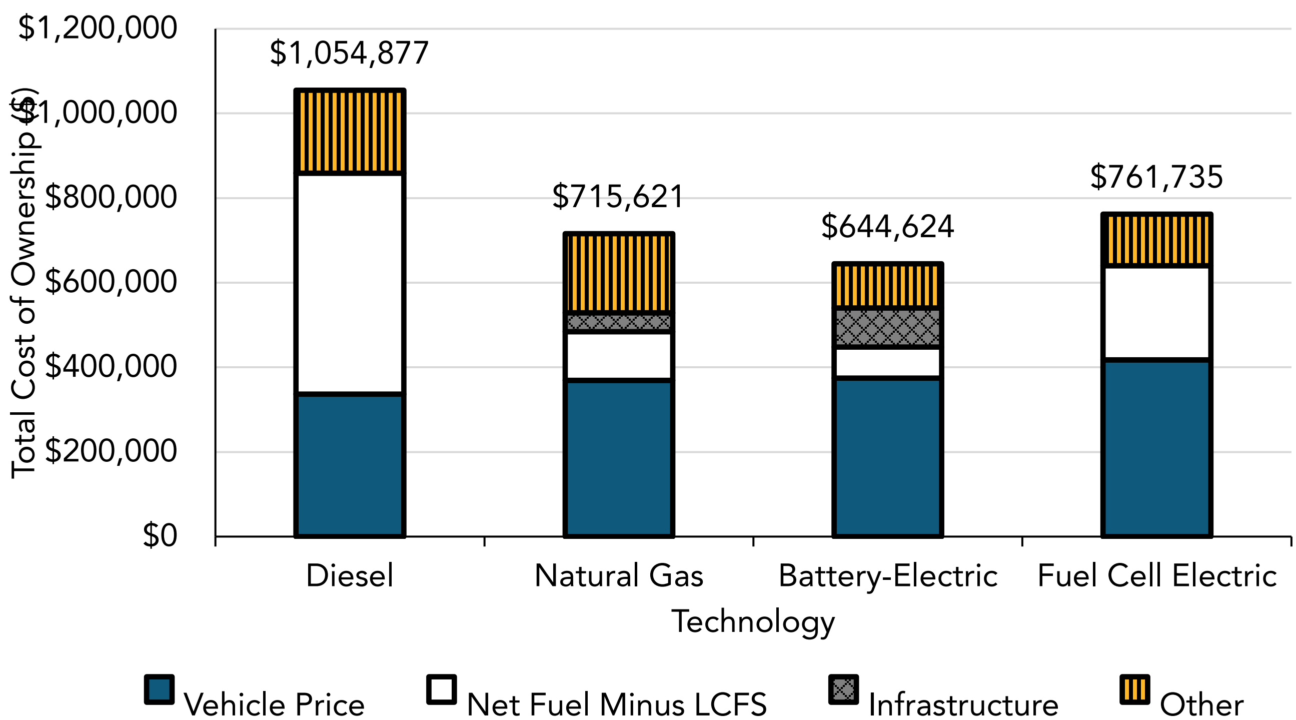


Figure 39: 2035 Refuse Packer Cashflow Comparison

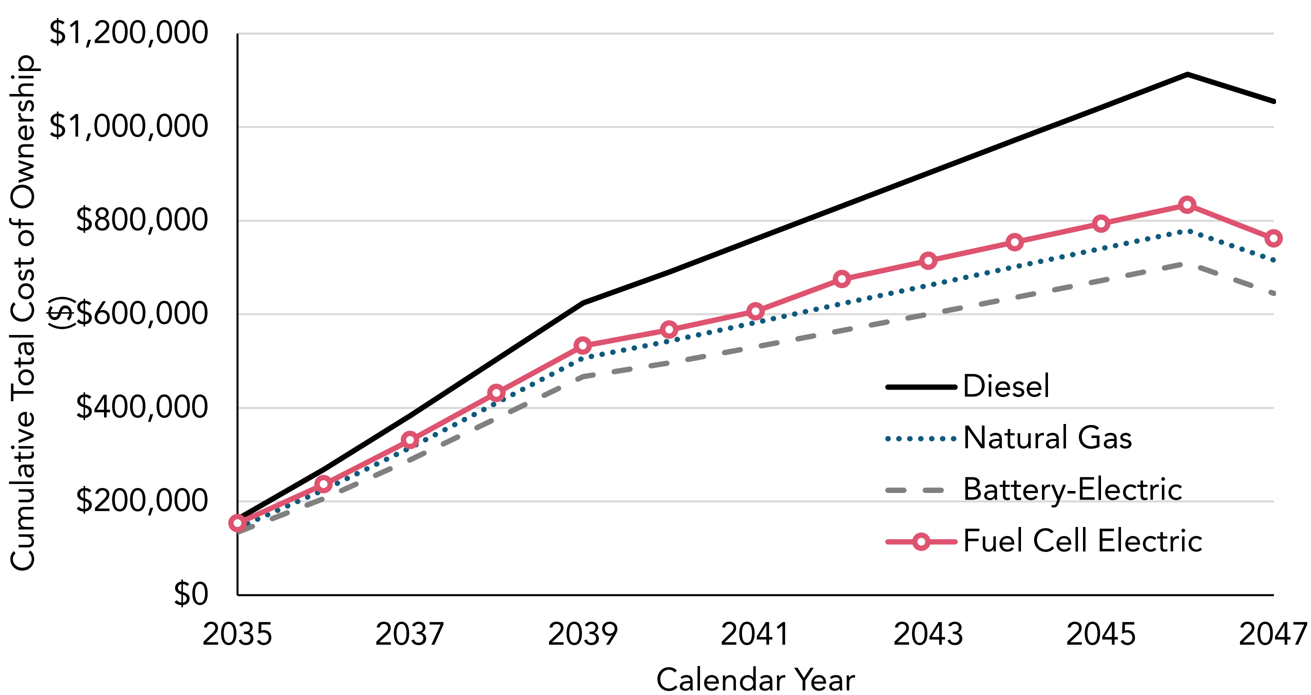


Table 28: 2035 Refuse Packer Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	290,640	290,640	290,640	290,640
Operating Years	12	12	12	12
Energy Storage	-	-	410 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$237,140	$259,972	$264,077	$294,089
Taxes	$47,428	$51,994	$52,815	$58,818
Financing Costs	$52,041	$57,052	$57,953	$64,539
Total Vehicle Cost	$336,609	$369,018	$374,845	$417,445
Fuel Economy	2.5 mpg	4.8 mpg	0.4 mi./kWh	5.5 mi./kg
Average Unit Fuel Cost	$4.41/gal	$1.91/gal	$0.22/kWh	$5/kg
Fuel Cost	$515,744	$114,843	$156,974	$263,744
DEF Consumption	$6,551	$0	$0	$0
LCFS Revenue	$0	$0	-$84,106	-$41,285
Total Fuel Cost	$522,295	$114,843	$72,868	$222,459
Maintenance Cost	$274,213	$274,213	$205,660	$205,660
Midlife Costs	$0	$0	$0	$29,750
Registration Fee	$29,811	$30,694	$19,261	$20,422
Depreciation	-$71,142	-$77,992	-$79,223	-$88,227
Residual Value	-$57,983	-$63,566	-$64,570	-$71,908
Insurance Costs	$21,073	$23,102	$23,467	$26,134
Total Other Costs	$195,972	$186,452	$104,595	$121,831
EVSE Cost	$0	$0	$42,477	$0
Infrastructure Upgrade Cost	$0	$45,309	$49,839	$0
Total Infrastructure Cost	$0	$45,309	$92,316	$0
TOTAL	$1,054,877	$715,621	$644,624	$761,735
Payback Period vs Diesel (yr)	-	-	2.9	2.6

