December 18, 2020: Modifications made to comply with AB 434. No changes made to content.

CALIFORNIA AIR RESOURCES BOARD

Advanced Clean Fleets – Cost Workgroup
Cost Data and Methodology Discussion Draft

Last updated December 4, 2020

Introduction

This document lists draft cost information to be used to evaluate the costs of deploying zero emission trucks in California for the period from 2023 to 2045. The purpose of this document is to foster discussion on the best available information regarding the costs of zero-emission technologies such as battery-electric and fuel cell electric versus their combustion-powered counterparts, and to solicit feedback on the data sources which may be more up to date than what staff is currently using. The information gathered through these workgroups will support the regulatory analysis. These costs include upfront costs associated with purchasing the vehicles, ongoing costs such as fuel and maintenance, infrastructure upgrades to support new technologies, and other cost elements that are associated with deployment of zero-emission vehicles (ZEVs). All prices will be converted into 2020 constant dollars for the purpose of this analysis.

Vehicle Cost

The vehicle cost is the price to a fleet to purchase a new or used vehicle. The vehicle cost will depend on a number of factors including the propulsion technology, the weight class, the model year, and they body installed on the vehicle.

Gasoline and Diesel Vehicles

The price for diesel and gasoline vehicles today is based on information available from manufacturer websites and online truck marketplaces such as TruckPaper.com and CommercialTruckTrader.com. The price for shuttle buses and transit buses is obtained from the Innovative Clean Transit Staff Report.[i]

Table 1: Current Price Estimates for Gasoline and Diesel-Powered Vehicles

Vehicle Category	Price
Class 2b Van – Diesel	$39,000
Class 2b Van – Gasoline	$35,000
Class 2b Pickup – Diesel	$46,000
Class 2b Pickup – Gasoline	$36,000
Class 3 Service – Gasoline	$46,000
Class 3 Service – Diesel	$53,000
Class 5 Shuttle Bus - Gasoline	$65,000

Vehicle Category	Price
Class 5 Walk-in Van	$87,000
Class 5 Utility Service	$65,000
Class 6 Box Truck	$85,000
Class 6 Bucket Truck	$126,000
Class 8 Refuse Packer	$226,000
Class 8 Transit Bus	$435,000
Class 8 Day Cab Tractor	$135,000

Future costs for combustion vehicles are expected to remain flat, in constant dollars, prior to modeling upcoming emissions regulations. Two major regulations have been adopted which will affect the price of new combustion-powered trucks, the Phase 2 GHG regulation and the Low-NOx Omnibus regulation. Both regulations are anticipated to decrease the emissions and increase the purchase price of these vehicles. Staff intends to model these increased costs for future model years of vehicles as part of the baseline for the analysis.

The Phase 2 GHG regulation requires manufacturers to build more fuel-efficient vehicles which are anticipated to cost more upfront. US EPA estimated the incremental cost to produce these vehicles which is displayed in Table 2, broken down by the model year and category definitions that that regulation uses.[ii]

Table 2: US EPA Phase 2 GHG Estimated Incremental Compliance Costs

Phase 2 GHG 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 Heavy-duty Low-NOx Omnibus rulemaking is a multi-pronged, holistic approach to decrease emissions of new heavy-duty engines sold in California. This rulemaking will lower NOx emissions by lowering tailpipe NOx standards, establishing a new low-load test cycle to ensure emissions reduction 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 model year is shown in Table 3.[iii]

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

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

Vehicle Category	Corresponding Weight Class	2024-2026 MY	2027-2030 MY	2031+ MY
Medium-Duty Otto	Class 3	$412	$412	$412

Based on the above information, staff estimates the future price of several representative diesel and gasoline powered vehicles as outlined in Table 4. Vehicles are diesel unless stated otherwise.

Table 4: Price Estimates for Gasoline and Diesel-Powered Vehicles

Vehicle Category	Today	2024-2026 MY	2027-2030 MY	2031+ MY
Class 2b Van – Diesel	$39,000	$39,963	$40,364	$40,364
Class 2b Van – Gasoline	$35,000	$35,963	$36,364	$36,364
Class 2b Pickup – Diesel	$46,000	$46,963	$47,364	$47,364
Class 2b Pickup – Gasoline	$36,000	$36,963	$37,364	$37,364
Class 3 Service – Gasoline	$46,000	$46,963	$47,364	$47,364
Class 3 Service – Diesel	$53,000	$53,963	$54,364	$54,364
Class 5 Shuttle Bus - Gasoline	$65,000	$67,528	$68,483	$68,677
Class 5 Walk-in Van	$87,000	$90,709	$94,403	$95,703
Class 5 Utility Service	$65,000	$68,709	$72,403	$73,703
Class 6 Box Truck	$85,000	$89,491	$93,725	$94,585
Class 6 Bucket Truck	$126,000	$130,491	$134,725	$135,585
Class 8 Refuse Packer	$226,000	$231,783	$236,085	$237,140
Class 8 Transit Bus	$435,000	$440,783	$445,085	$446,140
Class 8 Day Cab Tractor	$135,000	$148,862	$154,865	$155,920

Natural Gas Vehicles

Natural gas vehicles are currently commercially available in several vocations including refuse, delivery, tractors, and transit buses. Natural gas vehicles typically have an incremental cost over their diesel counterparts due to the additional cost of installing pressurized natural gas tanks. Incremental cost estimates are derived from the National Renewable Energy Laboratory cost model Vehicle Infrastructure Cash-Flow Estimation 2.0 (VICE 2.0).[iv] Natural gas transit buses costs are derived from the Innovative Clean Transit rulemaking. Natural gas tractor costs are derived from a JB Hunt paper and depend on the amount of natural gas storage installed.[v] These costs are then scaled past 2024 MY using the information previously discussed in Table 2 and Table 3. Generally, incremental costs decline over time for natural gas vehicles as it is less costly for them to meet lower NOx standards than a comparable diesel vehicle.

Table 5: Incremental Costs Estimates for Natural Gas-Powered Vehicles

Vehicle Category	Today	2024-2026 MY	2027-2030 MY	2031+ MY
Class 5 Shuttle Bus	$15,000	$15,000	$15,000	$15,000
Class 5 Walk-in Van	$17,500	$16,319	$13,580	$12,474
Class 8 Refuse Packer	$30,295	$27,040	$23,693	$22,832

Vehicle Category	Today	2024-2026 MY	2027-2030 MY	2031+ MY
Class 8 Transit Bus	$50,000	$46,745	$43,398	$42,537
Class 8 Day Cab Tractor	$55,000	$51,745	$48,398	$47,537

Battery-Electric and Hydrogen Fuel Cell Vehicles

Both battery-electric vehicles and fuel-cell electric vehicles are zero-emission vehicles (ZEVs) that produce zero tailpipe emissions under any modes of operation. Both vehicle types use electricity to propel the vehicle; battery-electric vehicles store energy in a battery while fuel cell vehicles store energy in the form of hydrogen which is converted to electricity and water using a fuel cell.

