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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Incremental Purchase Cost Methodology and Results for Clean Vehicles

Vehicle Technologies Office

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Note on December 2023 Amendments to the December 2022 Report

This amended report includes updated table headings in Tables 2 – 5 to clarify that the representative vehicle used to calculate the incremental costs applies across the whole vehicle Type or Class and not only to certain representative vehicles in each Class.

Introduction

The goal of reducing costs and in turn achieving cost parity for plug-in and fuel cell vehicles compared with internal combustion engine vehicles has driven numerous DOE research efforts. Achieving up front cost parity (i.e., reducing the purchase price differential, referred to hereafter as "incremental cost," to zero between these vehicle types) is of interest to those who purchase vehicles and to the companies that manufacture them. Variation across vehicle makes and models and the lack of a directly comparable vehicle in most cases may make it difficult to directly determine the incremental cost of vehicle electrification technologies by comparing two actual vehicles for sale. This document sets forth DOE's current approach for determining an incremental cost[1] for a plug-in hybrid electric vehicle (PHEV), battery electric vehicle (BEV), or fuel cell electric vehicle (FCEV) using current costs. The current results for several classes of vehicles are provided.

Background

"Cost parity" for plug-in and fuel cell vehicles compared with internal combustion engine vehicles is a relevant goal in the context of supporting new, efficient, and clean mobility options that are affordable for all Americans. DOE's support of clean vehicle and battery research has helped to drive the downward trajectory of clean vehicle and battery costs.[2] Prior DOE analyses estimate that the cost of an electric vehicle lithium-ion battery pack dropped 87% between 2008 and 2021 (using 2021 constant dollars), and they continue to decline.[3] Future research seeks to drive the cost of EV batteries to under $100/kWh, and ultimately $60/kWh[4] and the results of this research warrant updates to this analysis over time.

Cost parity refers to achieving an equal cost with another option, here a conventional internal combustion engine (ICE) vehicle, resulting in a zero incremental cost between the sales price of the two vehicle types. Industry and trade news routinely offer estimates for the year in which cost parity might be achieved. In addition to purchase price, some comparisons also incorporate the cost of owning, operating, and maintaining these vehicle types, that is, the total cost of ownership, or TCO. While cost parity is of interest to the public, auto manufacturers or original equipment manufacturers (OEMs) are also focused on the incremental cost as it is relevant to their overall business models.

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[1] These incremental costs are estimates for representative vehicle classes and do not necessarily reflect the incremental costs a consumer may experience for a particular model.

[2] ANL - ESD-2206 Report - 2022 DOE VTO HFTO Transportation Decarbonization Analysis.pdf

[3] 2018–2021 – U.S. DOE, Vehicle Technologies Office, using Argonne National Laboratory's BatPaC: Battery Manufacturing Cost Estimation Tool; 2017 – Steven Boyd, DOE, Vehicle Technologies Office, 2017 Annual Merit Review, Batteries and Electrification R&D Overview, June 18, 2018, PowerPoint presentation, p. 7; 2016 – David Howell, DOE, Vehicle Technologies Office, 2017 Annual Merit Review, Electrochemical Energy Storage R&D Overview, June 20, 2017, PowerPoint presentation, p. 6; 2008–2015 – National Academies of Sciences, Engineering, and Medicine 2017. Review of the Research Program of the U.S. DRIVE Partnership: Fifth Report. Washington, DC: The National Academies Press, p. 173.

[4] DOE FY23 Budget Volume 4, Energy Efficiency and Renewable Energy Proposed Appropriation Language, https://www.energy.gov/sites/default/files/2022-04/doe-fy2023-budget-volume-4-eere-v2.pdf, p. 21.

The incremental cost of a clean vehicle is the excess of the purchase price of such vehicle over the price of a comparable vehicle. For the purpose of this analysis, a comparable vehicle with respect to any BEV, PHEV, and FCEV is a vehicle that is powered solely by a gasoline or diesel internal combustion engine and is comparable in size and use to such vehicle.

Variation across vehicle makes and models and the lack of a directly comparable vehicle in many cases makes it difficult to determine the incremental cost of vehicle electrification technologies by comparing two vehicles currently for sale. However, it is relatively straight-forward to analytically estimate the incremental cost of deploying an electric powertrain (PHEV, BEV, or FCEV) in place of the powertrain of an ICE vehicle. Industry OEMs commonly use the proffered analytical approach to determine the incremental cost for a new BEV, PHEV, or FCEV.