16. 2025 Day Cab Tractor

Figure 40: 2025 Day Cab Tractor Total Cost of Ownership Comparison

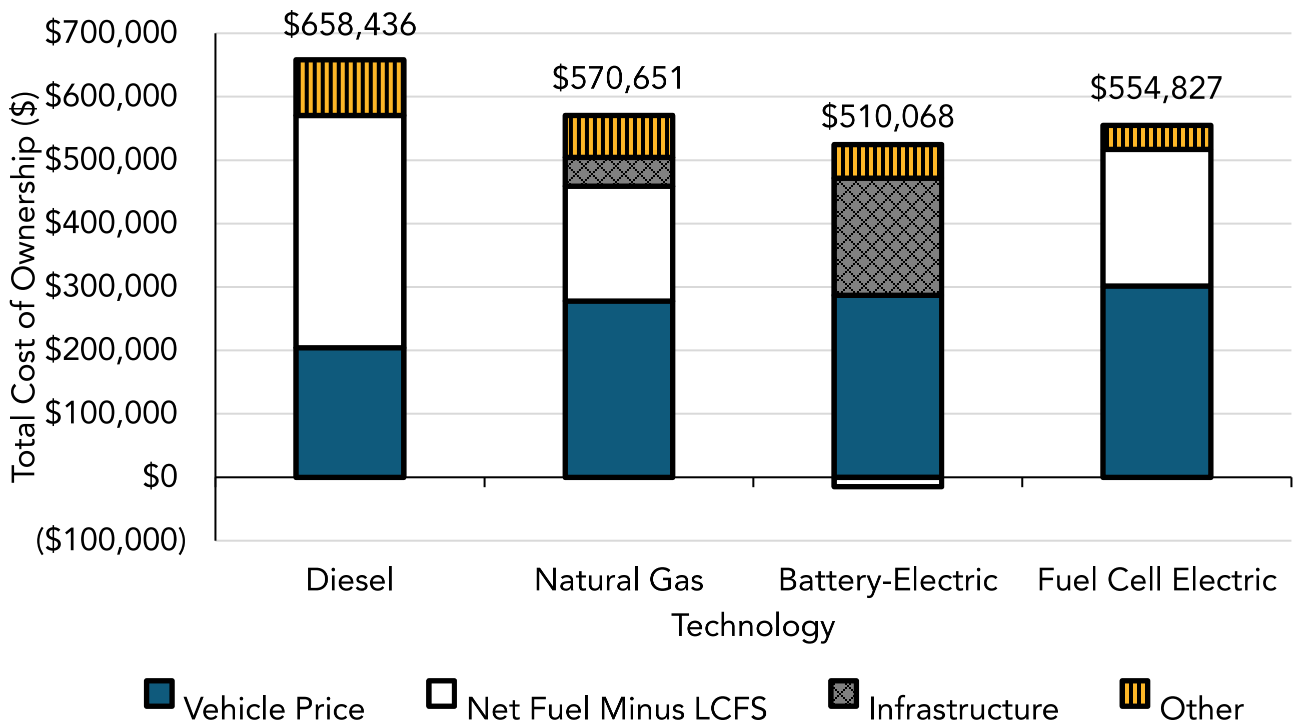


Figure 41: 2025 Day Cab Tractor Cashflow Comparison

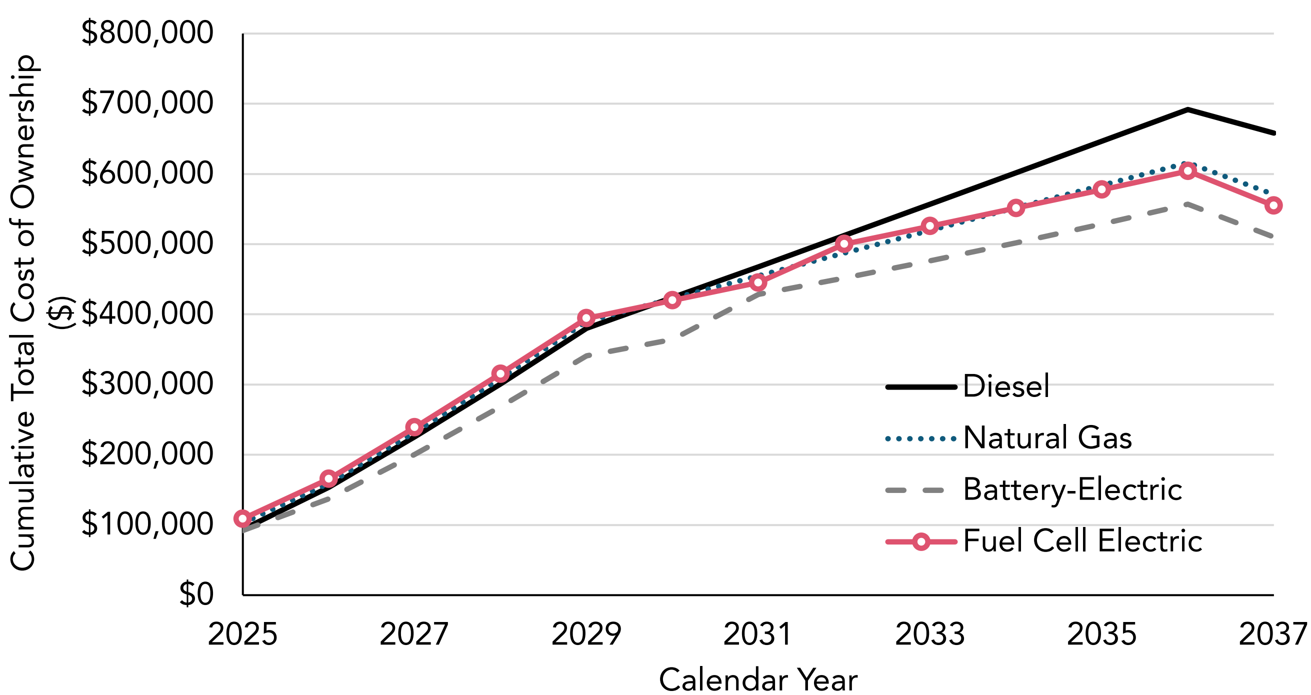


Table 29: 2025 Day Cab Tractor Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	599,280	599,280	599,280	599,280
Operating Years	12	12	12	12
Energy Storage	-	-	450 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$143,862	$195,607	$201,999	$212,353
Taxes	$28,772	$39,121	$40,400	$42,471
Financing Costs	$31,571	$42,927	$44,329	$46,602
Total Vehicle Cost	$204,205	$277,655	$286,727	$301,425
Fuel Economy	6.7 mpg	6.5 mpg	0.54 mi./kWh	10.9 mi./kg
Unit Fuel Cost	$4.06/gal	$1.98/gal	$0.21/kWh	$5.48/kg
Fuel Cost	$361,069	$181,399	$234,326	$300,201
DEF Consumption	$4,975	$0	$0	$0
LCFS Revenue	$0	$0	-$248,902	-$84,907
Total Fuel Cost	$366,045	$181,399	-$14,576	$215,293
Maintenance Cost	$118,898	$118,898	$89,174	$89,174
Midlife Costs	$0	$0	$40,545	$29,750
Registration Fee	$35,732	$37,733	$16,860	$17,261
Depreciation	-$43,159	-$58,682	-$60,600	-$63,706
Residual Value	-$33,363	-$45,363	-$46,845	-$49,246
Insurance Costs	$10,078	$13,702	$14,150	$14,876
Total Other Costs	$88,186	$66,289	$53,285	$38,108
EVSE Cost	$0	$0	$84,954	$0
Infrastructure Upgrade Cost	$0	$45,309	$99,679	$0
Total Infrastructure Cost	$0	$45,309	$184,633	$0
TOTAL	$658,436	$570,651	$510,068	$554,827
Payback Period vs Diesel (yr)	-	-	8.1	12.1