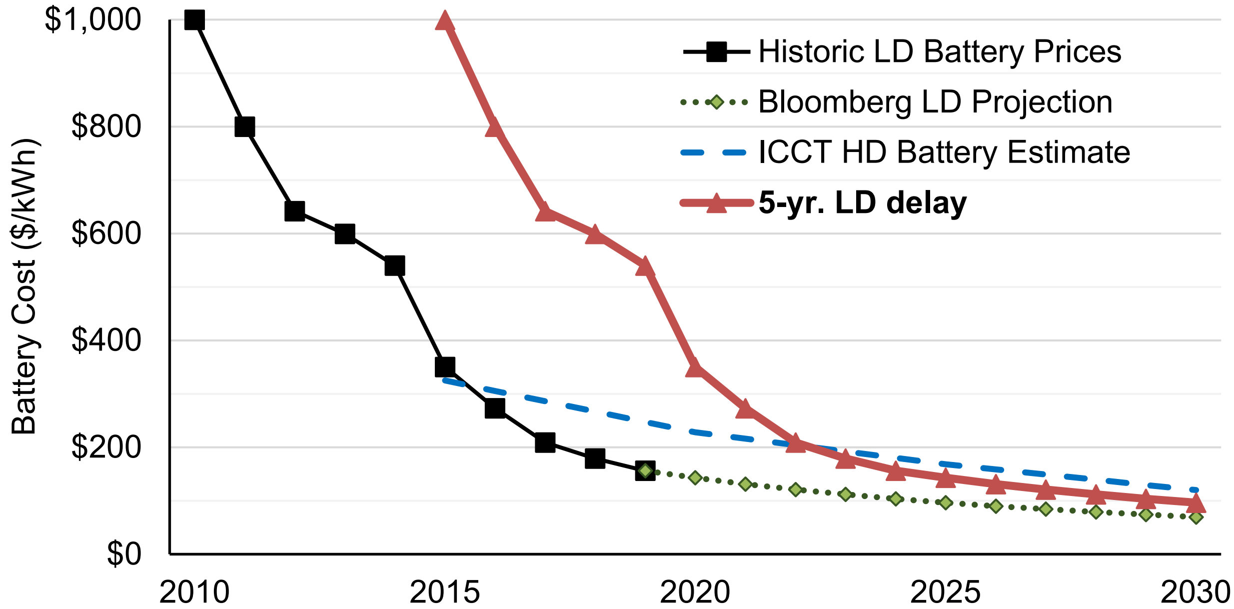
Staff's methodology for estimating the cost of battery-electric and fuel cell electric vehicles is to add electric components costs, fuel cell component costs, and energy storage costs to a chassis without a powertrain i.e. a glider, and then apply an additional 10 percent to represent other associated costs such as research, development, retooling, and overhead.

The cost of electrical components as well as fuel cell tanks is based the report from the International Council on Clean Transportation, "Transitioning to Zero-Emission Heavy-Duty Freight Vehicles".[vi] All ZEVs have electrical components such as electric motors, batteries, inverters, controllers, and others. The price for hydrogen fuel cell components including the fuel cell stack is based on a presentation from Strategic Analysis titled "Fuel Cell Systems Analysis" which estimated fuel cell system costs for medium- and heavy-duty trucks.[vii] All sources show that electrical component costs are anticipated to decline over time using constant dollars due to increasing economies of scale and production improvements.

The cost of battery storage is the biggest factor in battery-electric truck incremental cost. Battery pack costs have dropped nearly 80 percent since 2010 and are projected to continue declining. The CARB discussion document "Battery Cost for Heavy-Duty Vehicles" was a literature review published in 2016 using data sources from 2013 and 2014 to assess battery costs for buses and heavy-duty vehicles.[viii] Battery pack cost for heavy-duty applications are higher than for light-duty vehicles due to smaller volumes and differing packaging requirements even though many use the same cells. However, this report is somewhat dated and does not reflect the current state of the battery market. At the December 4th, 2018 Advanced Clean Trucks workgroup meeting, a number of manufacturers suggested we use light-duty battery prices with a five-year delay to reflect battery-price projections that are applicable to heavy-duty vehicles.

Figure 1 displays various battery price projections and the suggested 5-year light-duty delay. The 5-year delay of light duty battery pack prices is similar to projections made in the CARB discussion document for 2018 and becomes similar to the projection made by ICCT after 2020. Staff is soliciting feedback on any alternate sources or methodology for forecasting battery pack prices.

Figure 1: Battery Price History and Projections



Plug-in Hybrid Vehicles

A plug-in hybrid vehicle is a vehicle with two power sources that is capable of operating in a zero-emission mode for some distance and uses a combustion-powered engine otherwise. Staff did not model the cost of building and producing a plug-in hybrid vehicle in the ACT regulation and is soliciting feedback on an appropriate methodology to estimate these costs. Some questions include:

- How should we model physical parameters such as battery sizes, utility factors, and the size/power of electric and combustion motors?
- Will there be any potential to downsize the combustion engine or otherwise reduce the cost of the combustion powertrain? Would a gasoline or diesel engine be more appropriate to model?
- Are the costs of electric vehicle components the same for a battery-electric vehicles and a plug-in hybrid vehicle?

Vehicle Body Costs

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. 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.

Some vehicle bodies such as bucket bodies and refuse bodies require auxiliary power and use power takeoff which take power from the engine to power the body. ZEVs which need auxiliary power for the body with these will require new engineering solutions to power these bodies as current power take off solutions may not be suitable for fully electrified vehicles.

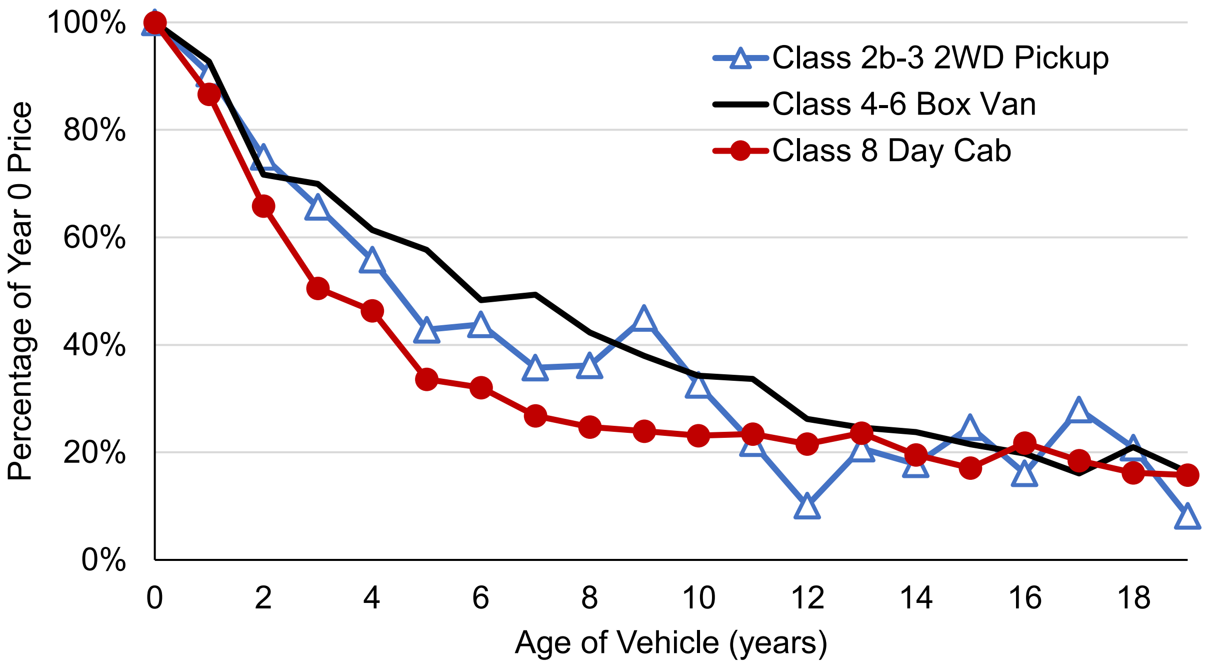
To reflect these considerations, staff is proposing that the body costs for a body with auxiliary needs (such as bucket trucks and refuse) would face a 10 percent higher body cost from 2024 to 2027, which then declines down to 0 percent by 2035. Staff is not proposing any higher body costs for bodies without PTO (such as box trucks, vans, and pickups).