The DOE Autonomie model, managed by Argonne National Laboratory, allows a user to switch out powertrain components and analyze the key powertrain technologies that differ between conventional and electric powertrains. Autonomie is updated regularly and has undergone extensive vetting and input from industry, including a recent major review by U.S. DRIVE[5] and 21st Century Truck Partnership,[6] two voluntary government-industry partnerships focused on advanced automotive and related energy infrastructure technology research and development.

Using the Autonomie model, DOE estimated the current incremental cost for each electrified powertrain for the different representative vehicle classes shown in Table 1. Vehicles modeled are representative of broader vehicles classes that use a range of battery and fuel cell sizes, and which are defined at 40 CFR § 600.315-08. Class 4-6 is represented by an average of cost across these size classes.

Table 1: Mapping of Modeled Vehicle to Broader Represented Classes of Vehicles[7]

Representative Vehicle Modeled	Representative of Vehicle Class	Gross Vehicle Weight Rating of Representative Vehicle Classes
Compact Car	Minicompact, Subcompact and Compact Cars	<14,000 lbs.
Midsize Car	Midsize and Large Car, All Station Wagons	<14,000 lbs.
Midsize SUV	Standard SUV, Small SUVs, Minivans	<14,000 lbs.
Pickup Truck	Pickup Trucks, including Classes 2/3	<14,000 lbs.
Class 4 - 6 Box	Classes 4 - 6	14,001 – 26,000 lbs.
Class 7 Daycab	Class 7	26,001 – 33,000 lbs.
Class 8 Longhaul	Class 8	>33,000 lbs.

[5] https://www.energy.gov/eere/vehicles/us-drive

[6] https://www.energy.gov/eere/vehicles/21st-century-truck-partnership

[7] 40 CFR § 600.315-08

For BEVs and PHEVs, battery costs comprise the majority of that incremental cost difference and thus are the primary determinant in estimating projected incremental costs for these vehicles. Additional costs include electric powertrain components. For FCEVs, hydrogen storage and fuel cell costs are the chief determinants of incremental cost, and additional powertrain components are also considered relevant to estimating projected incremental cost for FCEVs.

The values in Table 2 below show the current cost of representative vehicles across vehicle classes and powertrains, where only the powertrain elements are exchanged for BEVs, PHEVs, or FCEVs, rounded to the nearest five hundred dollars. In this analysis, battery sizes as well as fuel cell size and hydrogen storage were selected to match ranges across ICE and electric vehicles, as noted in Table 3 and Table 4. The selected vehicle range is based on current understanding of driving needs given still-developing plug-in vehicle charging infrastructure. The resulting incremental costs are shown in Table 5. All other inputs, such as lightweighting and trim level, are consistent across the relative comparison.

Table 2: Modeled Representative Vehicle Cost, 2022, rounded to the nearest $500.

Vehicle Type/Class	Conv	BEV	PHEV	FCEV
Compact Car	$24,500	$32,000	$31,500	$35,500
Midsize Car	$28,500	$37,000	$36,500	$43,500
Midsize SUV	$33,500	$47,500	$43,000	$52,500
Pickup Truck	$36,000	$55,500	$50,000	$71,500
Class 4 - 6	$72,500	$107,000	$100,500	$113,500
Class 7	$117,500	$211,000	$183,500	$198,000
Class 8	$160,000	$457,500	$324,000	$265,500

Table 3: Battery Size and Associated Range Assumptions

	Battery Size (kWh) / Range (Miles)	
Vehicle Type/Class	BEV	PHEV
Compact Car	70 / 300	19 / 50
Midsize Car	73 / 300	18 / 50
Midsize SUV	97 / 300	24 / 50
Pickup Truck	118 / 300	30 / 50
Class 4-6	191 / 150	95 / 75
Class 7	479 / 250	257 / 125
Class 8	1369 / 500	710 / 250

*Ranges for PHEVs will be variable, but in all instances will provide sufficient range to complete transportation duty cycles due to the availability of an internal combustion engine.

Table 4: Hydrogen Fuel Cell Size and Associated Range Assumptions

Fuel Cell Size (kW) / H_2 storage (kg) / Range (Miles)

Vehicle Type/Class	FCEV
Compact Car	36 / 3.7 / 300
Midsize Car	40 / 4.4 / 300
Midsize SUV	49 / 5.1 / 300
Pickup Truck	61 / 6.7 / 300
Class 4–6	75 / 10 / 150
Class 7	162 / 28 / 250
Class 8	180 / 69 / 500

The input costs used reflect battery costs of $150/kWh for higher volume purchases for light duty vehicles (LDVs), including sport utility vehicles (SUVs), and $200/kWh for lower volume purchases (medium and heavy-duty vehicles (MHDVs), Classes 3-8). These estimated costs were selected as conservative current estimates to be more inclusive of the various prices that OEMs across the market experience and to account for short-term price increases due to supply constraints, as has been the case in 2022. These values also include cost mark ups associated with low production volumes and they capture additional costs of smaller components and factor in the higher cost of low-volume FCEV production.