17. 2030 Day Cab Tractor

Figure 42: 2030 Day Cab Tractor Total Cost of Ownership Comparison

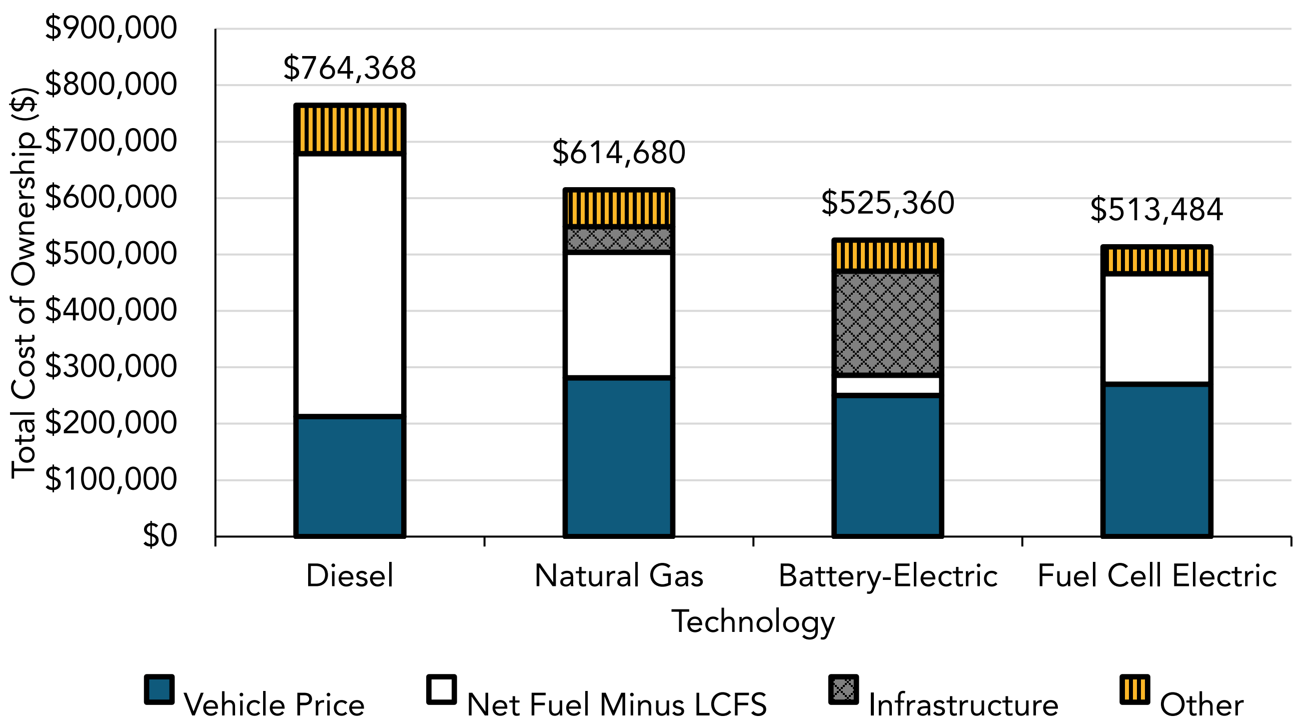


Figure 43: 2030 Day Cab Tractor Cashflow Comparison

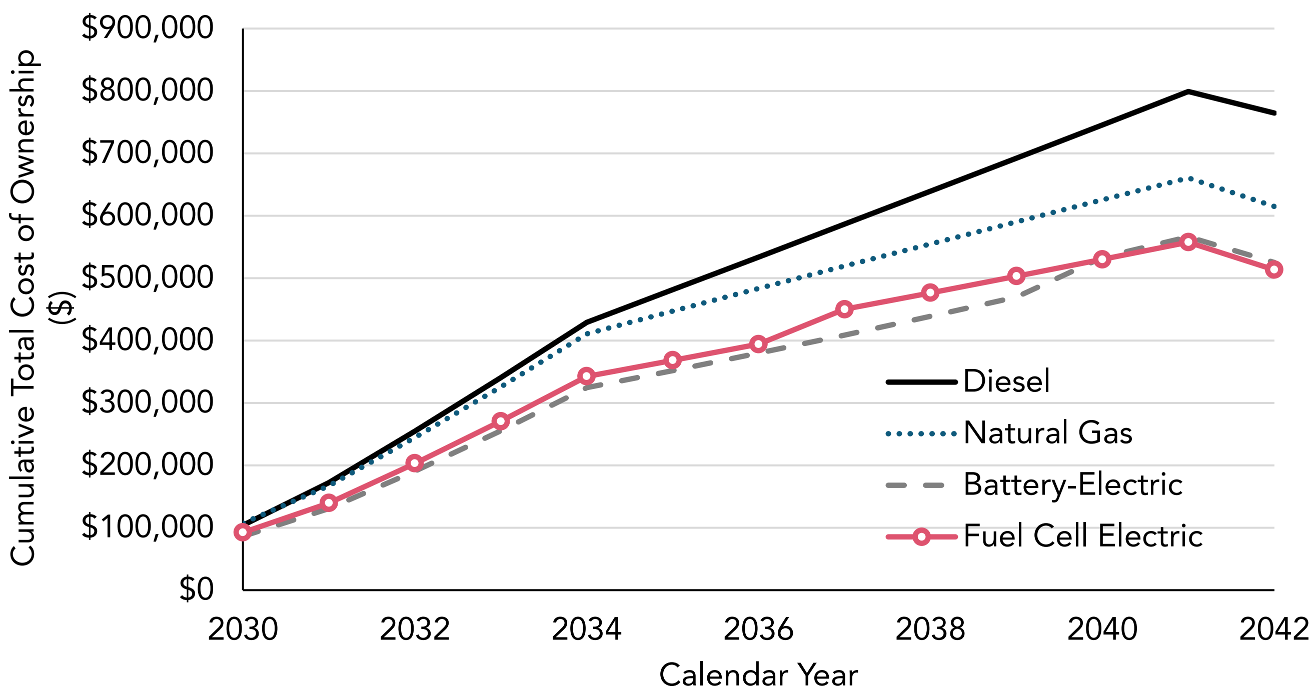


Table 30: 2030 Day Cab Tractor Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	599,280	599,280	599,280	599,280
Operating Years	12	12	12	12
Energy Storage	-	-	450 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$149,865	$198,263	$176,275	$190,161
Taxes	$29,973	$39,653	$35,255	$38,032
Financing Costs	$32,888	$43,510	$38,684	$41,731
Total Vehicle Cost	$212,726	$281,425	$250,214	$269,924
Fuel Economy	5.5 mpg	5.3 mpg	0.57 mi./kWh	11.6 mi./kg
Unit Fuel Cost	$4.26/gal	$1.95/gal	$0.21/kWh	$5/kg
Fuel Cost	$459,948	$222,782	$223,725	$258,849
DEF Consumption	$6,048	$0	$0	$0
LCFS Revenue	$0	$0	-$188,112	-$62,788
Total Fuel Cost	$465,996	$222,782	$35,613	$196,061
Maintenance Cost	$118,898	$118,898	$89,174	$89,174
Midlife Costs	$0	$0	$31,275	$29,750
Registration Fee	$35,964	$37,836	$15,865	$16,402
Depreciation	-$44,960	-$59,479	-$52,883	-$57,048
Residual Value	-$34,755	-$45,979	-$40,879	-$44,100
Insurance Costs	$10,498	$13,889	$12,348	$13,321
Total Other Costs	$85,646	$65,165	$54,900	$47,499
EVSE Cost	$0	$0	$84,954	$0
Infrastructure Upgrade Cost	$0	$45,309	$99,679	$0
Total Infrastructure Cost	$0	$45,309	$184,633	$0
TOTAL	$764,368	$614,680	$525,360	$513,484
Payback Period vs Diesel (yr)	-	-	5.8	2.3

