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Assessment of light-duty electric vehicle costs and consumer benefits in the United States in the 2022-2035 time frame

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Executive Summary

As global electric vehicle production volumes proliferate, their costs decline and the prospects of an electric vehicle transition increases. Improvements in battery and vehicle technology lead to questions about how quickly electric vehicle costs will decline and reach price parity with conventional vehicles, and about the magnitude of the associated fuel-saving benefits. This paper analyzes bottom-up vehicle component-level costs to assess battery electric, plug-in hybrid electric, and conventional vehicle prices across major U.S. light-duty vehicle classes through 2035. We find that battery electric vehicles have upfront prices that are about $3,000 to $25,000 greater than their gasoline counterparts in 2022. With declining electric vehicle battery and assembly costs, shorter-range BEVs of 150 to 200 miles are projected to reach price parity by 2024–2026, followed by mid-range BEVs with 250 to 300 miles around 2026–2029, and the longest-range BEVs with 350 to 400 miles around 2029–2032.

Keywords: Light vehicles, BEV, PHEV, ICE, cost

1 Introduction

The global transition to zero-emission vehicles continues to accelerate. On an annual basis, global light-duty electric vehicle sales—including both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)—increased from less than 10,000 in 2010, to more than 1 million in 2017, more than 3 million in 2020, and more than 6.5 million in 2021. Globally, nearly 17 million cumulative light-duty electric vehicles were sold through 202. BEVs represent about 70% of these sales and PHEVs represent 30%. The three markets of China, Europe, and the United States, where there are the most supporting policies in place, accounted for 92% of those sales. With this market growth, battery manufacturing and electric vehicle production continue to proliferate, and the development of a global automotive supply chain is underway.

As electric vehicle sales and production volumes continue to accelerate, key questions regarding their costs and benefits arise. To that aim, this paper analyzes bottom-up vehicle component-level costs to assess average plug-in electric (BEV and PHEV) and conventional vehicle prices across the major U.S. lightduty vehicle classes (car, crossover, sport utility vehicle, pickup) through 2035. These cost estimates are used to evaluate vehicle costs and broader consumer effects, as well as to discuss the implications for vehicle emission regulations in the United States.

2 Vehicle cost analysis

This section analyzes battery and electric vehicle manufacturing costs in the 2022–2035 time frame and compares them with the costs for manufacturing conventional gasoline vehicles. Based on the detailed engineering analysis of electric vehicle component costs, average BEV and PHEV costs for car, crossover, sport utility, and pickup light-duty vehicle classes in the United States are analyzed. The vehicle cost analysis is generally based on the approach of similar previous analyses [1, 2, 3] with several key improvements and updated with new research, data inputs, and U.S. light-duty vehicle technical specifications.

2.1 Battery pack cost

This analysis applies the most recent estimates for battery pack production costs and future projections based on detailed bottom-up technical studies of battery cost elements and overall battery pack costs. Projections with explicit technical specifications for battery pack production (e.g., material, cell, and pack costs; cost versus production volume; bottom-up cost engineering approach, etc.) and detailed automaker statements are included. Battery costs at the pack-level are shown below. Although different studies assess the associated costs differently, this analysis refers to the battery pack cost as seen by a manufacturer of light-duty vehicles, including battery production cost and any associated indirect costs to the supplier.

Figure 1 summarizes the data sources used to inform our projections for battery pack cost reductions through 2035, including expert sources, research literature projections, and automaker announcements. Our battery cost review includes the most recent projections by expert sources including the California Air Resources Board (2022), Roush Industries Inc., Bloomberg New Energy Finance (2020, 2021), UBS (2020) and technical research studies, including Mauler, Lou, Duffner, and Leker (2022), Nykvist, Sprei, and Nilsson (2019), Penisa et al. (2020), Hsieh, Pan, Chiang, and Green (2019), and Berckmans et al. (2017). The automaker announcements shown include Volkswagen for \$135 per kilowatt-hour in 2021–2022 (Witter, 2018), Tesla for \$55/kWh in 2025 (Tesla, 2020), and Renault and Ford for \$80/kWh in 2030 (Automotive News, 2021a, 2021b; Ford, 2021). [4]

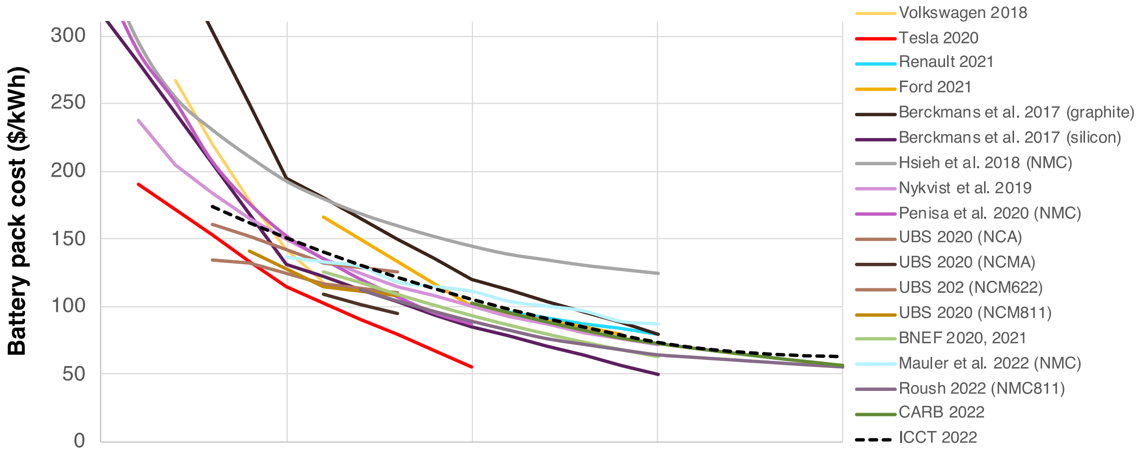

Figure 1: Electric vehicle battery pack costs from technical studies and automaker statements

