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Assessment of light-duty electric vehicle costs in Canada in the 2023 to 2040 time frame

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Introduction

Canada is poised to ban the sale of all conventional greenhouse gas-emitting passenger cars and light-duty vehicles in 2035. A federal regulation now in draft stage will phase in the zero-emission vehicle (ZEV) mandate starting in 2026. Nevertheless, the higher upfront cost of ZEVs relative to internal combustion engine vehicles (ICEVs) remains a key deterrent to consumers. As production of ZEVs ramps up, the cost to produce them will decrease over time. When their production price reaches parity with ICEVs is a critical consideration for the federal government, consumers, the auto industry, and many other stakeholders.

The key difference between a ZEV and an ICEV is the powertrain. With battery electric vehicles (BEVs), as well as with plug-in hybrid electric vehicles (PHEVs), the costs of the battery and electric drive components are the major contributors to higher production costs compared to ICEVs. PHEVs consist of a smaller battery (with a lower energy output) and an internal combustion engine (ICE), thereby resulting in additional powertrain production costs versus an ICEV. Other components, such as the vehicle body and interior, have similar costs across vehicle types.

This study presents detailed cost breakdowns of the battery and other electric drive components of the ZEV powertrain across several different classes of passenger vehicles in Canada and estimates how these costs will change over the next two decades. The paper first offers an overview of batteries—including subcomponents, raw material inputs, and cost forecasts—followed by a breakdown of components and processes in the manufacturing of ICEVs, BEVs, and PHEVs. The paper then presents the estimated upfront costs of BEVs and PHEVs in several vehicle segments as compared to their baseline ICEV counterparts. For each vehicle segment, we present the estimated year in which BEVs will reach production cost parity with ICEVs. Some

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passenger EVs could reach cost parity with ICEVs as early as 2028, depending on the scenario and the underlying assumptions, but other classes and segments of EVs won't achieve cost parity with ICEVs until after 2040.

Battery overview

The battery component of a BEV or PHEV powertrain is referred to as a battery pack. It consists of battery cells arranged in modules, with the modules arranged within a housing; the cells, modules, and housing together form the battery pack.

A battery cell generates the power to supply a vehicle's electric motor. Two key components of a battery cell are the cathode on one end and the anode on the other; these are known collectively as electrodes. The cathode accounts for more than half of the total direct production cost of a typical battery cell (Bhutada, 2022a). Table 1 outlines the relative cost of the materials along with the manufacturing and depreciation costs that make up the cost of producing a battery cell. The anode is the component with the second-highest cost of materials. The anode, however, is commonly made from graphite and is, therefore, less impacted by commodity cost pressures than the cathode. The materials in a cathode are subject to commodity price fluctuations, including recent pricing pressures from increasing EV demand and other geopolitical factors.

Table 1. EV battery cell components and their percentage of total cell cost.

EV battery cell components	Cell cost
Cathode	51%
Manufacturing and depreciation	24%
Anode	12%
Separator	7%
Electrolyte	4%
Housing and other materials	3%

Source: Bhutada, 2022a

Electric cars most commonly use lithium-ion batteries. These battery types have a high power-to-weight ratio, temperature-performance, and energy-efficiency (EnergySage, 2022). The common types of lithium-ion batteries, along with the respective percentages by weight of their component materials, are outlined in Table 2. The common types of lithium-ion batteries include nickel manganese cobalt (NMC), nickel cobalt aluminum oxide (NCA+), and lithium iron phosphate (LFP) batteries. Nickel is notable as the dominant element by weight in both NMC and NCA+ batteries. Among EVs in 2021, 80% of battery capacity had nickel-based cathodes; approximately 72% of EVs in 2020 (outside of China) were specifically NMC batteries (Bhutada, 2022b).

Table 2. Materials in various lithium-ion batteries and their percentage of total cell weight.

Battery cell material	Battery component	Percentage of weight by battery type				
		NMC811	NMC523	NMC622	NCA+	LFP
Lithium	**Cathode**	3%	4%	3%	4%	3%
Nickel	**Cathode**	23%	15%	18%	27%	0%
Manganese	**Cathode**	3%	8%	6%	0%	0%
Cobalt	**Cathode**	3%	6%	6%	1%	0%
Graphite	**Anode**	27%	28%	28%	28%	32%
Aluminum	**Cathode, casing, current collector**	18%	18%	18%	19%	21%
Copper	**Current collector**	12%	11%	11%	11%	12%
Steel	**Casing**	12%	11%	11%	11%	12%
Iron	**Cathode**	0%	0%	0%	0%	20%
		100%	**100%**	**100%**	**100%**	**100%**

Source: Bhutada, 2022b

As outlined in Table 3, the ratio of nickel, cobalt, and manganese varies among the battery types. The three numbers in the NMC nomenclature represent the battery's chemistry: the approximate percentage by weight of each of the three materials in the respective NMC battery.

Table 3. Chemistry of nickel, manganese, and cobalt in select NMC batteries.

	Relative percentage by weight of the three materials		
Cathode material	NMC811	NMC523	NMC622
Nickel	80%	51%	60%
Cobalt	10%	20%	21%
Manganese	10%	29%	19%
	100%	**100%**	**100%**

Battery cost

In 2020 management consulting firm Oliver Wyman estimated that the battery makes up 43% of the material cost of a compact (C-segment) vehicle and 39% of the total production cost, including assembly labor (Ruffo, 2020). This makes a compact EV 45% more expensive to make than an equivalent ICEV.