18. 2035 Day Cab Tractor

Figure 44: 2035 Day Cab Tractor Total Cost of Ownership Comparison

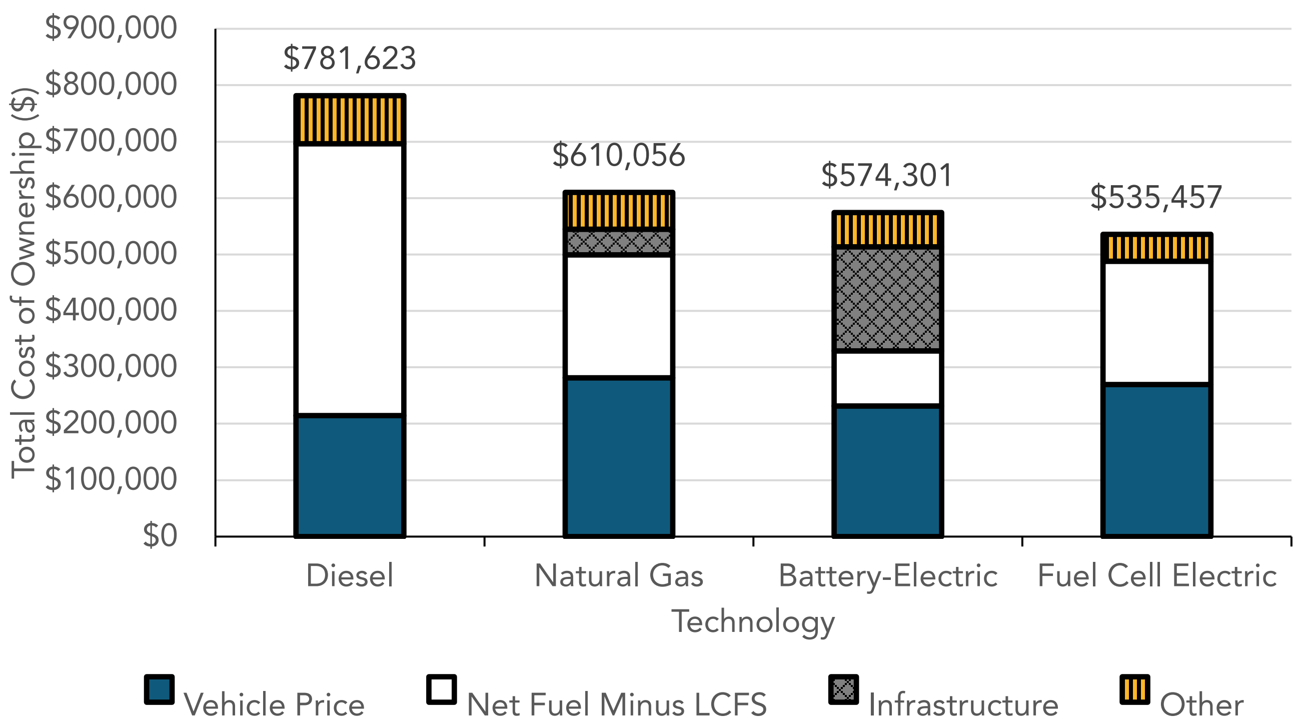


Figure 45: 2035 Day Cab Tractor Cashflow Comparison

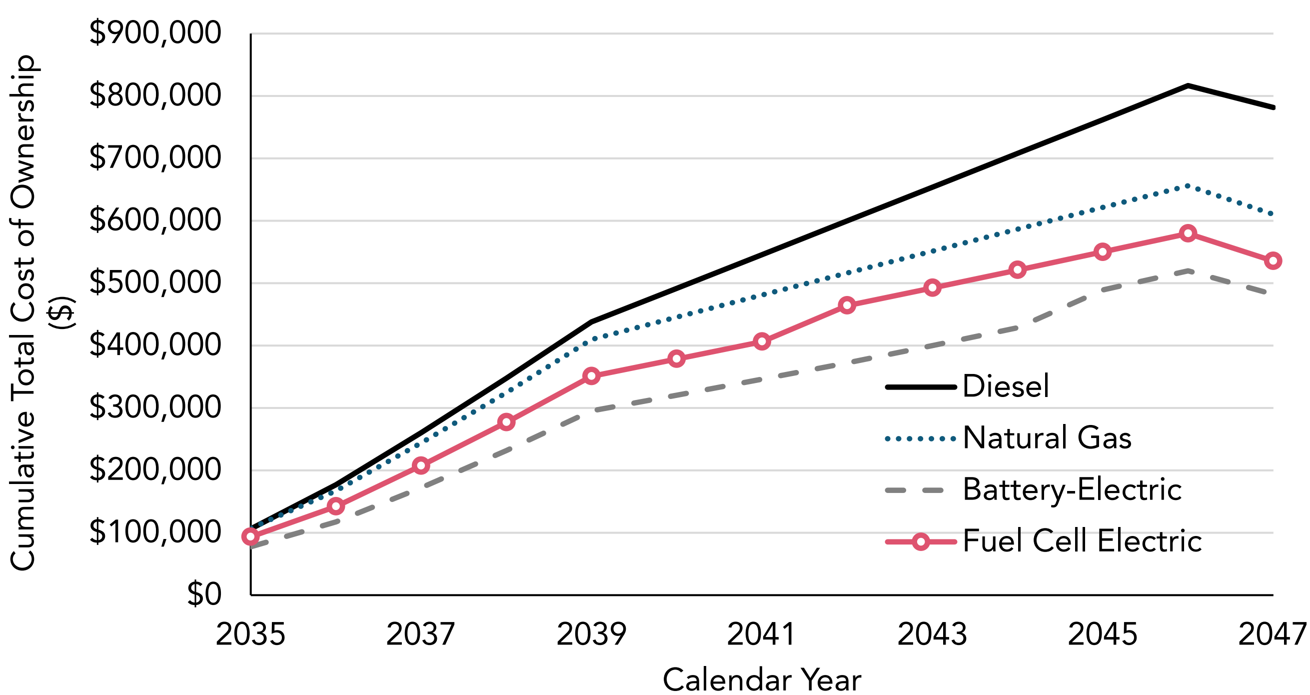


Table 31: 2025 Day Cab Tractor Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	599,280	599,280	599,280	599,280
Operating Years	12	12	12	12
Energy Storage	-	-	450 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$150,920	$198,457	$162,910	$189,864
Taxes	$30,184	$39,691	$32,582	$37,973
Financing Costs	$33,120	$43,552	$35,751	$41,666
Total Vehicle Cost	$214,224	$281,700	$231,243	$269,503
Fuel Economy	5.5 mpg	5.3 mpg	0.57 mi./kWh	11.6 mi./kg
Average Unit Fuel Cost	$4.41/gal	$1.91/gal	$0.21/kWh	$5/kg
Fuel Cost	$476,151	$217,964	$219,265	$258,849
DEF Consumption	$6,048	$0	$0	$0
LCFS Revenue	$0	$0	-$121,395	-$40,519
Total Fuel Cost	$482,199	$217,964	$97,869	$218,330
Maintenance Cost	$118,898	$118,898	$89,174	$89,174
Midlife Costs	$0	$0	$31,275	$29,750
Registration Fee	$36,005	$37,843	$15,349	$16,391
Depreciation	-$45,276	-$59,537	-$48,873	-$56,959
Residual Value	-$34,999	-$46,024	-$37,780	-$44,031
Insurance Costs	$10,572	$13,902	$11,412	$13,300
Total Other Costs	$85,200	$65,083	$60,556	$47,625
EVSE Cost	$0	$0	$84,954	$0
Infrastructure Upgrade Cost	$0	$45,309	$99,679	$0
Total Infrastructure Cost	$0	$45,309	$184,633	$0
TOTAL	$781,623	$610,056	$574,301	$535,457
Payback Period vs Diesel (yr)	-	-	5.5	2.2