The "ICCT 2022" black hashed line shows the U.S. battery pack cost estimate applied in this analysis for a BEV with a nominal 50 kWh battery pack. As shown, pack-level costs decline from \$131 per kWh in 2022 to \$105/kWh in 2025, \$74/kWh in 2030, and \$63/kWh in 2035; this represents a 7% annual reduction over the 2022–2030 time frame, which declines to an average annual reduction of 3% over the 2030–2035 time frame. A decreasing pack-to-cell ratio with increasing pack capacity is applied, which means that larger battery packs have lower per-kilowatt-hour costs [5]. Pack-level costs per kWh for PHEVs are 23% higher than those for BEVs throughout the analysis [6].

The projected continued decline in battery pack costs represents a continued trend toward lower cost and higher specific energy electrode materials, as well as improvements in cell and pack manufacturing. For battery materials, a continued global trend toward a higher market share of batteries using cobalt- and nickelfree lithium iron phosphate (LFP) cathodes is anticipated, resulting in lower overall material costs. In parallel, depending on the market segment, a continuous trend to nickel-rich nickel-manganese-cobalt (NMC) cathodes (e.g., NMC811) is typically expected. Nickelrich NMC cathodes have higher specific energy and require less of the expensive cobalt. The addition of silicon to a graphite silicon composite anode can help to increase the specific energy. With continued improvements in battery specific energy, measured in Watt-hours per kilogram (Wh/kg), and volumetric energy density, measured in Watt-hours per liter (Wh/L), the mass of materials per unit energy is reduced, and battery pack size is smaller and lighter for a given electric vehicle range, thus reducing total pack costs. Other factors include continued improvements in the cell-to-pack ratio and reduced production costs per unit volume due to an increase in production volume per pack design from about 50,000 to 100,000 battery packs annually in 2020 to about 500,000 and greater from 2025.

2.2 Vehicle manufacturing costs

Conventional vehicles. Table 1 summarizes the sales share and average technical specifications for model year (MY) 2020 U.S. conventional vehicle sales across the light-duty vehicle classes as applied in this analysis, based on data from the National Highway Traffic Safety Administration (2022).[7] The market-leading vehicle classes are crossovers (35% of U.S. MY 2020 sales), cars (27%), SUVs (23%), and pickups (15%); detailed information about how the classes are defined is in the notes below Table 1. The analysis below evaluates costs for those four classes. Average vehicle characteristics, including market share, rated engine power, curb weight, footprint, fuel economy, and price, are used to define reference conventional vehicles. The fuel economy values shown reflect the U.S. Environmental Protection Agency consumer label values. The prices shown reflect the manufacturer suggested retail price (MSRP).

Table 1: Average characteristics for 2020 reference combustion vehicles.

Vehicle class [a]	MY 2020 sales	Sales share	Rated power (kW)	Curb weight (lb)	Footprint (ft^2)	Fuel economy [b] (mpg)	Price [c] (2020 USD)
Car	3,579,198	27%	153	3,288	47	31.3	$29,709
Crossover	4,686,767	35%	146	3,594	46	28.0	$30,919
SUV	3,062,536	23%	227	4,583	54	21.5	$47,380
Pickup	1,943,537	15%	253	4,904	66	19.0	$42,765
Fleet average	13,272,038	100%	182	3,931	51	26.1	$36,126

Note: Based on data from NHTSA (2022). [7]

[a] *Our car class comprises NHTSA's SmallCar and MedCar "technology classes." Crossovers comprise SmallSUVs, which contains SUV-body style vehicles with curb weight, footprint, and 0-60 acceleration times similar to those of cars. SUVs comprise NHTSA's MedSUV class, which includes minivans, vans, and SUV-body style vehicles with characteristics greater than cars; about 97% of SUVs are categorized as light trucks. Our pickup class matches NHTSA's pickup class; about 4% are new pickups using gasoline fuel and the rest use diesel. Examples of high-selling MY2020 crossover vehicles include Honda CR-V, Ford Escape, and Toyota RAV4.*

[b] *US consumer label-equivalent fuel consumption (mpg) in miles per gallon of gasoline.*

[c] *Prices are in 2020 dollars.*

The NHTSA baseline dataset for MY 2020 vehicles provides information on vehicle class, engine and transmission technology, and price on a model-by-model basis. We assess 2020 baseline combustion vehicle powertrain total costs (i.e., direct and indirect) by sales-weighting the total costs of these technologies for each vehicle class. Estimates of aftertreatment system total costs and all-wheel drive/four-wheel drive (AWD/4WD) total costs were added to the engine and transmission total costs to quantify the full combustion powertrain total costs. Aftertreatment costs were estimated based on sales-weighted engine displacement and the corresponding aftertreatment system cost in Blanco-Rodriguez (2015) [8], adjusted to 2020 dollars by a 1.08 inflator and scaled upward by 10% to account for U.S. emissions standards' increased stringency over Europe's.[9] The total costs for AWD/4WD were approximated as $1,500 for cars, $2,000 for crossovers, $3,000 for SUVs, and $3,500 for pickups. These total costs were estimated by comparing the price premium between four-wheel drive/two-wheel drive models and their AWD/4WD counterparts within the NHTSA database.