This estimate was based on a battery cost of €160 per kWh, higher than the cost sourced from other literature. A 2022 analysis from BloombergNEF put the 2020 price (converted from U.S. dollars to euros) at €122.78 per kWh (BloombergNEF, 2022a). We recalculated the cost of producing a car using the BloombergNEF estimate for battery costs and the Oliver Wyman estimates for the other components. As shown in Table 4, this results in the battery making up 33% of production costs and 36% of material costs. This adjustment still yields an estimate that in 2020 a BEV cost 31% more to produce than an ICEV (€18,400 versus €14,000).

Table 4. 2020 estimate of ICEV versus BEV costs.

Vehicle components	ICEV cost in thousands EUR	Percentage of total ICEV cost	BEV cost in thousands EUR	Percentage of total BEV cost	Variance	Percentage of BEV material cost
50 kWh Battery (at €122.78 Euro/kWh)			€6.1	33%		36%
Electric drive unit			€2.0	11%		12%
Engine and auxilliary	€3.0	21%		0%		0%
Powertrain/drivetrain	€2.0	14%	€0.7	4%		4%
Interior	€2.7	19%	€2.7	15%	0%	16%
Electrical and electronics (E/E)	€ 1.8	13%	€2.0	11%	11%	12%
Body in white (BiW) exterior*	€1.7	12%	€2.1	11%	24%	12%
Chassis	€ 1.2	9%	€1.3	7%	8%	8%
Assembly labor	€1.6	11%	€1.5	8%	-6%	
Total	**€14.0**	**100%**	**€18.4**	**100%**	**31%**	**100%**

*Body in white is the vehicle frame before painting and all the components have been added.

Sources: Research from Oliver Wyman as reported by Ruffo (2020); historic 2020 figure of US$140/kWh from BloombergNEF (2022a), converted to Euros at Internal Revenue Service (n.d.) 2020 yearly average currency exchange rates.

Battery costs have decreased significantly since 2010 (BloombergNEF, 2022a). Figure 1 shows an 89% decrease in the price paid by an automaker to a battery producer from 2010 to 2021, a compound annual growth rate of -18%. Further decreases will be required for EVs to reach cost parity with ICEVs. A benchmark figure of US$100/kWh has been cited as the estimated price point for cost parity (BloombergNEF, 2022a). However, varying battery size requirements among vehicle classes and segments and the cost trends of other production components will also be factors.

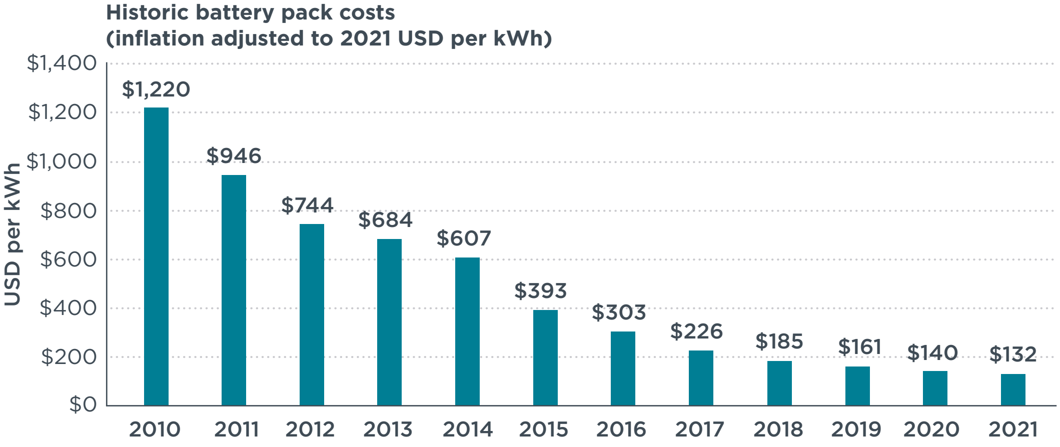

Figure 1. BloombergNEF historic cost of lithium-Ion batteries for BEVs ($/kWh).

Source: BloombergNEF, 2022a.

Earlier estimates forecasted a cost of USD $75 per kilowatt-hour by 2030. However, that cost could change if the production of key minerals lags growing EV sales (Arora et al., 2021). Volkswagen, for example, expects that their demand for batteries will increase by 240 GWh by 2030.

The elements making up the battery cathode, referenced in Table 2, are key in determining battery costs and ultimately EV costs. Although battery costs had been trending downward, there could be near-term increases in underlying commodity prices and subsequent increases in EV production costs. In December 2022, BloombergNEF (2022b) revised an earlier estimate for the average BEV battery pack cost in 2022. Citing higher prices for raw materials, the estimate was raised from US$135 to US$138 per kilowatt-hour, a 2.2% increase. This revised estimate is 4.5% higher than the 2021 average price of US$132/kWh. BloombergNEF said the increase was partially offset by the adoption of LFP chemistry, which had an average production cost 20% lower than NMC batteries in 2022.

Goldman Sachs also considered high commodity prices in revising near-term battery pack cost estimates, as shown in Table 5. These revisions demonstrate more gradual declines in battery costs from 2023 to 2025 than had previously been expected. Revised baseline prices are 7.3% higher than the previous 2024 baseline, for example. Goldman Sachs also estimated a scenario with high input costs (all the costs that factor into making a product). The high-input scenario estimates battery packs will cost 10.2% more in 2024 than the previous baseline (Goldman Sachs Research, 2022).

Table 5. Near-term battery pack cost forecast**.**

US$/kWh	2023	2024	2025
Previous baseline	$122	$110	$100
Revised baseline	$130	$118	$105
Revised vs. previous baseline	6.6%	7.3%	5.0%
High input prices	$139	$130	$123
High input prices vs. revised baseline	6.9%	10.2%	17.1%

Source: Goldman Sachs Research, 2022

Raw materials

Production of key battery materials such as lithium and nickel will need to increase 10 times by 2030 to support rising EV demand, according to some estimates (Arora, et al., 2021). Nickel's cost per metric tonne was US$25,860 as of February 2023, while cobalt was US$35,270 per tonne and lithium (lithium hydroxide) was priced at US$76,200 (London Metal Exchange, 2023a, 2023b, and 2023c).