Residual Values

The residual value represents the value of the vehicle at the point where the initial purchaser sells the vehicle to another party. The residual value of a vehicle depends on numerous factors including the type of vehicle, its age, the vehicle’s propulsion technology.

The residual values for diesel and gasoline powered trucks can be calculated using online truck marketplaces such as TruckPaper by measuring the price of a given body type over a number of model years. Figure 1 displays the results of three different vehicle body types over a 20-year period. The residual value becomes more significant when modeling vehicle replacement cycles that are less than 12 years.

Figure 2: Residual Values Over Time as a Percentage of the Original Price

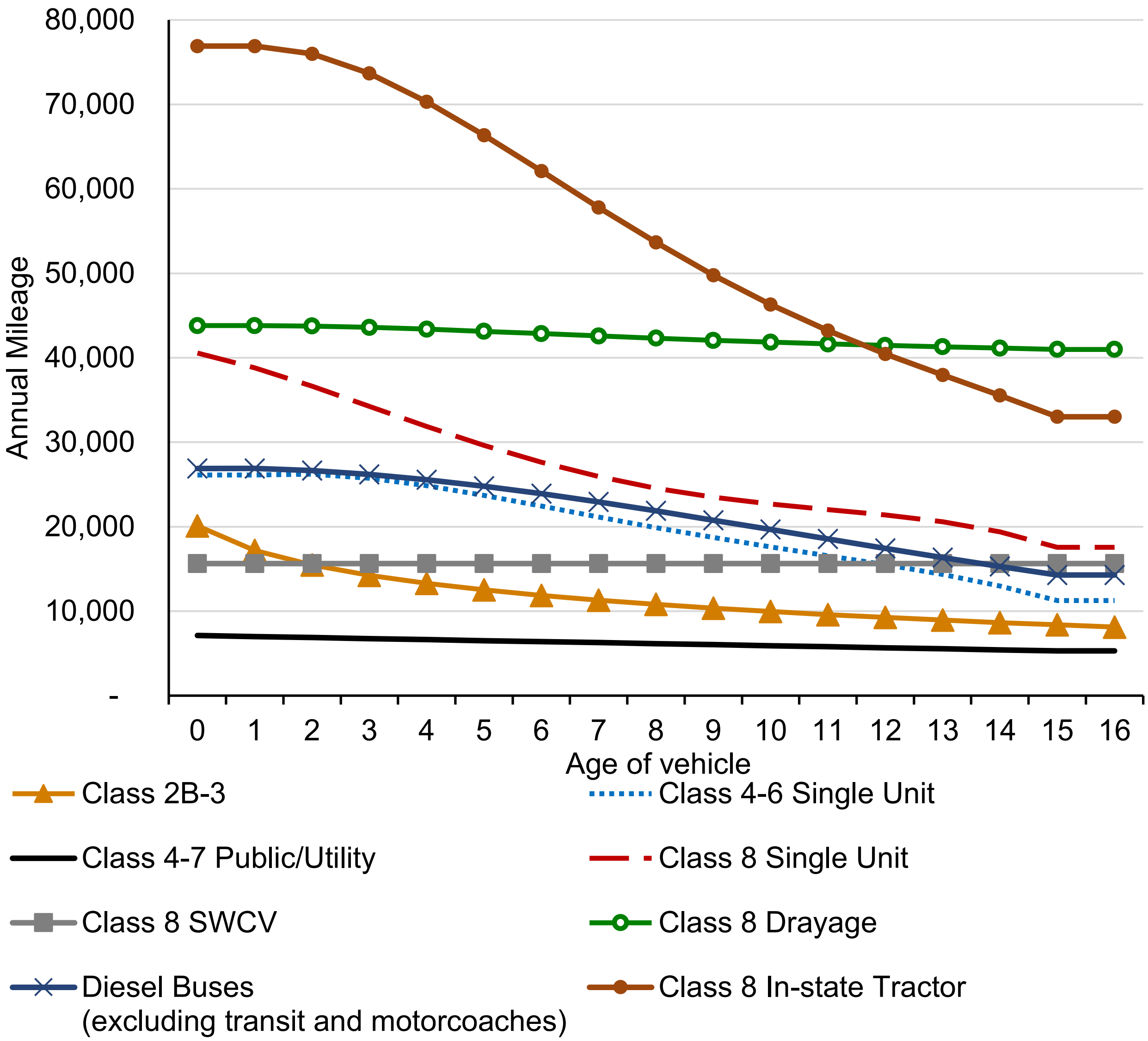


At this time, staff do not have a source of information to estimate the residual value of battery-electric and fuel cell electric vehicles.

Mileage Assumptions

Vehicle mileage factors into a number of costs in cost analyses including fuel costs, maintenance, LCFS revenue, and battery sizing assumptions for battery-electric vehicles. CARB's EMFAC emissions inventory contains mileage assumptions for all vehicle categories in the EMFAC model. [ix] The annual mileage for a variety of EMFAC categories are displayed in Figure 2 and represent averages for each category.

Figure 3: EMFAC Mileage Assumptions for Select Vehicle Categories



CARB is currently in the process of updating EMFAC to incorporate the newest information, currently titled EMFAC 202X. Once the updated inventory is finalized, staff will use EMFAC 202X in lieu of EMFAC 2017.

Fuel Cost

The fuel cost represents the cost to refuel or recharge the vehicle. This depends on both the cost of the fuel per unit and the vehicle's efficiency in using that fuel.

Fuel cost projections from 2018 through 2030 from CEC IEPR 2020 report. Hydrogen fuel costs displayed are from CEC IEPR 2017 report, as 2020 data was not yet available, and will be updated. Electricity rates are based on staff's electricity calculator for each utility and averaged statewide, while increasing over time.

Combustion Fuel Costs

Fuel cost projections for gasoline, diesel, and natural gas from 2018 through 2030 are derived from the California Energy Commission's 2020 Integrated Energy Policy Report. [x] From 2030 to 2050, staff is using the Energy Information Administration's Annual Energy Outlook 2020 report to model the changes past 2030.

Figure 4: California Energy Commission Fuel Cost Forecast from 2018 to 2030 in $2019 per Diesel Gallon Equivalent