This analysis assumes that the average price for each class shown in Table 1 represents a fixed percentage markup over direct manufacturing costs. NHTSA applies a retail price equivalent (RPE) factor of 1.5 in its CAFE standards. This means that the total costs are estimated as 1.5 times direct costs. We apply an RPE factor of 1.5 for all vehicle classes. Thus, we estimate vehicle direct manufacturing costs for combustion vehicle classes as average price divided by 1.5. Dividing the powertrain total costs by 1.5 gives powertrain direct costs. Subtracting powertrain direct costs from vehicle direct costs (calculated from the prices in Table

1) gives the remaining nonpowertrain direct costs (chassis, trim, assembly, etc.). As a point of reference, the U.S. Environmental Protection Agency dissected RPE into its constituent components.[10] Fleet average automaker profit was found to be around 6% of direct costs (supported by automaker financial reports), and total dealer selling and markup contributors amount to around 16% of direct costs. These same markups were assumed to apply to electric vehicles on a fleetwide average, as discussed below.

This analysis assumes that post-2026 U.S. light-duty vehicle regulations will continue to require new conventional vehicle fuel economy to improve annually, regardless of the level of electric vehicle penetration. Conventional vehicle efficiency improvements and the associated increase in manufacturing costs are modeled based on Lutsey, Meszler, Isenstadt, German, and Miller (2017).[11] For an annual average efficiency improvement of 3.5%, corresponding to a total 30% improvement from 2020 to 2030, total cost-effectiveness after adjusting for inflation was estimated as $37 per percent reduction for cars and crossovers and $44 per percent reduction for SUVs and pickups. Beyond 2030, a cost per percent improvement of $63 for cars and crossovers and $59 for SUVs and trucks was applied for the remaining approximately 11% improvement through 2035. This level of cost is assumed to represent deeper levels of electrification, further engine improvements, and high levels of mass reduction and aerodynamic improvements (these latter two are also applied to electric vehicles, discussed below). For a 41% overall improvement through 2035, total costs are expected to increase by around $1,800 for cars and crossovers and $2,000 for SUVs and trucks representing increases of about $1,200 and $1,300, respectively, in direct costs. This cost increase is equivalent to about 1% increase in powertrain direct costs per year. Table 2 summarizes the conventional vehicle fuel economy in miles per gallon (mpg) applied in this analysis for 2022, 2030, and 2035, as well as the associated cost increase relative to 2022.

Table 2: Summary of modelled new combustion vehicle fuel economy (mpg) for 2020, 2022, 2030, and 2035, and cost increase due to improved efficiency.

Vehicle class	Label fuel economy (mpg)				Increase in total costs relative to 2020 vehicle				Increase in direct costs relative to 2020 vehicle			
	2020	2022	2030	2035	2020	2022	2030	2035	2020	2022	2030	2035
Car	31.3	33.6	44.6	53.3	–	$225	$1,180	$1,823	–	$150	$787	$1,215
Crossover	28.0	30.1	40.0	47.8	–	$227	$1,183	$1,823	–	$151	$789	$1,215
SUV	21.5	23.0	30.6	36.6	–	$248	$1,295	$1,994	–	$166	$863	$1,329
Pickup	19.0	20.4	27.2	32.5	–	$250	$1,298	$1,994	–	$167	$865	$1,329
Fleet average	26.1	28.0	37.2	44.5	–	$234	$1,225	$1,887	–	$157	$817	$1,258

Using the SUV class as an example, Table 2 shows how an average new conventional SUV is estimated to improve in efficiency from 21.5 mpg in 2020 to 30.6 mpg in 2030 and 36.6 mpg by 2035. This comes with an average total cost increase of $1,295 by 2030 and $1,994 by 2035, relative to 2020. On average across the four vehicle classes, our U.S. new conventional gasoline vehicle fleet improves from a consumer label efficiency of about 26.1 mpg in 2020 to 37.2 mpg in 2030, while seeing a $1,225 total cost increase. By 2035, the average new gasoline vehicle fuel economy is about 44.5 mpg, which comes with an average total cost increase of $1,887 from 2020. The increase in direct costs shown on the right of Table 2 is the increase in total costs divided by 1.5.

Electric vehicles. Electric vehicle manufacturing costs are estimated on a bottom-up vehicle component cost basis. These costs are determined for representative vehicle classes in the U.S. new passenger vehicle market. The steps include initially quantifying the reference conventional vehicles and their technical specifications, then estimating the detailed components for equivalent electric vehicles and their associated costs. Table 3 summarizes the electric vehicle specifications for 2022 and 2030 for six different electric ranges of BEVs and PHEVs. The BEV and PHEV capabilities and rated power (kW) are matched with those of the reference conventional vehicles (see Table 1). The table shows electric vehicle range, electric efficiency, and battery pack size and cost, and gasoline fuel consumption for PHEVs. The technical specifications are based on official electric vehicle range and efficiency values from the U.S. Department of Energy and reflect consumer label efficiency.[12] Although it is not shown, we apply a charging efficiency factor of 93% for all years. A useable-to-total battery pack size ratio is also applied based on average high-volume MY 2022 electric vehicles such that BEVs can use 92% while PHEVs can use 85% of the kWh, which increases for new vehicles by less than 1% per year through 2030, based on the best available models from 2022. For context, several BEV models including the BMW i4, Chevrolet Bolt EV, Chevy Bolt EUV, Hyundai Ioniq 5, Nissan Leaf, Polestar 2, and Volvo C40 and XC40 have a useable-to-total battery ratio of 96% or greater in 2022. For PHEVs, the lower assumed useable battery fraction is due to the higher-power-to-energy packs having restrictions for thermal management, durability, and safety.