Lithium carbonate and lithium hydroxide are input compounds in the production of lithium-ion batteries. These compounds can come from either hard-rock mining of spodumene ore or by pumping water into the earth in high desert regions and then waiting for the resulting ponds of brine to evaporate (Piedmont Lithium, n.d.). High nickel-content batteries such as NCA and NCM811 must use lithium hydroxide, while NCM622 and NCM523 can use either lithium hydroxide or lithium carbonate (Shanghai Metals Market, 2022). Lithium hydroxide battery cathodes have the advantage of increased power density and a longer lifecycle, but lithium hydroxide can only be sourced directly from processing spodumene. Evaporated brine leaves behind lithium carbonate; lithium carbonate can be converted into lithium hydroxide, but the process adds to production costs.

Most lithium is found in Chile, Australia, and Argentina with 41%, 25%, and 10% respectively of global reserves. Production, however, is dominated by Australia at 55% of global output, followed by Chile at 26%, and China at 14%. While lithium prices have risen significantly in the last 2 years, an expected increase in lithium production could keep further cost hikes in check by 2024 (BloombergNEF, 2022b).

Nickel had an early automotive presence in the mid-1990s as part of the nickel metal hydride (NiMH) batteries powering the Toyota Prius, a hybrid vehicle (Nickel Institute, n.d.). Lithium batteries use nickel sulphate as the input material, which is sourced from nickel sulphide ore (BHP, n.d.). Nickel is the most predominant component by mass in NCA and NCM lithium-ion batteries. The benefits of higher nickel content in a battery cathode include increased energy density; this increases the range that can be achieved by a battery for a given weight (Rosevear, 2022).

Nickel prices soared following Russia's invasion of Ukraine in February 2022 (Rosevear, 2022). Russia has approximately 7.8% of nickel reserves and accounted for 9.2% of production before the invasion. Indonesia, however, is the leader in both reserves and production at 22% and 37% respectively (U.S. Geological Survey, 2022).

Cobalt is most often extracted through secondary production, as a by-product of mining for nickel and copper (Battery University, n.d.). Only 2% of cobalt production comes from primary production, including in Canada where cobalt comes from mined arsenide ores (Cobalt Institute, n.d.-b). Close to half of the world's estimated cobalt reserves of 8.3 million metric tonnes are in the Democratic Republic of Congo (DRC). Close to 70% of cobalt production also takes place in the DRC (U.S. Geological Survey, 2023). Adding cobalt, another high-energy-density material, to a lithium-ion battery also increases range (Cobalt Institute, n.d.-a).

LFP batteries, without any reliance on nickel or cobalt, may provide an alternative and gain market share. Research and consulting firm Wood Mackenzie has predicted that LFP will be the dominant battery chemistry by 2028. LFP batteries are of lower energy density than NMC batteries, but they have lower production costs, do not require nickel or cobalt, and demonstrate increased safety and longevity (Colthorpe, 2022). Ford Motor Company announced in February 2023 that it would build a US$3.5 billion plant in Michigan to start producing LFP batteries in 2026. The company said that it intended to use these batteries in the base-range versions of the Mustang Mach-E and F-150 Lightning, while continuing to use NCM batteries in extended-range versions of the vehicles (Moloughney, 2023). More recently, however, Ford announced that it would scale back the plant's capacity by 40%, from 35 gigawatt hours of batteries annually to 20 gigawatt hours annually (White, 2023). Further advancements in LFP battery chemistry to address range constraints could encourage more original equipment manufacturers (OEMs) to use the battery in longer-range vehicle models, thereby curbing dependencies on nickel and cobalt.

Overall, investments by OEMs to vertically integrate and to form partnerships will also be integral to increasing battery production capacity and stabilizing costs. Other examples of OEM initiatives include General Motors' recent investment in Lithium Americas (Blois, 2023), and Stellantis' supply agreement with Terrafame for nickel sulphate (Stellantis, 2023).

Current cost build

We examined the current cost estimates for producing BEVs, PHEVs and ICEVs. The vehicle classes and segments are outlined in Table 6 and Table 7. Table 8 summarizes the cost estimates for different combinations of classes and segments. A deeper discussion follows into each subcomponent of the direct and indirect costs.

Table 6. Vehicle classes investigated.

Class
Passenger car (PC)
Crossover utility vehicle (CUV)
Sport utility vehicle (SUV)
Light-duty truck (LDT)

Table 7. Vehicle segments investigated.

Segment
Economy
Midrange
Luxury

Table 8. Total 2022 production cost estimates of BEV, PHEV, and ICEV vehicles in Canadian dollars (CAD).