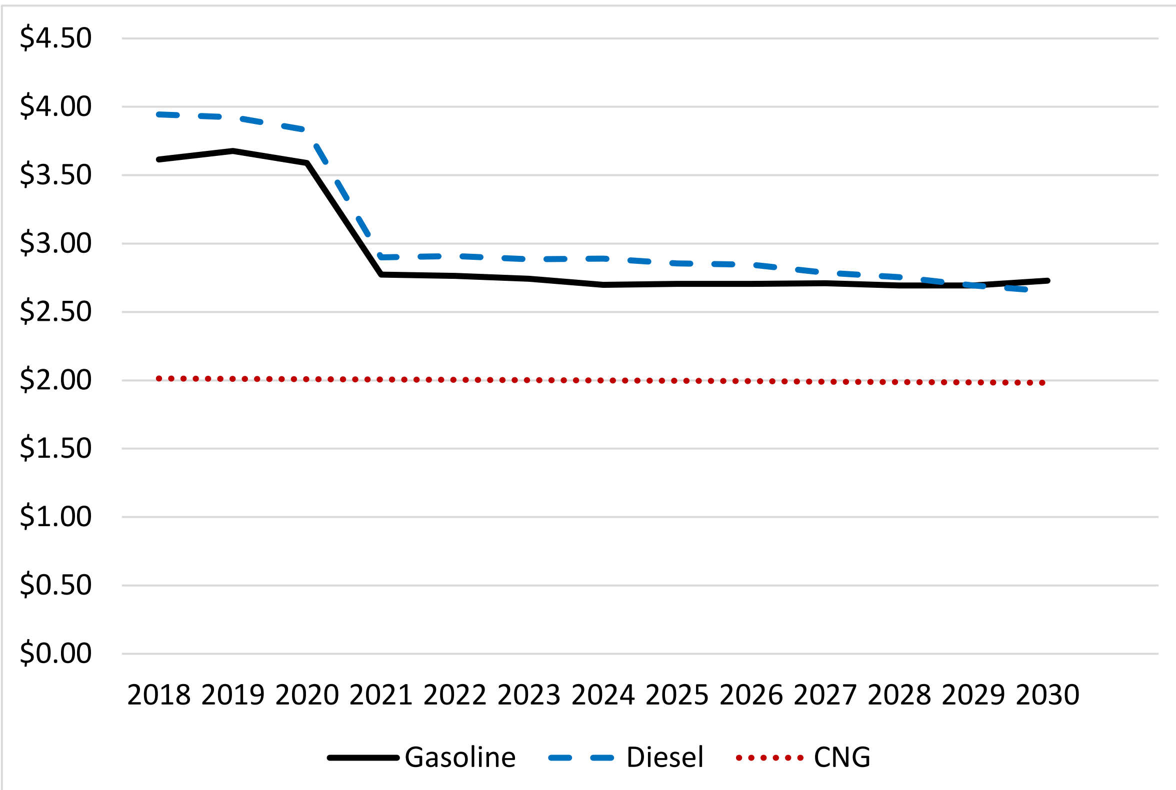
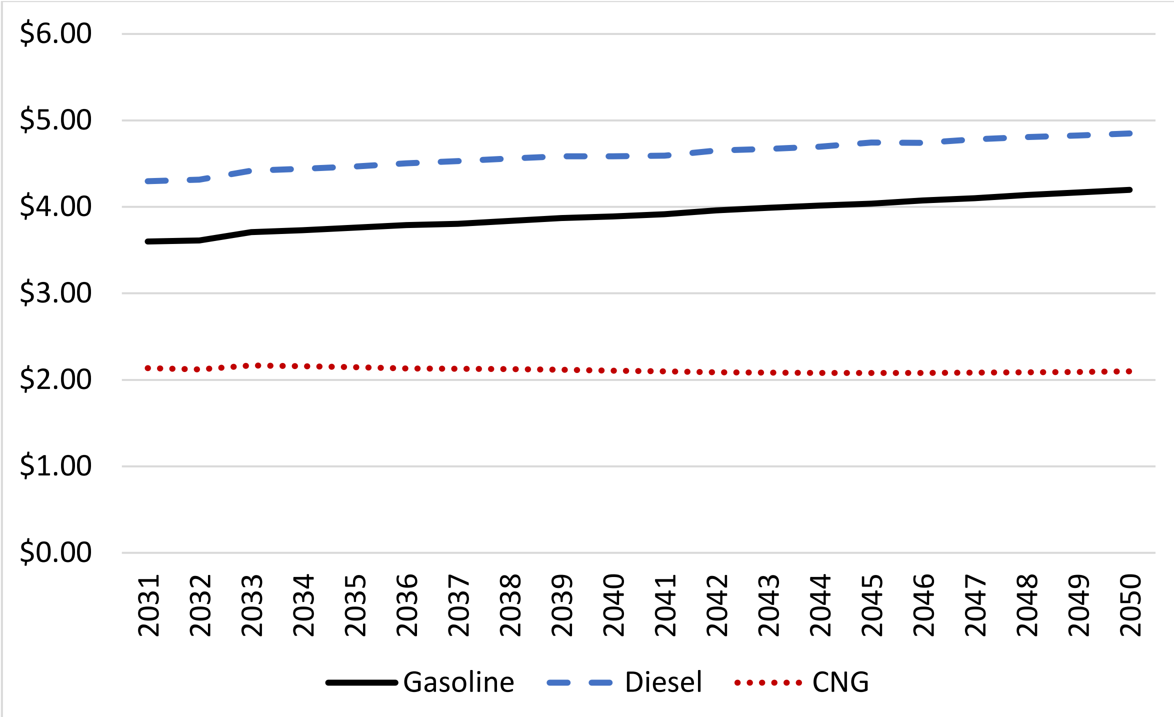


Figure 5: Energy Information Administration's Fuel Cost Forecast from 2031 to 2050



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Electricity Cost

Electricity cost used in the 2019 analysis for the Advanced Clean Trucks regulation was determined using CARB's Battery Electric Truck and Bus Charging Cost Calculator (Charging Calculator)[xii] and future prices are estimated by reflecting forecasted changes in future electricity prices. Example inputs and methodology for estimating daily charging costs for a fleet with the charging calculator are listed below.

Table 6: Sample of ACT Regulation Electric Vehicle Charging Assumptions

	Class 2b-3	Class 4-5	Class 7-8 Tractor
Number of Vehicles	20	20	20
Charger Rating	19 kW	19 kW	80 kW
Charger Efficiency	90%	90%	90%
Daily Miles	100 mi.	100 mi.	150 mi.
Energy Efficiency	0.56 kWh/mi.	0.96 kWh/mi.	2.1 kWh/mi.
Local Taxes and Fees	3 percent	3 percent	3 percent
Charging Period	Late evening charging period (9 PM – 6 AM)	Late evening charging period (9 PM – 6 AM)	Late evening charging period (9 PM – 6 AM)
Charging Strategy	Managed Charging	Managed Charging	Managed Charging

	Class 2b-3	Class 4-5	Class 7-8 Tractor
LADWP Rate	A-2(B)	A-2(B)	A-2(B)
PG&E Rate	CEV-L @ 350 kW	CEV-L @ 400 kW	CEV-L @ 1,200 kW
SMUD Rate	GS-GSS_T	GS-GSS_T	GS-TOU2
SDG&E Rate	AL-TOU2, EECC-CPP-D	AL-TOU2, EECC-CPP-D	AL-TOU2, EECC-CPP-D
SCE Rate	EV-8	EV-8	EV-9

Staff is planning to update the Charging Calculator and is soliciting feedback and data improvements on the Battery Electric Truck and Bus Charging Cost Calculator. Staff will use the feedback to update the electricity cost calculator and assumptions used.

Weights for the statewide average were determined from the California Energy Commission's Energy Consumption Database for Electricity Consumption in 2017 and are shown in Table 7.[xiii] These figures will be updated with current data.

Table 7: Energy Consumption by Utility 2017

Utility Provider	Total Usage (GWh)
Los Angeles Department of Water and Power	22,893
Pacific Gas and Electric	82,224
Sacramento Municipal Utility District	11,054
San Diego Gas and Electric	18,659
Southern California Edison	84,291

These inputs are used with the charging calculator to generate the example expected electricity prices and the statewide average as shown in Table 8.

Table 8: Cost per kWh per Utility and Statewide Average

Utility	Class 2b-3	Class 4-5	Class 7-8 Tractor
LADWP	$0.10	$0.10	$0.10
PG&E	$0.15	$0.14	$0.13
SMUD	$0.14	$0.11	$0.11
SDG&E	$0.21	$0.20	$0.19
SCE	$0.13	$0.12	$0.11
Weighted Average	**$0.14**	**$0.13**	**$0.12**

Electricity prices are expected to change over time. The US Energy Information Administration (EIA) has modeled potential electricity cost changes out to 2050 in their Annual Energy Outlook (AEO) "Energy Prices by Sector and Source" table, Pacific region.[xiv] These changes are displayed below.