Table 3: Technical characteristics of electric vehicles for 2022 and 2030

	Battery electric vehicle (BEV)									Plug-in hybrid electric vehicle (PHEV)								
	Range [a]	Car		Crossover		SUV		Pickup		Range	Car		Crossover		SUV		Pickup	
		2022	2030	2022	2030	2022	2030	2022	2030		2022	2030	2022	2030	2022	2030	2022	2030
Rated power (kW)		153	153	146	146	227	227	253	253		153	153	146	146	227	227	253	253
Fuel economy (mpg)		--	--	--	--	--	--	--	--		37	54	32	45	26	37	23	25
Efficiency (kWh/mile)[b]	BEV-150	0.27	0.19	0.32	0.20	0.37	0.24	0.45	0.31	PHEV-20	0.37	0.27	0.42	0.34	0.54	0.36	0.65	0.45
	BEV-200	0.28	0.20	0.33	0.21	0.38	0.26	0.46	0.33	PHEV-30	0.38	0.27	0.42	0.34	0.54	0.37	0.66	0.45
	BEV-250	0.28	0.21	0.34	0.22	0.39	0.27	0.47	0.35	PHEV-40	0.38	0.27	0.42	0.34	0.54	0.37	0.66	0.46
	BEV-300	0.29	0.22	0.35	0.24	0.40	0.28	0.48	0.36	PHEV-50	0.38	0.27	0.42	0.34	0.55	0.37	0.66	0.46
	BEV-350	0.30	0.23	0.36	0.25	0.40	0.30	0.49	0.38	PHEV-60	0.38	0.27	0.42	0.34	0.55	0.37	0.66	0.46
	BEV-400	0.31	0.25	0.36	0.26	0.41	0.32	0.50	0.40	PHEV-70	0.38	0.27	0.42	0.34	0.55	0.37	0.66	0.46
Battery pack[c] (kWh)	BEV-150	41	27	50	29	57	35	70	45	PHEV-20	8	6	9	7	12	8	14	10
	BEV-200	56	38	67	41	77	49	94	63	PHEV-30	12	8	14	11	18	12	22	14
	BEV-250	72	50	86	53	98	64	119	82	PHEV-40	17	11	18	14	24	16	29	19
	BEV-300	88	64	105	67	119	82	144	104	PHEV-50	21	14	23	18	30	20	36	24
	BEV-350	105	78	125	83	141	100	170	128	PHEV-60	25	17	28	22	36	24	44	29
	BEV-400	123	94	145	100	164	120	197	154	PHEV-70	30	20	33	25	42	28	51	34
Pack cost[d] ($/kWh)	BEV-150	$134	$79	$131	$78	$129	$77	$126	$75	PHEV-20	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-200	$129	$76	$126	$75	$124	$74	$121	$72	PHEV-30	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-250	$125	$74	$122	$73	$120	$71	$117	$69	PHEV-40	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-300	$122	$71	$119	$71	$117	$69	$117	$67	PHEV-50	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-350	$119	$70	$117	$69	$117	$67	$117	$66	PHEV-60	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-400	$117	$68	$117	$67	$117	$66	$117	$66	PHEV-70	$165	$97	$165	$97	$165	$97	$165	$97

Note: Numbers in table are rounded.

[a] *BEV-150 = 150-mile range battery electric vehicle; BEV-400 = 400-mile range BEV; PHEV-50 = 50-mile range plug-in hybrid electric vehicle.*

[b] *Vehicle efficiency and range reflect U.S. consumer label values.*

[c] *Battery pack is based on range, electric efficiency, usable fraction of battery pack, and charging efficiency.*

[d] *Larger battery packs have lower per-kWh pack costs, due to a decreasing pack-to-cell ratio [5].*

The initial 2022 electric vehicle efficiencies in Table 3 are based directly on existing MY 2022 BEV and PHEV models, accounting for increased electricity-per-mile for longer-range electric vehicles. We apply average technical specifications based on several high-volume MY 2022 electric vehicle models within each class. For example, our BEV crossover efficiency is based on the Tesla Model Y, Ford Mach-e, Volkswagen ID 4, Hyundai Kona, Kia Niro, Kia EV6, and Volvo XC40. Electric vehicle efficiency improves annually due to electric component (battery, motor, power electronic) and vehicle-level (mass reduction, aerodynamic, and tire rolling resistance) improvements. The 2030–2035 electric vehicle efficiencies are based on modeling by CARB (2022), accounting for range and adjusting for charging losses.[6] Between 2022 and 2030, we apply an average annual improvement that links the high-volume 2022 average electric vehicle model specifications with the 2030 CARB values. By 2030, the efficiencies are somewhat better than those of the "best in class" models from 2022. For example, our representative 350-mile range battery electric car is 0.23 kWh/mile compared to the 358-mile range 2022 Tesla Model 3 at 0.26 kWh/mile. Our representative 350-mile range crossover in 2030 is 0.25 kWh/mile, compared to the 330-mile range 2022 Tesla Model Y at 0.28 kWh/mile.

The total battery pack costs can be interpreted from the battery pack size (kWh) and cost per kilowatt-hour values shown in Table 5. For example, a 250-mile range battery electric car in 2022 has a 72-kWh battery pack that costs $125/kWh for a total battery pack cost of about $9,000. For a given range, the improved efficiency results in a smaller battery for future models. By 2030, the same 250-mile range battery electric car would require a 50-kWh battery pack at a cost of $74/kWh, for a total battery pack cost of about $3,700.