BEV		Direct cost					Indirect overhead		Total
		Powertrain	Non-powertrain materials	Labor					
Class	Segment	Total powertrain (CAD)	Other materials including body, interior, electronics (CAD)	Assembly labor (CAD)	Labor as % of other materials	Total direct cost (CAD)	Overhead including corporate, facility cost (CAD)	Overhead as % of direct cost (CAD)	OEM cost (direct cost plus overhead allocation, in CAD)
PC	Economy	$14,035	$12,391	$1,936	15.6%	$28,363	$9,019	31.8%	$37,382
PC	Midrange	$16,738	$14,870	$2,323	15.6%	$33,931	$11,473	33.8%	$45,404
PC	Luxury	$26,325	$18,587	$2,904	15.6%	$47,816	$15,205	31.8%	$63,021
CUV	Economy	$14,307	$12,391	$1,936	15.6%	$28,635	$9,105	31.8%	$37,740
CUV	Midrange	$19,414	$14,870	$2,323	15.6%	$36,607	$11,640	31.8%	$48,247
CUV	Luxury	$22,919	$18,587	$2,904	15.6%	$44,411	$14,122	31.8%	$58,533
SUV	Luxury	$32,406	$20,001	$3,125	15.6%	$55,532	$17,658	31.8%	$73,190
LDT	Midrange	$28,835	$20,688	$3,233	15.6%	$52,756	$16,775	31.8%	$69,531
LDT	Luxury	$35,184	$25,860	$4,041	15.6%	$65,084	$20,696	31.8%	$85,780

PHEV		Direct cost					Indirect overhead		Total
		Powertrain	Non-powertrain materials	Labor					
Class	Segment	Total powertrain (CAD)	Other materials including body, interior, electronics (CAD)	Assembly labor (CAD)	Labor as % of other materials	Total direct cost (CAD)	Overhead including corporate, facility cost (CAD)	Overhead as % of direct cost (CAD)	OEM cost (direct cost plus overhead allocation, in CAD)
PC	Economy	$15,934	$12,391	$2,374	19.2%	$30,699	$9,762	31.8%	$40,461
PC	Midrange	$17,701	$14,870	$2,849	19.2%	$35,420	$11,263	31.8%	$46,683
PC	Luxury	$18,156	$18,587	$3,562	19.2%	$40,305	$12,816	31.8%	$53,121
CUV	Economy	$16,547	$12,391	$2,374	19.2%	$31,313	$9,957	31.8%	$41,270
CUV	Midrange	$17,941	$14,870	$2,849	19.2%	$35,660	$11,339	31.8%	$46,999
SUV	Midrange	$18,767	$16,001	$3,066	19.2%	$37,834	$12,031	31.8%	$49,865
SUV	Luxury	$19,251	$20,001	$3,833	19.2%	$43,085	$13,700	31.8%	$56,785

ICEV		Direct cost					Indirect overhead		Total
		Powertrain	Non-powertrain materials	Labor					
Class	Segment	Total powertrain (CAD)	Other materials including body, interior, electronics (CAD)	Assembly labor (CAD)	Labor as % of other materials	Total direct cost (CAD)	Overhead including corporate, facility cost (CAD)	Overhead as % of direct cost (CAD)	OEM cost (direct cost plus overhead allocation, in CAD)
PC	Economy	$11,396	$11,321	$2,013	17.8%	$24,729	$6,003	24%	$30,731
PC	Midrange	$11,969	$13,585	$2,415	17.8%	$27,968	$6,789	24%	$34,757
PC	Luxury	$12,069	$16,981	$3,019	17.8%	$32,068	$7,784	24%	$39,852
CUV	Economy	$11,822	$11,321	$2,013	17.8%	$25,155	$6,106	24%	$31,261
CUV	Midrange	$11,855	$13,585	$2,415	17.8%	$27,854	$6,761	24%	$34,616
CUV	Luxury	$11,855	$16,981	$3,019	17.8%	$31,854	$7,732	24%	$39,587
SUV	Economy	$12,781	$12,182	$2,166	17.8%	$27,129	$6,585	24%	$33,714
SUV	Midrange	$12,781	$14,618	$2,599	17.8%	$29,998	$7,282	24%	$37,280
SUV	Luxury	$12,781	$18,273	$3,248	17.8%	$34,303	$8,326	24%	$42,629
LDT	Economy	$11,741	$15,750	$2,800	17.8%	$30,291	$7,353	24%	$37,644
LDT	Midrange	$11,741	$18,900	$3,360	17.8%	$34,001	$8,253	24%	$42,254
LDT	Luxury	$13,485	$23,625	$4,200	17.8%	$41,311	$10,028	24%	$51,339

Cost estimates were based on information derived from literature reviews for the various stages and components of the manufacturing process for BEVs, PHEVs, and ICEVs in 2022.

The analysis was performed on both direct costs (DC) and the indirect overhead costs (OH) allocated to each vehicle. The direct and indirect costs combined are the costs incurred by an OEM. We used the OEM cost rather than the manufacturer's suggested retail price (MSRP) for this analysis to focus on production costs and the OH for OEMs, while excluding markups added by OEMs and dealers.

All direct costs

Table 9 summarizes the components and processes that make up the direct production costs for BEVs, ICEVs, and PHEVs.

Table 9. Sources of direct production costs.

Cost categories	BEV	ICEV	PHEV
Powertrain	**Battery:** • Battery pack • Battery cell	**ICE components:** • Engine • Emission control • Transmission	**Battery** • Battery pack • Battery cell
	Non-battery material: • Battery management system • Thermal management • Inverter • Power distribution module • High-voltage cables • Electric drive module • Vehicle communication interface module and electric vehicle communication controller		**Non-battery materials:** • Battery management system • Thermal management • Inverter • Power distribution module • High-voltage cables • Electric drive module • Vehicle communication interface module and electric vehicle communication controller
			ICE components: • Engine • Emission control • Transmission
Non-Power Train Materials	• Body (body-in-white) • Interior • Chassis • Non-powertrain electronics	• Body (body-in-white) • Interior • Chassis • Non-powertrain electronics	• Body (body-in-white) • Interior • Chassis • Non-powertrain electronic
Assembly	• Assembly Labor	• Assembly Labor	• Assembly Labor

Powertrain (BEV and PHEV battery portion)

Tables 10, 11, and 12 detail powertrain cost estimates. BEVs and PHEVs were categorized into classes and segments based on the database published by Natural Resources Canada (2023) and on MSRP price points of similar ICEVs.[1] An average battery size by class and segment was determined with data sourced from Plug'n Drive, a Canadian non-profit promoting EV adoption. Battery pack costs were determined by drawing on estimates of the current production cost of battery packs in US$/kWh.