Battery costs are the key determinant of incremental cost for BEVs/PHEVs. Battery costs have decreased dramatically since 2010[8] and the costs noted above reflect an average price that DOE estimates OEMs can currently achieve for batteries given the state of technology and the cost of battery inputs. These prices may be higher or lower for any one OEM based on its specific supplier relationship and volumes. DOE expects the cost in the market to remain stable in the near term. As new production comes online both globally and in the United States, it is expected that these prices will decrease relatively quickly. Additional cost reductions are expected from EV battery manufacturing advances. Cost reductions in hydrogen fuel cells and storage are expected to occur more slowly until production volumes grow.

Based upon these assumptions, the resulting incremental costs are shown in Table 5.

[8] FOTW #1206, Oct 4, 2021: DOE Estimates That Electric Vehicle Battery Pack Costs in 2021 Are 87% Lower Than in 2008 | Department of Energy

Table 5: Resulting Incremental Cost, Vehicle Classes, 2022.

Vehicle Type/Class	BEV	PHEV	FCEV
Compact Car	$7,500	$7,000	$11,000
Midsize Car	$8,500	$8,000	$15,000
Midsize SUV	$14,000	$9,500	$19,000
Pickup Truck	$19,500	$14,000	$35,500
Class 4-6	$34,500	$28,000	$41,000
Class 7	$93,500	$66,000	$80,500
Class 8	$297,500	$164,000	$105,500

Because incremental cost is primarily a function of the battery cost for BEVs/PHEVs and the fuel cell and hydrogen tank size for FCEVs, generic equations (below) provide a framework for estimating the incremental cost of any given vehicle. This framework can be especially useful for MHDVs, of which there are many sizes and uses, and for which various battery sizes and fuel cell systems may lead to different calculated incremental costs. Additionally, equations will enable OEMs to use their knowledge of projected costs to estimate for the long term any incremental costs. These equations afford manufacturers the capability of calculating the relevant incremental cost for their BEVs, PHEVs, and FCEVs. As costs of batteries, fuel cells, and hydrogen tanks decrease over time, DOE may update the analysis.

Equations

- Incremental Price of BEV or PHEV = Battery Total Energy (kWh)*Battery Price ($/kWh) + Intercept
- Incremental Price of FCEV = [FC Power (kW)*Fuel Cell Price ($/kW) + H_2 storage constant Price + (H_2 mass(kg) * H_2 Price ($/kg))] + Intercept

Where:

- The **Intercept** incorporates powertrain cost savings from the conventional powertrain (e.g., engine, transmission, and other components) less costs from components added for the new electric powertrain (e.g., motor and other key components).

Results

Based on current costs, representative clean vehicles under 14,000 pounds have generalized incremental costs relative to conventional vehicles that range from $7,000 to $35,500. With the exception of PHEV Compact cars,[9] all vehicles under 14,000 pounds have an incremental cost of $7,500 or greater. For vehicle classes over 14,000 pounds, the incremental cost relative to a conventional vehicle ranges from $28,000 to $297,500. Battery size and fuel cell costs are the key

[9] 40 CFR § 600.315-08

drivers of incremental cost, resulting in an incremental cost for Class 4-6 vehicles of $34,500 (BEV), $28,000 (PHEV), and $41,000 (FCEV). All other vehicle classes larger than 14,000 pounds have incremental costs of $66,000 or greater.

DOE anticipates that incremental costs for clean vehicles will decline as costs of EV batteries and hydrogen fuel cells continue to decline, as they have dramatically since 2010. DOE’s expectation is based upon the Department’s keen understanding of advances in battery production over the years, industry statements, trade press estimates, and DOE’s own predictive modeling. Pending future market trends, DOE intends to revisit and refine both its approach and/or the predictive equations set forth in this document, if needed, to update its calculation of cost comparability.

Summary

Variation across vehicle makes and models and the lack of a directly comparable vehicle in most cases makes it difficult to directly determine the incremental cost of vehicle electrification technologies by comparing two actual vehicles for sale. Using the Autonomie model, DOE has determined incremental cost values that are representative for several representative vehicle classes. The model offers a simplified approach that affords certainty for both vehicle manufacturers and regulators. DOE research seeks to drive EV battery costs down further, and as the costs decline consistent with prior DOE market assessments, an update to this analysis will be relevant and appropriate.