The other nonbattery manufacturing cost components for electric vehicles are based on several sources. Nonbattery powertrain costs are assessed primarily based on a 2017 teardown analysis by UBS [13] and the 2021 National Academies of Sciences Engineering and Medicine (NASEM) fuel economy technology assessment [14]. Virtually all electric vehicles equipped with AWD do so with additional motors, rather than electronic AWD or another AWD system used on combustion vehicles. By matching electric and combustion vehicle power, combined motor power for electric vehicles with multiple motors is the same as the power for single motor vehicles. With additional motors, costs for high voltage cables and motor cooling increase. It is unclear from the literature whether motor costs include driveshaft, which would also increase with the number of motors. According to NASEM, future permanent magnet motor costs are expected to decline due to reduced magnetic material requirements. These future costs scale proportionally with motor power, suggesting that certain cost elements that increase with motor number are not included.

Nonpowertrain costs for 2020, including electric vehicle assembly costs, are based on the baseline conventional vehicle nonpowertrain costs for each vehicle class with a 5% decrease due to 30% lower cost of assembly for BEVs, and assembly comprising about 17% of nonpowertrain direct costs.[15] From 2020 through 2035, the BEV nonpowertrain components and assembly costs are further reduced by about 5% for several reasons. As automakers expand their BEV model offerings and increase production volumes, there is a shift from modified internal combustion engine (ICE) platforms toward dedicated BEV platforms that enable new areas of cost reductions due to increased economies of scale, cross-segment parts sharing, partnerships among other automakers and suppliers, modified price points on the same vehicle, and better design-to-cost strategies that conventional vehicles have benefitted from for decades.[16] Mass reduction and aero improvements modeled in Lutsey et al. (2017) are applied incrementally through 2035. Two electric vehicle nonpowertrain cost components were not analyzed due to unavailability of data and presumed small impact: heat pumps, and electric vehicle weight-related modifications to brake rotors/calipers/pads, suspension system, tires, and body structure due to higher mass of electric vehicles.

PHEVs are assumed to inherit the costs of both the combustion and battery electric vehicle powertrain. However, several modifications are made to the respective powertrain costs when applied to PHEVs. From the BEV powertrain, PHEV battery pack sizes are reduced relative to BEVs, due to their much shorter all-electric ranges, varying from 20 to 70 miles. Motor and inverter costs on PHEVs are also reduced 25% to 40%, inversely dependent on range.[17] Longer range PHEV motors have less cost reduction since they are assumed to have higher power. From the combustion powertrain, total powertrain costs are reduced 10% to 15%, with greater reductions for longer-range PHEVs. As PHEV motors can supplement engine power, the engines on PHEVs do not need to be sized to meet maximum power demands in the same way as ICE-only vehicles, leading to some small cost savings. Consistent with industry, the arithmetic sum of engine and motor powers is greater than the combined rated power (Table 2).[18] However, the above-described engine and motor cost reductions lead to PHEV combined rated power equivalent to their ICE-only and BEV counterparts (Table 2).

Figure 2 shows the direct vehicle manufacturing costs for electric and conventional vehicles for cars, crossovers, SUVs, and pickups for six BEV ranges (150, 200, 250, 300, 350, and 400) and a 50-mile PHEV. Costs are shown for 2022 and 2030. As indicated on the left half of the figure, direct manufacturing costs for BEVs in 2022 are higher than those of conventional vehicles for the four vehicle classes, ranging from $1,400 for a 150-mile battery electric car to $18,200 for a 400-mile battery electric pickup. The right of Figure 2 shows how, by 2030, direct manufacturing costs for BEVs are less than those of combustion vehicles for all vehicle classes and electric ranges up to 300 miles. In 2030, direct costs for 400-mile range BEVs are between $800 to $1,250 greater than combustion cars, crossovers, and SUVs, and $3,200 greater than conventional pickups. PHEVs experience relatively lower cost reductions; by 2030, PHEV direct manufacturing costs are $3,400 (cars) to $5,000 (pickups) greater than conventional vehicles. The powertrain costs for PHEVs in the figure include the costs of both the combustion and battery electric vehicle powertrain.

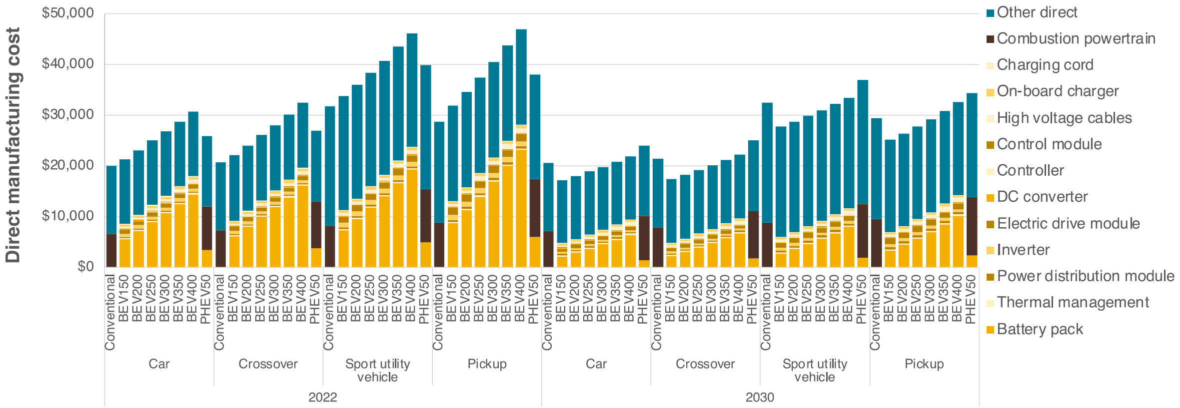

Figure 2: Direct manufacturing costs for conventional and electric vehicles in 2022 and 2030 for cars, crossovers, SUVs, and pickups

The largest electric vehicle direct cost decreases from 2022 to 2030 are in batteries. For an example 300-mile range SUV, reduced battery costs account for about 85% of the total direct manufacturing cost reduction, declining from about $14,000 in 2022 to about $5,650 in 2030. This is the result of reduced per-kilowatt-hour battery cell costs, lower pack-level assembly costs, and improved vehicle efficiency enabling reduced battery size for the same range. Other electric vehicle direct manufacturing cost reductions include non-battery powertrain costs which decline by about $500-$800 from 2022 to 2030, and non-powertrain and vehicle assembly costs which decline by about $300-$650 from 2022 to 2030.