19. 2030 Sleeper Cab Tractor

Figure 46: 2030 Sleeper Cab Tractor Total Cost of Ownership Comparison

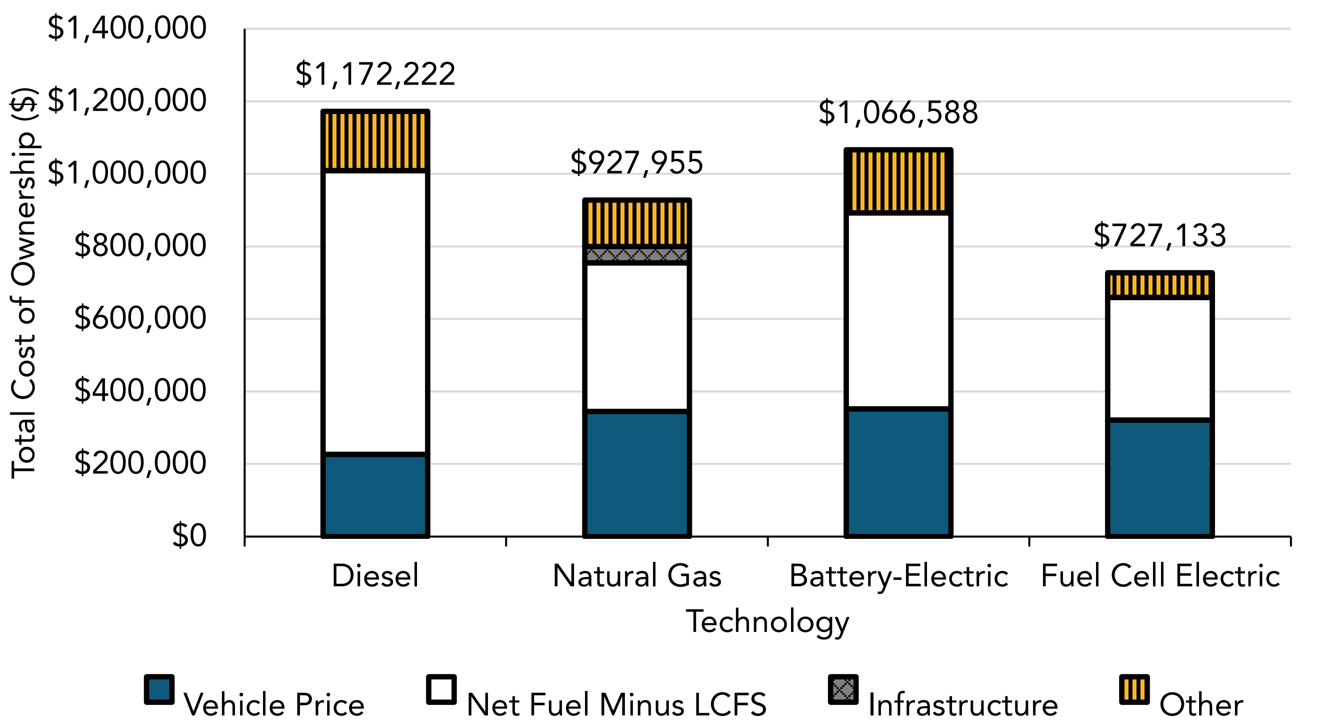


Figure 47: 2030 Sleeper Cab Tractor Cashflow Comparison

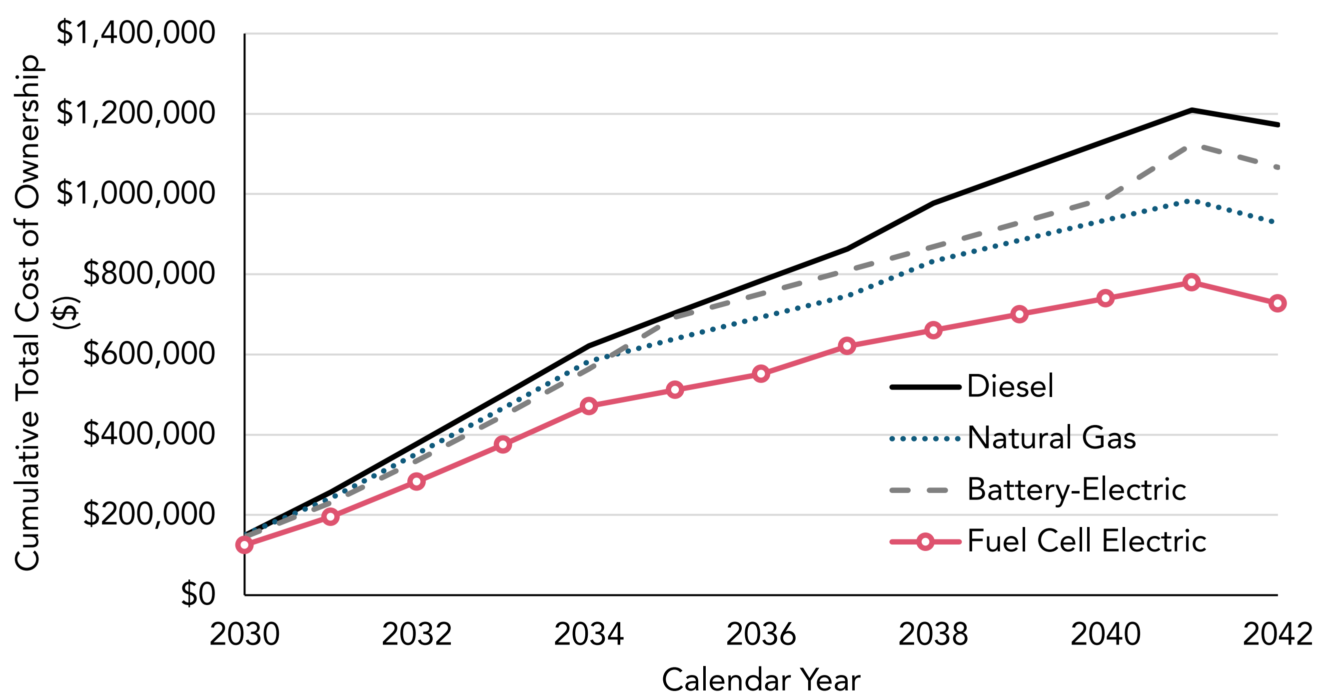


Table 32: 2030 Sleeper Cab Tractor Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	1,044,802	1,044,802	1,044,802	1,044,802
Operating Years	12	12	12	12
Energy Storage	-	-	1050 kWh	10 kWh/80 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$159,865	$243,263	$248,215	$226,277
Taxes	$31,973	$48,653	$49,643	$45,255
Financing Costs	$35,083	$53,385	$54,472	$49,657
Total Vehicle Cost	$226,921	$345,301	$352,330	$321,190
Fuel Economy	5.8 mpg	5 mpg	0.5 mi./kWh	11.6 mi./kg
Average Unit Fuel Cost	$4.25/gal	$1.95/gal	$0.44/kWh	$5/kg
Fuel Cost	$771,536	$409,042	$923,557	$449,235
DEF Consumption	$10,169	$0	$0	$0
LCFS Revenue	$0	$0	-$383,817	-$110,894
Total Fuel Cost	$781,705	$409,042	$539,740	$338,341
Maintenance Cost	$166,080	$166,080	$124,560	$124,560
Midlife Costs	$35,000	$35,000	$145,950	$29,750
Registration Fee	$36,351	$39,576	$18,648	$17,799
Depreciation	-$47,960	-$72,979	-$74,465	-$67,883
Residual Value	-$37,074	-$56,414	-$57,563	-$52,475
Insurance Costs	$11,199	$17,041	$17,388	$15,851
Total Other Costs	$163,596	$128,304	$174,518	$67,602
EVSE Cost	$0	$0	$0	$0
Infrastructure Upgrade Cost	$0	$45,309	$0	$0
Total Infrastructure Cost	$0	$45,309	$0	$0
TOTAL	$1,172,222	$927,955	$1,066,588	$727,133
Payback Period vs Diesel (yr)	-	-	5.8	2.1