Table 9: Cumulative Electricity Price Growth per Year

Year	Cumulative Electricity Cost Growth
2020	100%
2021	97%
2022	97%
2023	100%
2024	101%
2025	103%
2026	106%
2027	106%
2028	107%
2029	107%
2030	107%
2031	109%
2032	109%
2033	109%
2034	109%
2035	108%
2036	107%
2037	106%
2038	106%
2039	105%
2040	105%
2041	104%
2042	104%
2043	103%
2044	103%
2045	103%
2046	103%
2047	103%
2048	103%
2049	103%
2050	102%

Hydrogen Fuel Cost

Trillium projected hydrogen costs at different volume thresholds using four different production methods. [xv] Trillium provided updated numbers in an email conversation with CARB afterwards, shown in Table 10. [xvi]

Table 10: Trillium Projected Hydrogen Costs

H_2 Volume	Gaseous Delivery ($/kg)	Liquid Delivery ($/kg)	On-site SMR ($/kg)	On-site Electrolysis ($/kg)
Low Volume (150 kg/day)	$11.49	$10.21	$10.43	$11.05
Intermediate Volume (1,000 kg/day)	$7.67	$6.39	$5.81	$6.46
High Volume (6,000 kg/day)	$5.72	$4.43	$4.21	$4.90

This report uses liquid hydrogen delivery numbers based on what Trillium presented as being most feasible for production at scale. In the Advanced Clean Trucks regulation, the low volume cost was used in 2018, the intermediate volume in 2030, and the high volume in 2050 with intermediate years being interpolated. These assumptions were based on expecting low volume production, intermediate volume by 2030 when staff expect some moderate sized deployments but no complete conversions yet, and continuing price reductions out to 2050.

Staff are soliciting any additional or more current information on pricing, projections, and assumptions for hydrogen costs.

Diesel Exhaust Fluid Costs

Diesel-powered vehicles equipped with modern emissions control devices require diesel exhaust fluid to break down nitrogen oxides in the exhaust stream. Argonne National Laboratory estimates DEF consumption as being 2 percent of total fuel usage in their online 2019 AFLEET tool (https://greet.es.anl.gov/index.php?content=afleet). This assumption will be applied to the fuel economy discussed previously to estimate the DEF consumption per mile. DEF is assumed to cost $2.91 per gallon per the Heavy-Duty Low-NOx Omnibus Staff Report.

Retail Fueling

Retail fueling refers to publicly accessible stations that charge a fee based on the amount of electricity or hydrogen dispensed. Staff did not model the costs of public retail charging in the ACT regulation. The proposed Advanced Clean Fleet regulation seeks to achieve a full transition to zero emission vehicles which is expected to require a ZEV fueling network. Staff is soliciting feedback on an appropriate methodology to estimate these costs. Some questions include:

- How should staff estimate the price to the fleet for each kWh or kg dispensed?

- Should the differing infrastructure installation costs associated with hydrogen and electric fueling be considered?
- Should parameters such as maintenance, location, and time of refueling be taken into account?
- How should staff model LCFS credit revenue? Are these savings passed through to the fleet customer or held by the charging station owner?

Fuel Efficiency

Fuel economy data was derived from EMFAC2017[xvii] inventory projections for diesel and gasoline groups, and incorporates anticipated increases in fuel economy from GHG Phase II regulation. Battery-electric vehicle (BEV) fuel economy is derived from in-use data collected from a variety of vehicles. FCEV fuel economy is estimated by applying the LCFS[xviii] program's Energy Efficiency Ratio (EER) of 1.9 compared to a similar diesel vehicle's fuel economy. Natural gas vehicle fuel economy is estimated by applying the LCFS program's EER of 0.9 compared to a similar diesel vehicle. Efficiency for BEV and FCEV is assumed to improve at the same rate as gasoline and diesel vehicles.

Table 11: Fuel Economy Table

Vehicle Group	Technology	Fuel Economy 2024-2026MY	Fuel Economy 2027MY and Beyond	Units
Class 2b-3	Gasoline	10.9	11.7	mpg
Class 2b-3	Diesel	23.0	24.8	mpg
Class 2b-3	BEV	2.0	2.1	mi./kWh
Class 2b-3	FCEV	31.1	33.3	mi./kg
Class 4-5	Diesel	13.8	14.3	mpg
Class 4-5	NatGas	12.4	12.9	mpdge
Class 4-5	BEV	1.3	1.3	mi./kWh
Class 4-5	FCEV	29.9	31.0	mi./kg
Class 6-7	Diesel	9.6	9.9	mpg
Class 6-7	NatGas	8.6	8.9	mpdge
Class 6-7	BEV	0.8	0.8	mi./kWh
Class 6-7	FCEV	20.8	21.4	mi./kg
Class 8	Diesel	7.7	8.1	mpg
Class 8	NatGas	6.9	7.3	mpdge
Class 8	BEV	0.6	0.7	mi./kWh
Class 8	FCEV	16.7	17.5	mi./kg
Class 7-8 Tractor	Diesel	8.8	9.2	mpg
Class 7-8 Tractor	NatGas	7.9	8.3	mpdge
Class 7-8 Tractor	BEV	0.6	0.6	mi./kWh
Class 7-8 Tractor	FCEV	19.1	19.9	mi./kg

Low Carbon Fuel Standard

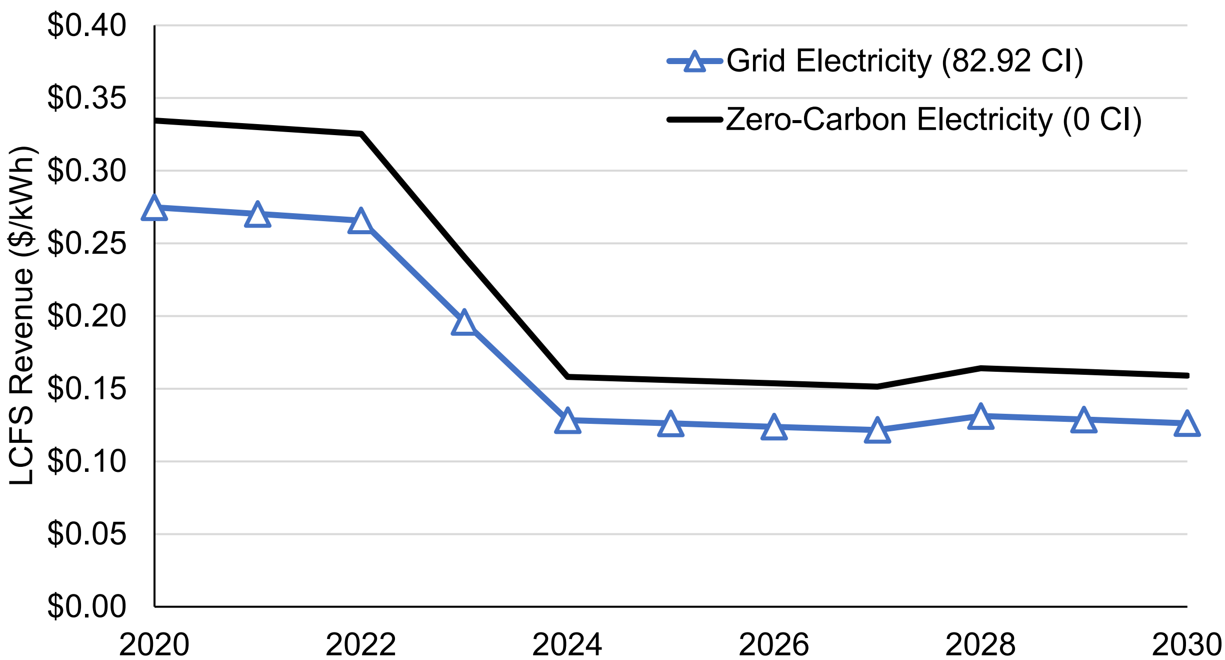
The Low Carbon Fuel Standard (LCFS) regulation creates a market mechanism that incentivizes low carbon fuels by requiring California's transportation fuels to reduce their carbon intensity (CI). Low-carbon fuels such as electricity and hydrogen are eligible to earn credits that can be sold to offset the cost of these fuels. Revenue generated from the LCFS program can be calculated using the LCFS Credit Price Calculator, located here: http://ww3.arb.ca.gov/fuels/lcfs/dashboard/creditvaluecalculator.xlsx.