2.3 Vehicle prices

For electric vehicles, the direct manufacturing cost analysis is used to estimate electric vehicle prices by technology and range. Price is distinguished from direct manufacturing costs by the addition of indirect costs, which include depreciation & amortization, R&D, selling and general and administrative expenses, automaker profit, and dealer selling and markup. No state or federal vehicle purchase incentives are included.

Indirect vehicle costs for battery electric vehicles are first assessed based on estimates of D&A, R&D, and SG&A on a per-vehicle basis; automaker profit and dealer selling and markup are assessed separately. Our analysis of D&A, R&D, and SG&A is based automaker financial reporting and how those indirect costs have evolved as their sales volumes have increased. The D&A and SG&A costs for electric vehicles are based on average annual 2017–2021 light-duty indirect cost data for the six largest global automakers in 2021 with at least 6 million in annual light-duty sales: Toyota Group, VW Group, Renault-NissanMitsubishi, Hyundai-Kia Group, General Motors, and Stellantis. Per-vehicle costs are about $1,050 for D&A and about $2,250 for SG&A, and these costs are assumed to remain constant and are applied for all years in the analysis.

The primary driver for declining indirect electric vehicle costs is reduced R&D costs on a per-vehicle basis. For BEVs, R&D costs are based on publicly available data from Tesla, the world's only high-volume all-electric automaker. Specifically, we apply annual R&D costs and annual BEV sales data from Tesla to quantify the R&D costs on a per-vehicle basis for 2017–2021. Tesla's annual R&D costs are increased by 50% to account for an expanding product lineup. Future year R&D costs are based on expected U.S. electric vehicle market growth and, thus, greater manufacturing volumes. The Tesla-derived per-vehicle R&D costs are added to D&A and SG&A costs then applied to the broader U.S. automotive market with a three-year lag period to estimate an industry-average BEV indirect cost that declines from about $11,300 per vehicle in 2020, to about $6,450 per vehicle in 2025, and to about $5,400 in 2030. Indirect costs for PHEVs are calculated as the sum product of BEV and ICE indirect costs and the cost share of electric and combustion components of the PHEV powertrain.

Electric vehicle automaker profit and dealer selling and markup are calculated based on conventional vehicle markups by applying equivalent per-vehicle D&A, SG&A, and R&D costs to all conventional classes in a manner consistent with electric vehicles. A fleet average of 6% automaker profit and a 16% dealer selling and markup are applied to the direct manufacturing costs, based on RPE component breakdown data from EPA.[10] The remaining fleet average indirect costs (D&A, SG&A, R&D) are applied to each class equally.

Figure 3 shows the vehicle prices by technology for 2022 through 2035 for cars, crossovers, SUVs, and pickups. The black lines represent average conventional gasoline vehicle prices, which rise slightly along with their improved efficiency. BEVs experience substantial cost reductions from 2022 to 2035. The pink, purple, blue, green, orange, and yellow lines correspond shortest to longest range BEVs. As shown, the BEVs' reduced prices bring price parity with conventional gasoline vehicles as soon as the 2024–2025 time frame, but the timing varies by electric range and vehicle class. Shorter-range BEVs with 150 to 200 miles of range reach price parity around 2024–2026, mid-range BEVs with 250 to 300 miles of range reach price parity around 2026–2029, and the longestrange BEVs with 350 to 400 miles of range reach price parity around 2029–2033. Cars, crossovers, and SUVs reach price parity one to three years earlier than pickups for a given BEV range. PHEVs with 20 to 70 miles of range, shown as the dotted lines, tend to have lower prices than the longest range BEVs in the near term, but are more expensive than any battery electric or combustion vehicle by 2030 for every electric range and vehicle class.