20. 2035 Sleeper Cab Tractor

Figure 48: 2035 Sleeper Cab Tractor Total Cost of Ownership Comparison

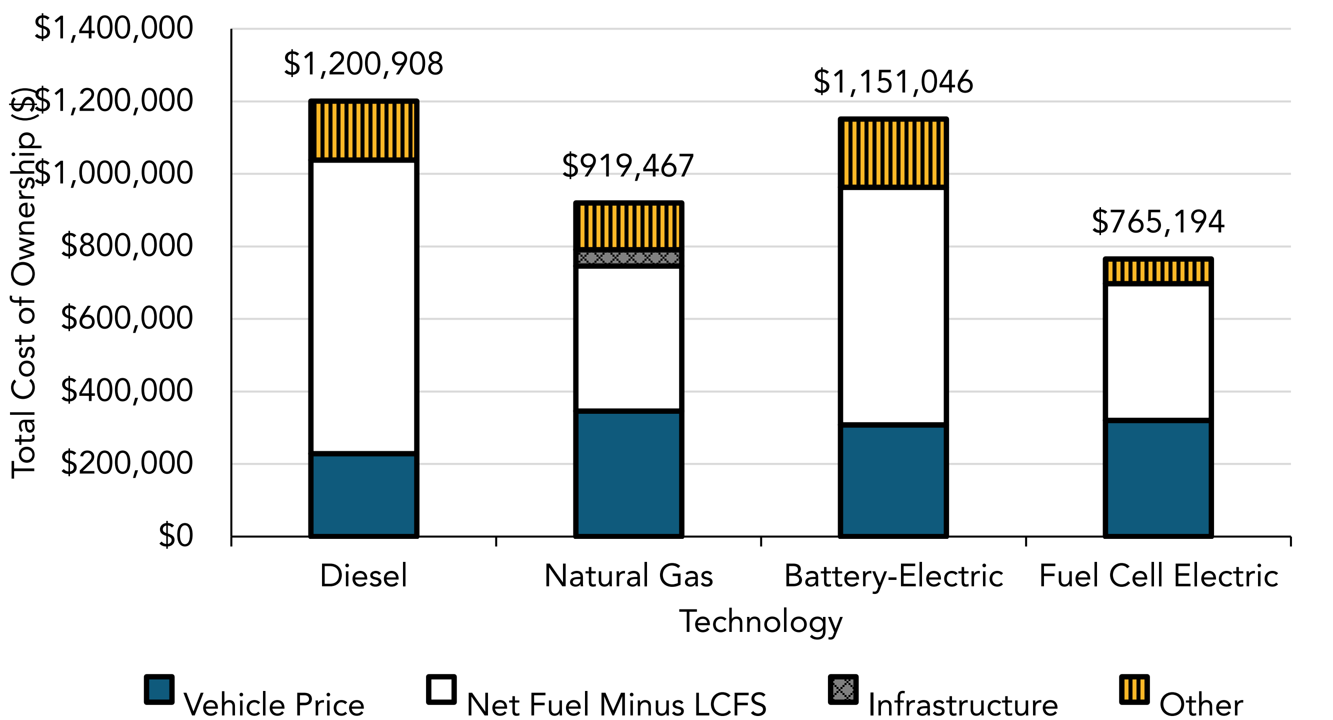


Figure 49: 2035 Sleeper Cab Tractor Cashflow Comparison

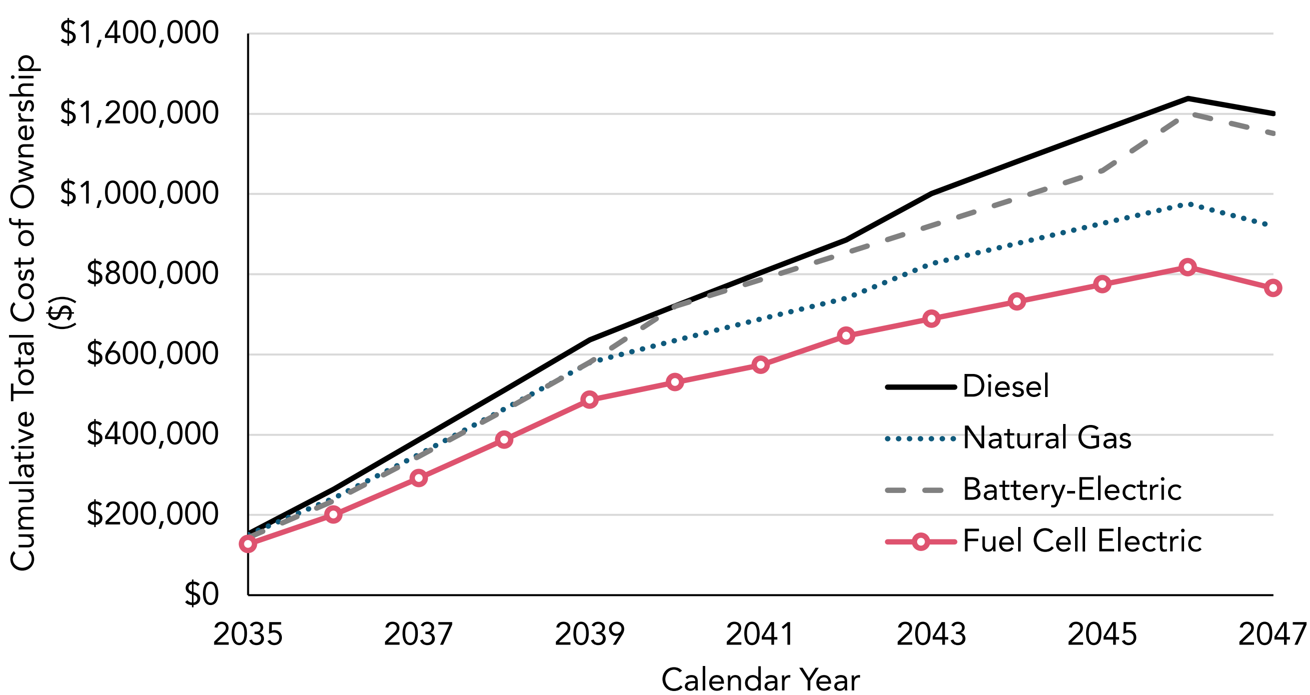


Table 33: 2035 Sleeper Cab Tractor Cost Breakdown

Cost Component	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	1,044,802	1,044,802	1,044,802	1,044,802
Operating Years	12	12	12	12
Energy Storage	-	-	1050 kWh	10 kWh/80 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$160,920	$243,457	$217,030	$225,980
Taxes	$32,184	$48,691	$43,406	$45,196
Financing Costs	$35,314	$53,427	$47,628	$49,592
Total Vehicle Cost	$228,418	$345,576	$308,064	$320,769
Fuel Economy	5.8 mpg	5 mpg	0.5 mi./kWh	11.6 mi./kg
Average Unit Fuel Cost	$4.4/gal	$1.91/gal	$0.43/kWh	$5/kg
Fuel Cost	$799,171	$400,361	$906,328	$449,235
DEF Consumption	$10,169	$0	$0	$0
LCFS Revenue	$0	$0	-$251,061	-$72,537
Total Fuel Cost	$809,339	$400,361	$655,267	$376,698
Maintenance Cost	$166,080	$166,080	$124,560	$124,560
Midlife Costs	$35,000	$35,000	$145,950	$29,750
Registration Fee	$36,392	$39,584	$17,442	$17,788
Depreciation	-$48,276	-$73,037	-$65,109	-$67,794
Residual Value	-$37,319	-$56,459	-$50,331	-$52,406
Insurance Costs	$11,273	$17,054	$15,203	$15,830
Total Other Costs	$163,150	$128,222	$187,715	$67,727
EVSE Cost	$0	$0	$0	$0
Infrastructure Upgrade Cost	$0	$45,309	$0	$0
Total Infrastructure Cost	$0	$45,309	$0	$0
TOTAL	$1,200,908	$919,467	$1,151,046	$765,194
Payback Period vs Diesel (yr)	-	-	5.1	2.0

I. Summary of Results

The result of this analysis suggests the following:

- Through a combination of lower fuel costs, decreased maintenance expenses, and revenue from California's LCFS program, ZEVs achieve lower operational costs versus their combustion counterparts. These savings typically outweigh higher upfront costs over the lifetime of the ZEV.
- Costs of batteries and fuel cell components are expected to decline substantially over the next decade and will bring down the incremental capital costs of zero-emission trucks and buses. This will improve their TCO compared to the combustion equivalents. Cost reductions beyond what is modeled are feasible and become more likely with large scale investment into ZEV technologies by manufacturers and fleets.