The amount of credits generated depends on the CI of fuel and the market credit price. Should staff use a constant credit price to simplify the analysis or use the same credit price as described in the staff report for the 2019 LCFS amendments. In summary, the 2019 LCFS amendments price remains at $200 until 2022, declines to $100 by 2024 and increases to $110 in 2028 and remains at that level afterwards.[xix]

Battery-Electric Vehicles

Owners of non-residential charging stations are eligible to earn LCFS credits. As a result, fleets who own their own chargers can earn credits and sell them to offset or eliminate their fuel costs. The amount of credit depends on the CI of the electricity source with lower CI fuel sources generating more credits. As of today, the CI of grid electricity is 82.92 gCO_2e/MJ and is projected to continue declining as a result of the state's renewable energy policies.[xx] Fleets can use non-grid sources with lower or zero CI in lieu of grid electricity. Figure 3 illustrates the estimated LCFS revenue from vehicles using electricity as a transportation fuel.

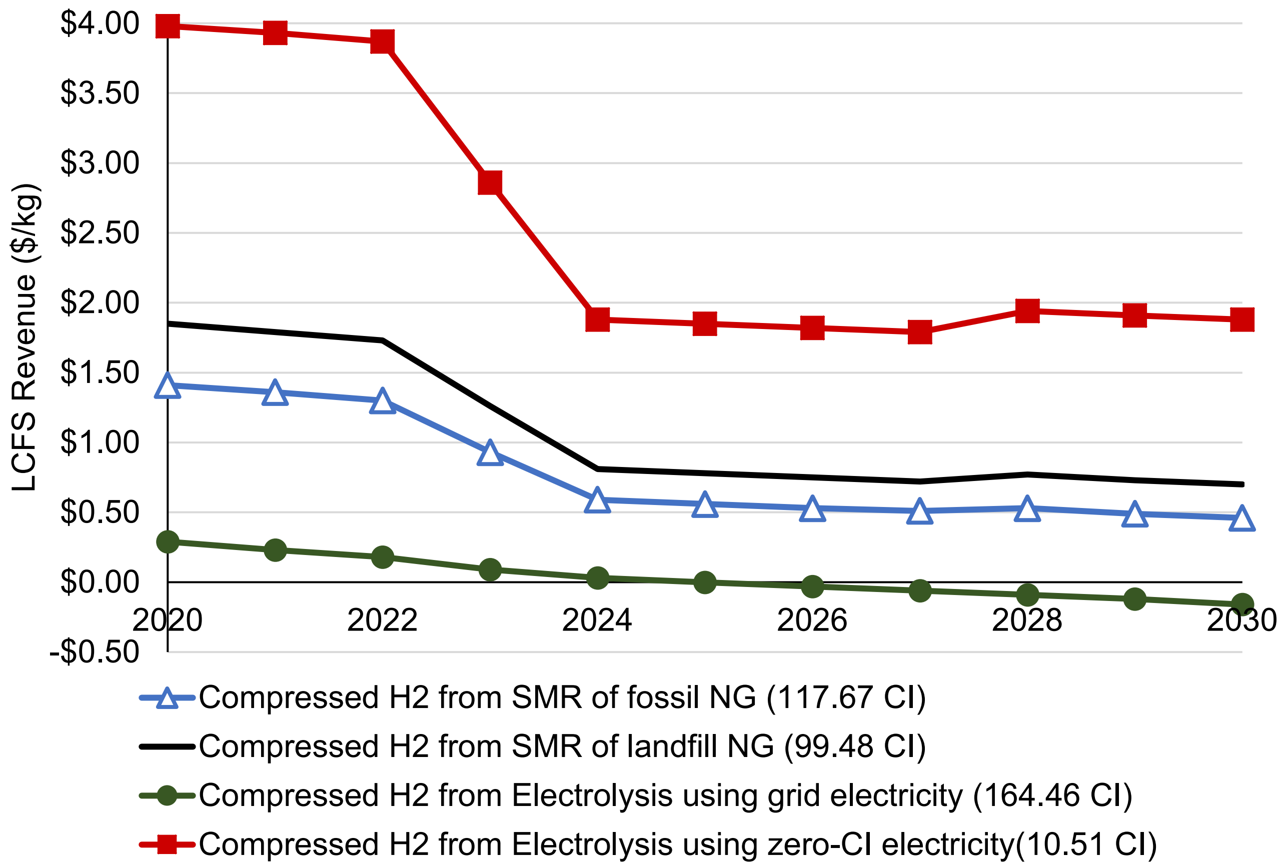
Figure 6: LCFS Revenue of Electricity per kWh Over Time for a Class 4-8 Vehicle



Hydrogen Fuel Cell Vehicles

The hydrogen station owner is eligible to earn LCFS credits based on the CI of the hydrogen source and the amount of fuel dispensed. Hydrogen station owners may also designate another party such as a fleet to receive the LCFS credits in lieu of themselves. Figure 4 illustrates the amount of LCFS revenue that would be generated based on the different hydrogen production methods over time. These revenue projections are dependent on the credit price as discussed previously.

Figure 7: LCFS Revenue of Hydrogen per Kilogram over Time for a Class 4-8 Vehicle



Maintenance Cost

The maintenance cost reflects the cost of labor and parts for routine maintenance, preventative maintenance, and fixing broken components.

Table 12: Maintenance Cost Data Sources

Cost ($/mi.)	Vehicle Studied	Data Source
$0.16	ADA Minivan – CNG	Access LA Report[xxi]
$0.20	ADA Minivan – Gasoline	Access LA Report