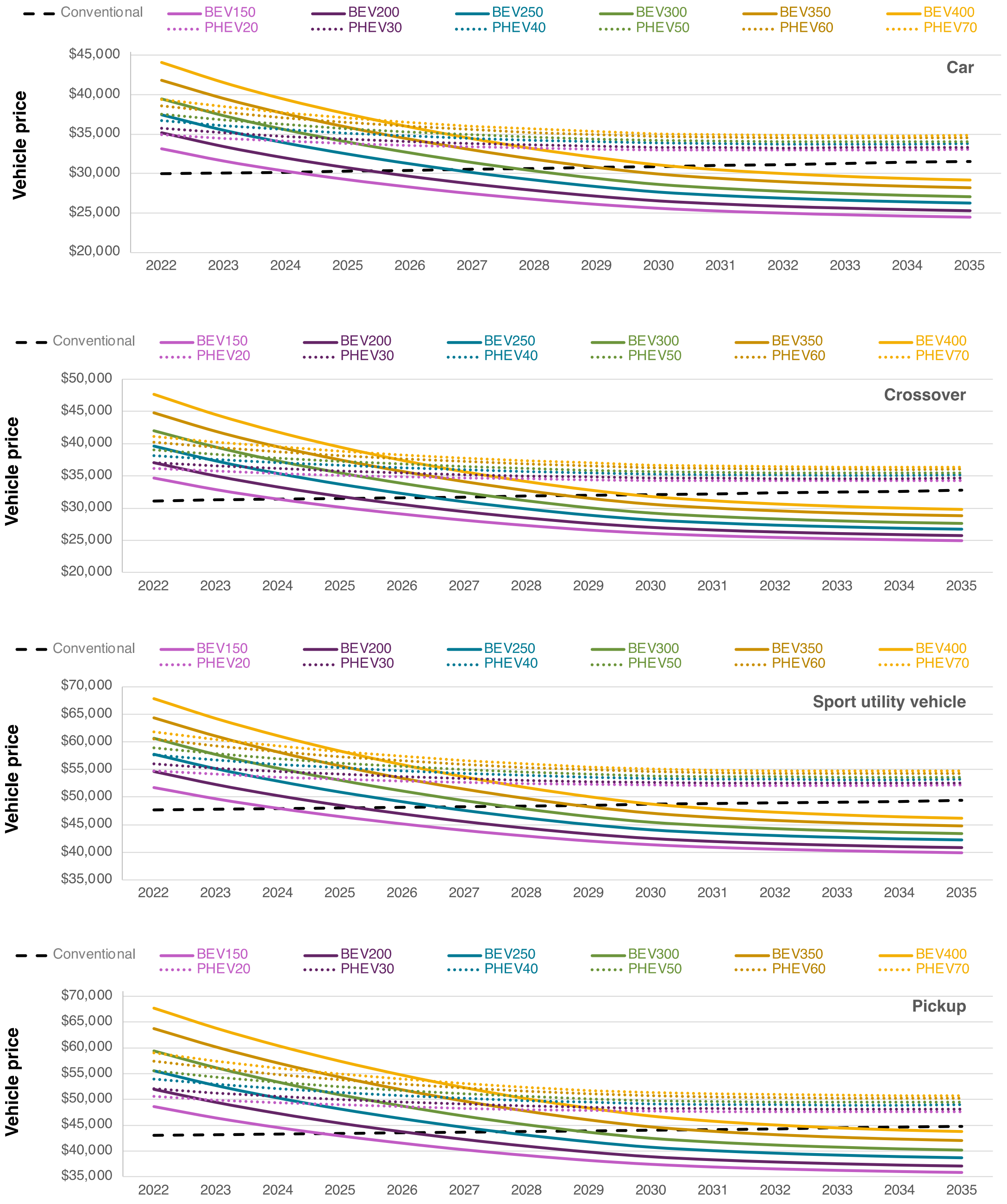

Figure 3: Initial price of conventional and electric vehicles for 2022–2035 for four vehicle classes

The expected timing for BEV price parity with conventional gasoline vehicles varies slightly among cars, crossovers, and SUVs, across all ranges. However, for heavier and less energy-efficient pickups requiring relatively more kilowatt-hours of battery for each additional mile of electric range, price parity occurs 1 to 3 years later, dependent on range. As previously introduced, the initial conventional vehicle prices in this analysis are based on a sales-weighted assessment of all conventional light-duty vehicles in the United States and, thus, represent average prices. There are, of course, variations in powertrain, performance, luxury features, and other components across conventional and electric vehicles alike. These factors have implications on vehicle price, which means that some models may reach price parity sooner, and others later, than the average values shown here.

Within each vehicle class, longer-range BEVs' larger battery packs add substantial costs over shorter-range BEVs. For example, a car buyer in 2026 can purchase a 200-mile range BEV that is less expensive than a conventional gasoline car. If that car buyer was concerned about range and charging infrastructure, they could pay \$3,000 more for a 300-mile range BEV or \$6,300 more for a 400-mile range BEV. Similarly, a SUV buyer in 2026 could purchase a 200-mile BEV for less than a comparable gasoline SUV or pay \$4,100 more for a 300-mile battery electric SUV or \$8,900 more for a 400-mile battery electric SUV. In each situation, vehicle buyers can essentially choose price parity for shorter-range BEVs or pay approximately 10% more for every additional 100 miles of range. These examples demonstrate the trade-off for consumers between lower cost and longer range, and the opportunity for widespread charging infrastructure to enable lower-cost shorter-range vehicle purchases.

Plug-in hybrid electric vehicles with 20 miles to 70 miles of electric range are shown in Figure 3 by the dotted lines. The PHEV price differential versus conventional gasoline vehicles is reduced from 2022 to 2035, but there are no price parity points with conventional vehicles in any class. This is for two primary reasons: PHEVs have the complexity of having both the combustion and electric powertrain components, and the battery pack is a much lower contributor to the PHEV price, so battery cost reductions have a smaller effect on the total price. As an example, the cost differential for a crossover PHEV with a 50-mile electric range is about \$8,000 in 2022, which declines to about \$3,800 in 2030 and \$3,200 in 2035. Overall, by 2035 PHEV prices range from about \$2,000 more than their conventional gasoline counterparts for a passenger car PHEV with a 20-mile electric range to \$6,200 more for a pickup PHEV with a 70-mile electric range.

The price parity findings were tested for their sensitivity to annual battery cost reductions. Compared to our central case, an annual battery cost reduction of 7% from 2022 through 2030, a lower annual battery cost reduction of 4% (reflecting relatively slower innovation, production volume, and potential raw material price constraints), and a higher annual price reduction of 10% (reflecting greater battery breakthroughs, potentially including solid-state, sodium-ion, or other next-generation battery technologies) are assessed. Toyota, for example, has begun testing solid-state batteries in its electric vehicle concept models, and Nissan aims to sell electric vehicles with solid-state batteries by 2028. Nissan estimates solid-state batteries will cost \$75/kWh in 2028, which can be reduced to \$65/kWh.[19]

Figure 4 illustrates how the year of BEV price parity with conventional vehicles varies with changes to battery cost reductions. The blue triangles reflect the central case findings and are the same as Figure 3 above. The whiskers to the left and right of the blue triangles reflect the price parity findings for the lower and higher battery cost cases, respectively, compared to the central case. The higher battery cost case (4% annual reduction) typically delays price parity by about one year for a 250-mile range BEV and two to four years for a 350-mile range BEV. The lower battery cost case (9% annual reduction) typically accelerates price parity by about one year for a 250-mile range BEV and one to two years for a 350-mile range BEV. The effect of battery cost reduction on the timing for price parity is greater for larger vehicle classes because of their larger battery packs.