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[1] ICEV segments were categorized based on MSRP price points of economy (under $40,000), midrange ($40,000–$80,000), and luxury (more than $80,000).

While 2022 battery pack cost estimates sourced from literature ranged from US$135 per kWh to US$147 per kWh, we used the BloombergNEF December 2022 estimate of US$138/kWh, converted at 80 cents per Canadian dollar to C$173/kWh (Bloomberg, 2022b).

Electronics and other components supporting the battery were collectively tagged as ‘Electronics’ in Table 10 and Table 11. A 2017 vehicle teardown analysis by investment research firm UBS on a Chevy Bolt identified these components as including: the battery management system (BMS), thermal management system, inverter, DC/DC converter, power distribution module, high-voltage cables, electric drive module, vehicle interface control module (VCIM), electric vehicle communication controller (EVCC), and onboard charger and charging cord (UBS Global Research, 2017, figure 76). The UBS study determined a 2017 estimate for the cost of these components and projected a cost estimate for 2025. An average of these figures was taken as the current non-battery powertrain material cost estimate for this study. Although the UBS study was specific to a Chevy Bolt, it was used as a proxy for the passenger car class/economy segment BEV for this analysis. Adjustments were made to this estimated figure to account for variations in power across the vehicle classes and segments by linearly scaling costs for the inverter, power distribution module, and electric drive module subcomponents to power output. Scaling factors were applied to costs for the thermal management system and high-voltage cables subcomponents based on the underlying vehicle range.

Table 10. BEV powertrain current (2022) range, efficiency, and cost by vehicle class and segment.

BEV						Powertrain costs		
Class	**Segment**		**Average range (km)**	**Estimated average battery size (kWh)**	**Implied efficiency kWh/100km**	**Battery cost (CAD)**	**Electronics (CAD)**	**Total powertrain (CAD)**
PC	Economy	PC Economy	344	55.8	16.23	$9,644	$4,392	$14,035
PC	Midrange	PC Midrange	430	71.4	16.60	$12,347	$4,392	$16,738
PC	Luxury	PC Luxury	487	93.1	19.11	$16,112	$10,212	$26,325
CUV	Economy	CUV Economy	351	56.5	16.11	$9,774	$4,534	$14,307
CUV	Midrange	CUV Midrange	408	76.5	18.78	$13,238	$6,176	$19,414
CUV	Luxury	CUV Luxury	417	88.0	21.11	$15,223	$7,697	$22,919
SUV	Luxury	SUV Luxury	532	111.5	20.98	$19,288	$13,118	$32,406
LDT	Midrange	LDT Midrange	443	114.5	25.88	$19,807	$9,028	$28,835
LDT	Luxury	LDT Luxury	494	133.0	26.92	$23,007	$12,177	$35,184

Note: The BEV database did not include any vehicles that could be categorized as SUV economy, SUV midrange, or LDT economy.

Table 11. PHEV powertrain current (2022) range, efficiency, and cost by vehicle class and segment**.**

PHEV						Powertrain costs			
Class	**Segment**		**Average battery range (km)**	**Estimated average battery size (kWh)**	**Implied efficiency kWh/100km**	**Battery cost (CAD)**	**Electronics (CAD)**	**ICE powertrain (CAD)**	**Total powertrain (CAD)**
PC	Economy	PC Economy	40.00	8.0	20.00	$1,384	$3,154	$11,396	$15,934
PC	Midrange	PC Midrange	32.43	15.0	46.26	$2,595	$3,138	$11,969	$17,701
PC	Luxury	PC Luxury	31.75	15.8	49.61	$2,724	$3,363	$12,069	$18,156
CUV	Economy	CUV Economy	51.00	11.0	21.57	$1,903	$2,822	$11,822	$16,547
CUV	Midrange	CUV Midrange	48.22	14.9	30.88	$2,576	$3,510	$11,855	$17,941
SUV	Midrange	SUV Midrange	42.50	15.0	35.29	$2,595	$3,391	$12,781	$18,767
SUV	Luxury	SUV Luxury	34.33	17.7	51.46	$3,056	$3,413	$12,781	$19,251

Note: The PHEV database did not include any vehicles that could be categorized as LDTs, CUV luxury, or SUV economy.

ICE powertrain (ICEV and PHEV ICE portion)

For ICEVs and PHEVs, the ICE powertrain cost was based on data on engine cost by engine type (number of cylinders and banks) from the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) (2021). We calculated a weighted average engine cost for each of the 10 NHTSA vehicle categories based on 2020 U.S. sales.[2] We then used estimates for supporting powertrain components (such as emissions controls, transmission, and electrical components) to develop a powertrain cost for each NHSTA category. These values were then allocated to the corresponding class and segment per Tables 6 and 7 above. ICE powertrain costs are shown in Table 11 for PHEVs and Table 12 for ICEVs.

Table 12. ICEV powertrain cost estimates by vehicle class and segment.