Cost ($/mi.)	Vehicle Studied	Data Source
$0.353	Utility Cargo Van - Diesel	Argonne NL AFLEET 2019[xxii]
$0.14	Diesel SUV	CEC Presentation[xxiii]
$0.23	Diesel SUV	Argonne NL AFLEET 2019
$0.16	1/2 Ton Pickup – 4x2 and 4x4	Utilimarc Report[xxiv]
$0.07	Compact Pickup – Gasoline	CEC Presentation
$0.06	Midsize Pickup – Gasoline	CEC Presentation
$0.08	1/2 Ton Pickup	AAA Brochure[xxv]
$0.313	Medium-Duty Pickup - Diesel	Argonne NL AFLEET 2019
$0.22	Class 4 Stepvan - Diesel	2011 NREL Report[xxvi]
$0.21	Class 4 Stepvan - Hybrid Gasoline	2011 NREL Report
$0.201	Delivery Stepvan - Diesel	Argonne NL AFLEET 2019
$0.13	Class 4 Stepvan - Diesel	2012a NREL UPS Study[xxvii]
$0.14	Class 4 1st Gen Stepvan - Hybrid Diesel	2012a NREL UPS Study
$0.17	Class 6 Stepvan - Diesel	2012b NREL UPS Study[xxviii]
$0.22	Class 6 2nd Gen Stepvan - Hybrid Diesel	2012b NREL UPS Study
$0.22	Class 6 Stepvan - Diesel	Fleet estimate
$0.236*	Class 4 Stepvan - Diesel	2002 NREL UPS Study[xxix]
$0.263*	Class 4 Stepvan - CNG	2002 NREL UPS Study
$0.29	Class A,B,C Cutaway Shuttle	Access LA Report
$0.321	Shuttle/Paratransit Van - Diesel	Argonne NL AFLEET 2019
$1.00	Shuttle/Paratransit Bus - Diesel	Argonne NL AFLEET 2019
$0.14	Class 7 Straight Truck – Hybrid	2012 NREL Coca-Cola Study[xxx]
$0.29	Class 7 Straight Truck – Diesel	2012 NREL Coca-Cola Study
$0.204	Delivery Straight Truck - Diesel	Argonne NL AFLEET 2019
$0.31	Straight Truck	2017 ATRI Report[xxxi]
$0.199	Street Sweeper, Sewer Cleaner, Snow Plow/Sander, Bucket/Aerial Truck, Dump Truck - Diesel	Argonne NL AFLEET 2019
$0.19	Class 8 Tractor – LTL	2018 ATRI Report[xxxii]
$0.19	Regional Haul Freight Tractor - Diesel	Argonne NL AFLEET 2019
$0.22	Class 8 Tractor – Specialized	2018 ATRI Report
$0.13	Class 8 Tractor – TL	2018 ATRI Report
$0.14	Class 8 Tractor	Fleet Advantage[xxxiii]
$0.19	Long-haul Freight Tractor - Diesel	Argonne NL AFLEET 2019
$0.28	Class 8 Diesel Tractor	Manufacturer estimate
$0.19	Class 8 Drayage Tractor	Bloomberg[xxxiv]
$0.80	Class 8 Diesel - Refuse	M.J. Bradley and Associates[xxxv]
$0.143	Aggregated 2019 All Categories	2020 ATRI Report

*Data from 2002 has been adjusted using CPI

Battery-electric

- A paper by Propfe, B. et. al. estimates based on a component level analysis that a battery-electric light-duty vehicle will have maintenance costs 20% lower than a comparable ICE vehicle while an extended-range electric vehicle could see maintenance savings of nearly 30%.[xxxvi]
- A paper by Taefi, T. et. al. found an estimated 20%-30% maintenance savings on electric freight vehicles based on feedback from fleets operating these vehicles.[xxxvii]
- A whitepaper by the Electrification Coalition estimated a battery-electric car have 28% reduced maintenance costs compared to a gasoline car, and a plug-in hybrid would have 6% reduced maintenance costs.[xxxviii]
- A CARB study analyzed data available on the maintenance cost of battery-electric buses versus diesel and CNG buses. It found the maintenance cost of a battery-electric bus was $0.60/mi. versus $0.85/mi. for a diesel or $0.79/mi. CNG bus, reflecting a 30% maintenance cost reduction.[xxxix]
- A report by Gladstein, Neandross, and Associates cites a 50% maintenance cost reduction for battery-electric trucks based on feedback from manufacturers.[xl]
- Numerous electric vehicle manufacturers that staff has spoken to are seeing an 80% reduction in maintenance costs, although this is based on limited data.
- UC Davis Report: BEVs show 50% reduction in maintenance costs vs. equivalent diesel vehicles.[xli]

Hydrogen

- Ballard recommends estimating a fuel cell bus's maintenance costs as the same as a battery-electric bus plus $0.20/mi. for fuel cell maintenance. This adjustment will put a fuel cell bus in line with a diesel or CNG bus.[xlii]
- UC Davis Report: FCEVs show 50% reduction in maintenance costs vs. equivalent diesel vehicles.[xliii]
- Nikola reports 50% reduction in maintenance costs vs equivalent diesel in 2016 article from TTNews.[xliv] ($0.06/mi for FCEV vs $0.12/mi. diesel)

Infrastructure Costs

Charger Costs

EVSE units come in a variety of designs and are available from many different manufacturers with cost affected by charging level, number of ports, type of mount, location, and communication system being networked or non-networked. Estimated charger costs derived from August 2019 ICCT report.

Table 13: Estimated Charger Costs per Type and Power Level

Charging Type	Power Level	Price Range ($)
Level 1 AC (Non-Networked)	< 2 kW	$500-1,000
Level 2 AC (Non-Networked)	< 8 kW	$500-1,000
Level 2 AC (Non-Networked)	10-20 kW	$700-1,500
Level 2 AC (Networked)	< 8 kW	$500-1,000
Level 2 AC (Networked)	10-20 kW	$3,000-6,500
Level 3 DC (Networked)	20-30 kW	$10,000-40,000
Level 3 DC (Networked)	50-150 kW	$50,000-100,000
Level 3 DC (Networked)	150+ kW	$150,000+

Electrical Site Upgrades

The costs associated with installing and operating EVSE vary depending on unit features, site location, available electrical capacity, and labor costs. Some locations will need minimal to no utility upgrades for deploying a few ZEVs and as a result the fleet will only need to pay for the charger. For larger deployments, in most cases, electrical infrastructure (e.g. trenches, transformers, switchboards, and conduit) will need to be upgraded or installed in order to accept the high-power service necessary to support multiple chargers in a depot or yard. Estimated installation cost by power level and number of chargers per site from August 2019 ICCT report.

Table 14: Cost of Installing 50 kW Chargers per Site

Cost Center	1 Charger	2 Chargers	3-5 Chargers	6-50 Chargers
Labor	$19,200	$15,200	$11,200	$7,200
Materials	$26,000	$20,800	$15,600	$10,400
Permit	$200	$150	$100	$50
Taxes	$106	$85	$64	$42
Total	$45,506	$36,235	$26,964	$17,692

Table 15: Cost of Installing 150 kW Chargers per Site

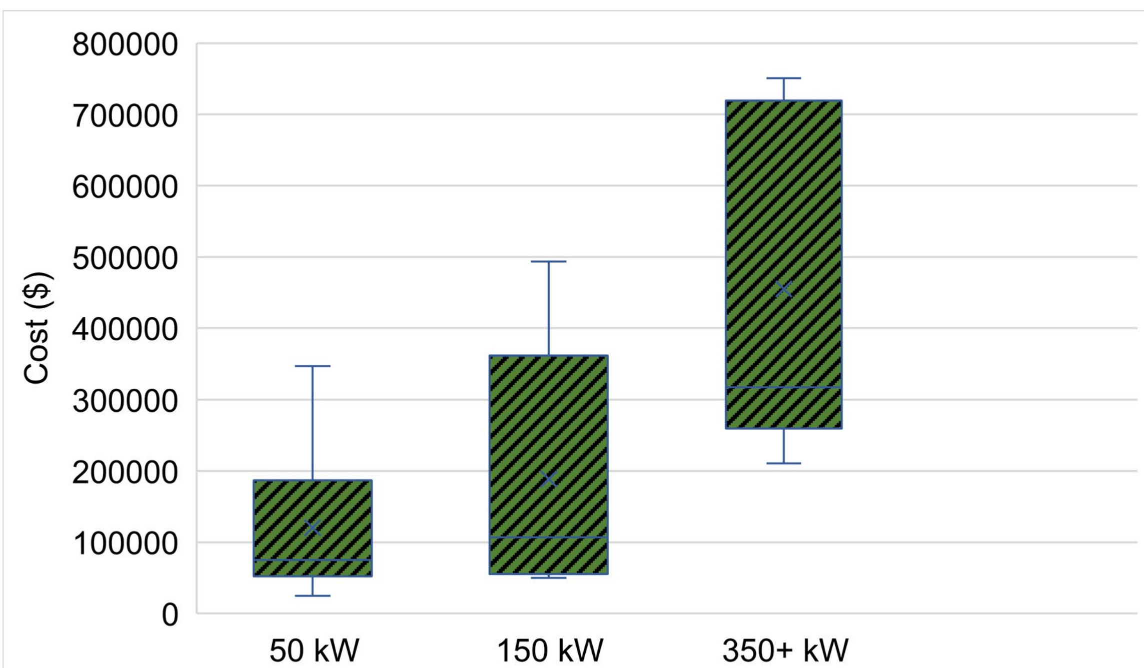
Cost Center	1 Charger	2 Chargers	3-5 Chargers	6-20 Chargers
Labor	$20,160	$15,960	$11,760	$7,560
Materials	$27,300	$21,840	$16,380	$10,920
Permit	$210	$158	$105	$53
Taxes	$111	$89	$67	$45
Total	$47,781	$38,047	$28,312	$18,577