- Both battery-electric and fuel cell electric vehicles are projected to be cost competitive with combustion-powered vehicles over the course of this analysis. Battery-electric vehicles appear competitive in many categories beginning 2025, while fuel cell electric vehicles appear competitive in either 2025 or 2030 depending on the type of vehicle modeled.
- ZEVs can result in significantly lower TCO for fleets in specific scenarios. For example, by 2030, a battery-electric Class 5 walk-in van is expected to have a 22 percent lower TCO versus their diesel counterpart resulting in a savings of $47,000 per vehicle. A battery-electric and fuel cell electric day cab operating in a drayage duty cycle is expected to have a 31 and 33 percent lower TCO versus diesel, respectively, resulting in savings of $239,000 and $251,000, respectively.
- Further cost reductions may be feasible as this report does not model potentially reduced costs to fleets as a result of the Advanced Clean Trucks manufacturer ZEV sales requirement. Investments and action by manufacturers can lead to lower costs throughout the entire ZEV ecosystem including parts suppliers, infrastructure providers, service technicians, and others.
- Upfront costs are expected to be higher for ZEVs due to additional vehicle and infrastructure expenses. However, by financing these costs and allowing operational savings to accrue, fleets can operate ZEVs with minimal cashflow impact in the initial years. Once the vehicle is paid off, operational savings continue to accrue over time. This allows fleets to purchase and operate ZEVs without seeing the additional costs associated with ZEVs.
- The payback period for ZEVs versus their diesel counterpart varies among vehicles but ranges from five to ten years in the 2025 analysis. This drops to two to five years in the 2030 and 2035 analyses, indicating that ZEVs are able to recoup their additional costs in a reasonable timeframe.
- Revenue from LCFS credits significantly improves the TCO for battery-electric and fuel cell electric vehicles. LCFS credits can completely offset the cost of charging a battery-electric vehicle and significantly reduce the costs of refueling fuel cell electric vehicles.

- Although they are not included in this analysis, grants, incentives, and utility infrastructure programs can further reduce the upfront costs to get fleet owners to act early.