ICEV		Powertrain costs
Class	**Segment**	**Total powertrain (CAD)**
PC	Economy	$11,396
PC	Midrange	$11,969
PC	Luxury	$12,069
CUV	Economy	$11,822
CUV	Midrange	$11,855
CUV	Luxury	$11,855
SUV	Economy	$12,781
SUV	Midrange	$12,781
SUV	Luxury	$12,781
LDT	Economy	$11,741
LDT	Midrange	$11,741
LDT	Luxury	$13,485

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[2] Ten NHSTA categories: medium SUV (MedSUV), medium performance SUV (MedSUVPerf), small performance car (SmallCarPerf;), medium performance car (MedCarPerf), pickup truck (pickup), high towing pickup truck (PickupHT), medium car (MedCar), small SUV (SmallSUV), small performance SUV (SmallSUVPerf), and small car (SmallCar).

Non-powertrain material

Costs of non-powertrain materials include vehicle body materials, chassis materials, vehicle interior materials, and other electronics that do not directly support the powertrain. The costs for this analysis were based on estimates developed in 2020 by Oliver Wyman for a compact (C-segment) vehicle (Ruffo, 2020). The Oliver Wyman study shows equal non-powertrain material costs for BEVs and PHEVs, as shown in Table 13. The 2020 estimates in euros were converted to Canadian dollars at the Bank of Canada average rate for 2020.

Table 13. Non-powertrain material cost estimates for ICEV, BEV, and PHEV (thousands of Canadian dollars).

	Material costs in thousands CAD		
	ICEV	**BEV**	**PHEV estimate**
Interior	$4.13	$4.13	$4.13
Electrical and electronics (E/E)	$2.75	$3.06	$3.06
Body in white (BiW) exterior	$2.60	$3.21	$3.21
Chassis	$1.84	$1.99	$1.99
Non-powertrain total material cost	$11.32	$12.39	$12.39

Source: Research from Oliver Wyman as reported by Ruffo (2020)

The Oliver Wyman cost study looked at a compact vehicle with a 50 kWh battery. To scale up these costs for larger vehicles, we adjusted for the vehicle footprint with information from the U.S. Environmental Protection Agency 2020 Automotive Trends Report (U.S. Environmental Protection Agency, 2021). As shown in Table 14, a scaling factor was also applied to capture the higher-quality material used in midrange and luxury vehicles versus economy vehicles. For a midrange vehicle, the factor was 1.2 times an economy vehicle. For a luxury vehicle, the factor was 1.5 times an economy vehicle.

Table 14. Non-powertrain material costs with vehicle footprint adjustments and vehicle segment scaling factors applied.

			Non-powertrain material costs in thousands CAD						
Class	**Segment**		**BEV**	**PHEV**	**ICEV**	**Footprint scaling**	**2020 footprint in square feet**	**EPA classification**	**Scaling to economy segment**
PC	Economy	PC Economy	$12.39	$12.39	$11.32	1.000	46	Car SUV	1.0
PC	Midrange	PC Midrange	$14.87	$14.87	$13.58	1.000	46	Sedan/Wagon	1.2
PC	Luxury	PC Luxury	$18.59	$18.59	$16.98	1.000	46	Sedan/Wagon	1.5
CUV	Economy	CUV Economy	$12.39	$12.39	$11.32	1.000	46	Car SUV	1.0
CUV	Midrange	CUV Midrange	$14.87	$14.87	$13.58	1.000	46	Car SUV	1.2
CUV	Luxury	CUV Luxury	$18.59	$18.59	$16.98	1.000	46	Car SUV	1.5
SUV	Economy	SUV Economy	$13.33	$13.33	$12.18	1.076	49.5	Truck SUV	1.0
SUV	Midrange	SUV Midrange	$16.00	$16.00	$14.62	1.076	49.5	Truck SUV	1.2
SUV	Luxury	SUV Luxury	$20.00	$20.00	$18.27	1.076	49.5	Truck SUV	1.5
LDT	Economy	LDT Economy	$17.24	$17.24	$15.75	1.391	64	Pickup	1.0
LDT	Midrange	LDT Midrange	$20.69	$20.69	$18.90	1.391	64	Pickup	1.2
LDT	Luxury	LDT luxury	$25.86	$25.86	$23.63	1.391	64	Pickup	1.5

Labor

The assembly labor estimates are also based on the Oliver Wyman study. As outlined in Table 15, labor costs for ICEVs represent 17.8% of total non-powertrain costs. For BEVs, labor represents 15.6% of total non-powertrain costs. An adjustment was made to estimate PHEV labor costs by first scaling up the ICEV labor cost by 20% (Barret & Bivens, 2021), from $2,450 to $2,940. This results in labor accounting for 19.2% of non-powertrain costs for PHEVs.

Table 15. Labor as a percentage of non-powertrain material costs.

	2020 non-powertrain costs in thousands CAD		
	ICEV	**BEV**	**PHEV estimate**
Interior	$4.13	$4.13	$4.13
Electrical and electronics (E/E)	$2.75	$3.06	$3.06
Body in white (BiW)	$2.60	$3.21	$3.21
Chassis	$1.84	$1.99	$1.99
Assembly	$2.45	$2.29	$2.94
TOTAL			
Non-powertrain total material cost	$11.32	$12.39	$12.39
Non-powertrain total cost (material and labor)	$13.77	$14.69	$15.33
Assembly labor percentage of non-powertrain total cost	17.8%	15.6%	19.2%

Source: Research from Oliver Wyman as reported by Ruffo (2020)

Indirect overhead costs

Indirect overhead costs (OH) incurred by the OEM are fixed costs allocated to each vehicle produced to calculate a cost per vehicle metric. Manufacturing overhead costs include expenses such as fuel and utilities used at the plant during the manufacturing process, the labor of plant maintenance staff, and depreciation of manufacturing equipment. Corporate overhead includes costs incurred at a company's corporate offices, such as sales, marketing, advertising, and research and development.