Table 16: Cost of Installing 350 kW Chargers per Site

Cost Center	1 Charger	2 Chargers	3-5 Chargers	6-10 Chargers
Labor	$27,840	$22,040	$16,240	$10,440
Materials	$37,700	$30,160	$22,620	$15,080
Permit	$290	$218	$145	$73
Taxes	$154	$123	$92	$62
Total	$65,984	$52,541	$39,097	$25,654

This ICCT report represents a majority of the less complicated infrastructure installations but fails to account for the large costs associated with electrical utility upgrades needed for some projects. This is shown below in the larger range of 350 kW infrastructure installations as those are typically the ones in need of more extensive site upgrades. Data was compiled from estimates, budgets, and finalized invoices from 20 projects containing 50, 150, and 350 kW chargers after removing 2 extreme outliers. It should be noted that total average cost is represented per EVSE and does not account for the multiple ports some of these chargers provide. Several projects also include the cost of installing non EVSE equipment which was unable to be extracted from available itemized invoice data creating inflated upper bounds in the price predictions.

Figure 8: Total Average Cost per Charger Installer



Ongoing Expenses

Transitioning to a new technology has inherent costs associated with its deployment, including shifts in operational and maintenance practices. These recurring costs include operator and technician trainings, purchasing and upgrading of software, securing additional spare parts to replace charger heads, connectors, and other components, as well as labor costs for regular inspections. Charger maintenance costs vary based on the service contract but are estimated at $500/ year/ charger.

Natural Gas Infrastructure Costs

Natural gas vehicles require stations to dispense compressed or liquid natural gas. For the development of the Innovative Clean Transit regulation, staff used values of $4,000,000 for a 100 bus CNG station and $6,000,000 for a 200 bus CNG station.[xlv]

Other

Sales Tax & Federal Excise Tax

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. California's basic sales tax rate is 7.25 percent with 3.94 percent going to the State and the rest to local authorities. In addition to the basic sales tax, districts levy special taxes that differ amongst districts. A sales tax value of 8.5 percent was used for staff's analysis 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.

Financing Costs

ATRI Operational Costs of Trucking 2019[xlvi] reports an average marginal cost per mile in 2018 for Truck/Trailer Lease or Purchase Payments of $0.265/mi.

Insurance

ICE

Insurance premiums are included in equipment-related cost centers. Newer trucks may have less crashes due to better safety equipment, but also cost more to repair. According to ATRI[xlvii], "trucking fleets are assuming higher risk levels through higher deductibles, self-insurance, expanding use of insurance captives, and lower levels of excess liability coverage", and may have "reached a ceiling in its ability to continuously cover annual double-digit increases in insurance premiums."

- According to ATRI, smaller fleets appear to be disproportionately affected by higher insurance costs - ~$0.15/mi. in 2019 for fleets under 26 power units, while fleets with over 1,000 units had ~$0.053/mi. Specialized fleets also carry higher risk premiums. Private fleets show insurance costs around ~$0.09/mi. due to ability to hedge insurance costs through other parts of the business. Carriers at or under 100 unites had $0.107/mi. average, while fleets over 100 units had $0.060/mi.

- Costs are likely to increase over time, but likely at a low growth rate. 2011-2018 showed a 12% increase, but costs dropped from 2018 to 2019, such that 2011-2019 shows a growth of 1.5%.
- ATRI Operational Costs of Trucking 2020 reports an average marginal cost per mile in 2019 for Insurance Premiums for all respondent vehicles of $0.068/mi. In 2019, the share of the total average marginal cost to the motor carrier for insurance premiums was about 4%. In the breakdown by region, the West region has the second highest average marginal cost per mile at $0.077.

BEV/FCEV

No empirical data found to compare cost of insuring ZEVs vs ICE medium- and heavy-duty vehicles. Some data is available for light duty.

- A FleetOwner.com article[xlviii] from January 10, 2020 states “items like insurance, permits, and licenses… are likely to be on a par with what a fleet is paying for its diesel-powered vehicles.
- MyEV.com article states “In a study conducted by the personal finance website NerdWallet.com, auto insurance quotes for electric cars were found to be 21 percent higher, on average, than comparable gas-powered models.”[xlix] Higher cost of repair is primary factor.
- Insure.com article states “Insure.com reviewed five popular electric vehicles (EVs) and found that they cost 15.5 percent more per year on average to insure than their gas-powered cousins.”[l]
- Whatcar.com article states higher insurance costs in the early market were due to lack of available/historical data on which to base actuarial risk assessments, but as the market develops costs come down as more cars are available, more insurers enter the market, mechanics/technicians have more expertise to lower repair costs.[li]
- Thesimpledollar.com article states “Typically, electric cars cost at least 20 percent more to insure than combustion engine models, because they have higher sticker prices and they cost more to repair.”[lii]
- Arthur D Little consultant firm put out a comparison report in November 2016 which projects a 2025 mid-size BEV will have a 5% increase in premiums vs an ICE vehicle.[liii]

Battery/Fuel Cell End of Life Recycling and Disposal

The energy capacity of the batteries used in ZEVs will naturally degrade over their useful life and require battery replacements. When battery capacity is not sufficient for meeting daily range needs for a truck or bus, it is expected that there will be a second life for the batteries. The used battery at the end of its vehicle useful can be repurposed into other applications such as stationary storage, then at the end of the battery life it can be recycled and non-recyclable materials can be disposed. The cost for battery recycling at the end of battery life is not included here, because this cost could be offset by the residual value of the battery at the end of its useful life in a truck or bus. The end of life may be a revenue source depending on whether the battery can be recycled and repurposed, or could become a cost if it must be disposed of. Today, light-duty vehicle batteries are already being repurposed for second life applications including stationary storage (Nissan, 2018), (BMW, 2018). Even today, some lithium-ion battery manufacturers provide an attractive residual value to customers upon the retirement of a battery. Therefore, staff believes that the residual value will offset the recycling cost and become a revenue source, but does not include a residual battery value in the economic analysis.

Maintenance Bay Upgrades

Maintenance bays are facilities used to service vehicles. Services performed can include inspections, routine maintenance, preventative maintenance, repairs, overhauls and more. Servicing electric vehicles requires separate safety equipment, diagnostic tools, and equipment which will incur costs to the facility. Based on transit agency data, upgrading a fifteen-bus maintenance bay to handle battery-electric buses would cost $25,000, and upgrading to handle fuel cell electric buses would cost $750,000. For this analysis, it is assumed that the cost per maintenance bay is the same and a fifteen-bus maintenance bay could accommodate 25 trucks due to their smaller size. The number of maintenance bay upgrades each year is based on the increase in ZEV population per year to avoid double-counting in situations where a ZEV is replaced by a ZEV.

Weight and Payload Effects

Staff are soliciting feedback to assess weight and payload effects on cost.

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