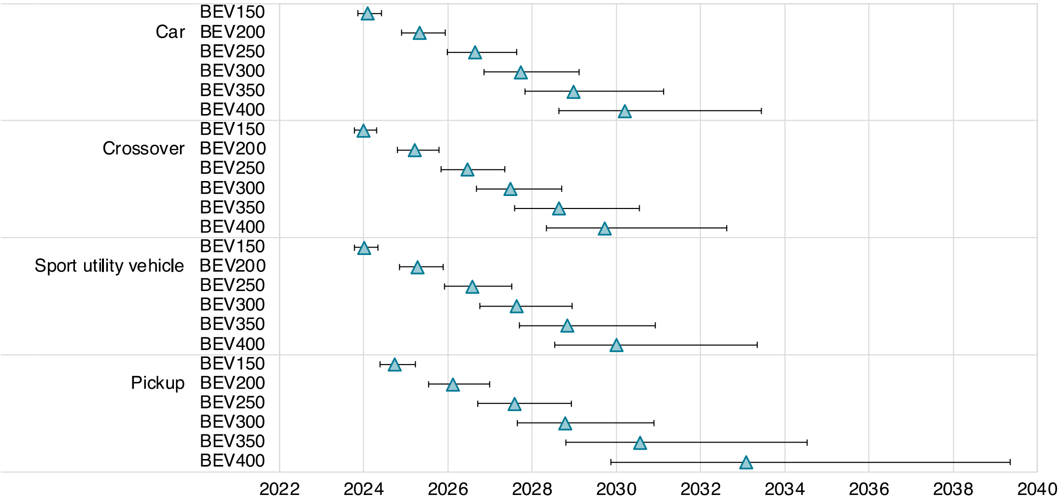

Figure 4: Battery electric vehicle price parity year for varied battery costs.

The Figure 4 results reinforce how price parity in major vehicle classes is expected to be reached in the 2027 to 2028 time frame for 250-mile range BEVs, from 2028 to 2029 for 300-mile range BEVs, and from 2030 to 2033 for the longest-range 400- mile BEVs. The sensitivity demonstrates how relatively higher or lower battery costs lengthen or shorten the expected timing for price parity by a few years, depending on the vehicle range and class. These findings underscore the importance of continued developments regarding battery manufacturing innovation, greater production volumes, and stable raw material prices. The price parity findings were also tested for their sensitivity to annual electric vehicle energy consumption improvement. Compared to the central case, we reduce the annual BEV improvement by 50% from 2022. Doing so increases the average BEV energy consumption values in Table 5 by 6% in 2025 and 17% in 2030. Increasing BEV energy consumption means that larger, more expensive battery packs are needed for the same all-electric range, and the timing for price parity is delayed. The effect of increased BEV energy consumption on the timing for price parity is greater for larger vehicle classes because of their larger battery packs. We find that reducing annual BEV efficiency improvement by 50% delays price parity by an average of less than one year for 350-mile range BEVs. Price parity is delayed by an average of about one year for 400-mile range BEVs.

3 Conclusions

This paper analyses key questions about the expected timing for electric vehicle parity in the United States based on available technical data and research literature. Electric vehicle manufacturing costs and upfront vehicle prices are quantified across the major light-duty vehicle classes and compared with their conventional gasoline counterparts, illustrating the potential value proposition that many consumers will consider over the next decade.

We find that battery electric vehicle purchase price parity is coming before 2030 for BEVs with up to 300-miles of range across all light-duty vehicle classes. Continued technological advancements and increased battery production volumes mean that pack-level battery costs are expected to decline to about $105/kWh by 2025 and $74/ kWh by 2030. These developments are critical to achieving electric vehicle initial price parity with conventional vehicles, which this analysis finds to occur between 2024 and 2026 for 150- to 200-mile range BEVs, between 2027 and 2029 for 250- to 300-mile range BEVs, and between 2029 and 2033 for 350- to 400-mile range BEVs. These findings apply to electric cars, crossovers, SUVs, and pickup trucks, which cover all light-duty vehicle sales in the United States. Pickups, which represent 15% of new 2020 light-duty vehicle sales, are the slowest to reach price parity. Battery cost sensitivity analyses illustrate the key impact of battery costs on price parity timing. Increasing the annual battery cost reduction from 7% to 9% typically accelerates the timing for parity by about 1–2 years, while decreasing the annual battery cost reduction from 7% to 3% typically delays parity by about 1–4 years. These findings underscore the importance of continued developments regarding battery manufacturing innovation, greater production volumes, and stable raw material prices.

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Pete Slowik is a Senior Researcher on the Electric Vehicles team, with expertise in electric vehicle technology, cost, and policy. His work supports local, regional, and national policymakers around the world who aim to accelerate the transition to all zero-emission vehicles. In addition to his research duties, Pete assists in the ICCT's role as the Secretariat for the International Zero-Emission Vehicle (ZEV) Alliance. He also serves as the cluster coordinator for all of the ICCT's city-based work. Peter holds an M.S. in Energy Policy and Climate from the Johns Hopkins University and a B.S. in Environmental Science from the University of California, Los Angeles.