Markups are applied by the OEM when they deliver vehicles to the dealer (wholesale markup) and by the dealer when they sell vehicles to consumers (dealer markup or retail markup). While markups contribute to the prices paid by dealers and consumers, these are not actual costs incurred by the OEM in vehicle production and are not considered in this analysis.

Table 16. Components of indirect overhead costs and markups.

Overhead costs	Manufacturing overhead	• Plant fuel and utilities • Maintenance staff • Plant engineering costs • Depreciation (plant equipment)
	Corporate overhead	• Sales, general, and administrative costs, • research and development
Markups	Wholesale markup	• Markup applied to vehicle when delivering to dealer
	Retail markup	• Markup applied by dealer when selling to consumer

To assess the portion of the total vehicle cost representing overhead, we examined a factor known as retail price equivalent (RPE). This scaling factor captures both indirect overhead costs and markups to arrive at a retail price. An RPE value of 1.5 (representing a retail price 50% above direct costs) was sourced from literature for ICEVs. The percentage of OEM costs attributable to wholesale and dealer markups was also sourced from literature (Kelley, 2020). From the RPE and markup percentages, we derived that these overhead costs (excluding markups) added 24% to the direct costs of producing an ICEV in 2022.

BEVs and PHEVs, however, are expected to have a higher percentage of costs coming from overhead, partly because these overhead costs are spread over the smaller number of EVs currently being produced. Higher overhead costs are also expected from the increased spending on research and development, advertising, and maintenance of specialized equipment.

The 2021 financials of General Motors show selling, general, and administrative (SG&A) costs are equivalent to 7.5% of automotive sales revenue (General Motors Company, 2021). For Tesla, SG&A was 9.9% of automotive sales revenue; or 1.31 times that of GM (Tesla Inc., 2022). Using GM and Tesla vehicles as proxies for ICEVs and EVs, we applied a factor of 1.31 to the above calculation for ICEV overhead costs. Thus, to estimate the overhead costs involved in producing BEVs and PHEVs, we multiply direct costs by 31.8% as opposed to 24%.

While corporate overhead can be sourced directly from annual financials of OEMs, manufacturing overhead costs are buried in the cost of sales figure in the OEM financials. Nevertheless, the corporate overhead analysis was deemed applicable for deriving a scaling factor for both corporate and manufacturing overhead costs.

Forecast

Battery cost behaviours over time are a key factor in the total OEM cost of producing EVs. We used the December 2022 BNEF estimate (cited above) of dollars per kilowatt-hour as the starting point. The near-term forecast uses a March 2022 analysis by Goldman Sachs estimating battery pack costs for 2023, 2024 and 2025 (Goldman Sachs Research, 2022). From 2026 to 2040, a 5% year-over-year (YoY) reduction in costs was assumed.

Further, a battery-efficiency improvement of 2% YoY was applied assuming that vehicles can use a smaller battery size (in kWh) while maintaining the same range. A 2% improvement was also applied to the cost of non-battery electronics material and non-powertrain materials. Labor costs were adjusted downward by 0.25% YoY to account for productivity improvements and increased automation.

These baseline assumptions are summarized in Table 17 along with notes on the drivers of battery pack cost forecasts. These will also be explored in subsequent sections in two additional scenarios. Notes are also provided on YoY changes in ICEV overhead costs, to conversely examine a fourth possible scenario of a per-vehicle increase in overhead costs.

Baseline forecast assumptions

» Current (2022) Battery Cost: US$138/kWh (converted to C$173/kWh at USD x $1.25)

Table 17. Overview of anticipated cost reductions for components, labor, and overhead.

	Component/production stage	Baseline assumptions for forecast years	Notes

Powertrain	Battery pack cost YoY reduction	Goldman Sachs Research (2022) baseline estimate for 2023-2025 and assumed YoY cost decrease from 2026 onward of 5% per year	• Baseline estimates for 2023, 2024, and 2025 are US$130/kWh, US$118/kWh, and US$105/kWh, per Goldman Sachs' revised baseline outlined in Table 5
			• Continued high input prices applicable to a pessimistic scenario for 2023, 2024, and 2025 are US$139/kWh, US$130/kWh, and US$123/kWh, per Goldman Sachs 'high input prices' in Table 5
			• Compound annual growth rate (CAGR) of YoY cost reductions to 2025 against BloombergNEF (2022b) battery cost of US$138/kWh (C$173/kWh)
			  • 8.7% Baseline
			  • 3.8% Continued high input prices
			• Glidepath YoY cost reduction from 2026 onwards tempered down from 8.7% to 5% for this study's baseline as the calculated CAGR value of 8.7% is on a high current value of $138/kWh; representing a cost already impacted by inflation
			• An 8% glidepath YoY cost improvement from 2026 onwards however is applied in an optimistic scenario also discussed below

	Battery efficiency improvement	2% YoY decrease	• Reduction in kWh requirement per 100km thereby necessitating a smaller battery (in kWh) for the same range (Slowik & Lutsey, 2016).
	ICE powertrain cost decrease	1 % YoY decrease	• Assumption: variable cost decrease due to production efficiencies at powertrain plant. Impacts both ICEV costing and PHEV costing
	Non-battery material (battery-supporting electronics) cost decrease	2% YoY decrease	Assumption
Non-power train material	Non-powertrain material Cost decrease	2% YoY decrease	Assumption
Labor	Labor cost improvement (percentage decrease related to non-battery powertrain material)	0.25% decrease	Assumption
Indirect overhead (OH)	Reductions in overhead cost per vehicle due to efficiencies	5% YoY decrease for BEV 2% YoY decrease for PHEV 1% YoY decrease for ICEV	Assumptions Scenario of ICEV overhead cost as a percent of direct costs increasing also explored in the results section
OEM cost	Cost to OEM to produce car: variable direct cost (DC) plus allocation to each vehicle of indirect overhead (OH) cost		

Results

Tables 18, 19, 20, and 21 show results from four different cost parity scenarios comparing BEV and ICEVs. While we discussed PHEVs above as part of the cost-build analysis, a cost parity comparison with ICEVs is not presented here, because PHEV costs largely mirror those of ICEVs while also including the incremental added cost of the battery. Therefore, PHEV-ICEV cost parity is not achieved across vehicle classes and segments in any of the scenarios.

Scenario 1 is the baseline case for this study. Scenarios 2 and 3 apply different assumptions on forward-looking battery costs. In Scenario 2, a more pessimistic outlook, battery costs increase slightly in 2023 with a gradual decrease in 2024 and 2025 as per the Goldman Sachs forecast for high input prices. This forecast represents a situation in which inflationary pressures persist and gradually drop after 2025 at 5% YoY. Scenario 3 examines a more optimistic scenario in which battery prices decline in 2023 and continue to do so in 2024 and 2025, while decreasing even faster at an 8% YoY rate after 2025. This accelerated rate of cost decreases would represent a situation that might include low inflation, greater efficiencies in battery production and improved supply chain efficiencies.

Scenario 4 examines the overhead allocation applied to ICEV vehicles. Contrary to the baseline assumption—in which overhead costs per ICEV vehicle decrease at 1% YoY—an *increase* is applied to YoY costs to account for expected reduced volumes as this vehicle category is phased out. Higher overhead costs could also come from R&D costs associated with more stringent fuel-economy requirements placed on ICEVs.

In tables 18, 19, 20, and 21, each respective break-even year for all classes and segments are displayed for: 1. the powertrain only; 2. direct costs only (including powertrain costs); and 3. total OEM costs (direct costs and indirect costs).

Scenario 1: Baseline

- As per forecast assumptions in Table 17
- C$125/kWh (US$100/kWh) in 2026

Table 18. Scenario 1 (baseline) cost parity years.

BEV/ICEV parity year		**Economy**	**Midrange**	**Luxury**
Passenger car	Powertrain	2025	2032	Beyond 2040
	Direct cost	2028	2035	Beyond 2040
	Total OEM cost	**2029**	**2035**	**Beyond 2040**
CUV	Powertrain	2025	2033	2038
	Direct cost	2027	2035	Beyond 2040
	Total OEM cost	**2029**	**2035**	**2039**
SUV	Powertrain			Beyond 2040
	Direct cost			Beyond 2040
	Total OEM cost			**Beyond 2040**
LDT	Powertrain		Beyond 2040	Beyond 2040
	Direct cost		Beyond 2040	Beyond 2040
	Total OEM cost		**2039**	**Beyond 2040**

Note: No comparable BEVs and ICEVs were identified for economy and midrange SUVs and economy LDTs.

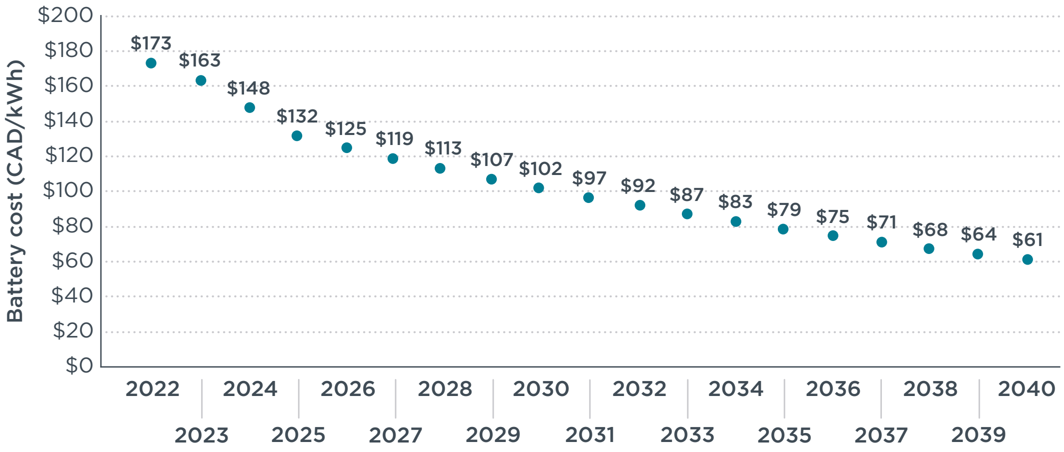

Figure 2. Baseline battery cost forecast.

Scenario 2: Pessimistic battery cost forecast

» Inflationary environment 2023–2025 (per Goldman Sachs high input price forecast) impacting battery cost; same 5% glidepath on YoY declines thereafter

» C$125/kWh (US$100/kWh) in 2028

Table 19. Scenario 2 (pessimistic) cost parity years.

BEV/ICEV Parity		Economy	Mid Range	Luxury
Passenger Car	Powertrain	2028	2034	Beyond 2040
	Direct cost	2030	2037	Beyond 2040
	Total OEM Cost	**2031**	**2036**	**Beyond 2040**
CUV	Powertrain	2027	2035	2040
	Direct cost	2029	2037	Beyond 2040
	Total OEM Cost	**2030**	**2037**	**2040**
SUV	Powertrain	N/A	N/A	Beyond 2040
	Direct cost	N/A	N/A	Beyond 2040
	Total OEM Cost	**N/A**	**N/A**	**Beyond 2040**
LDT	Powertrain	N/A	Beyond 2040	Beyond 2040
	Direct cost	N/A	Beyond 2040	Beyond 2040
	Total OEM cost	**N/A**	**2040**	**Beyond 2040**

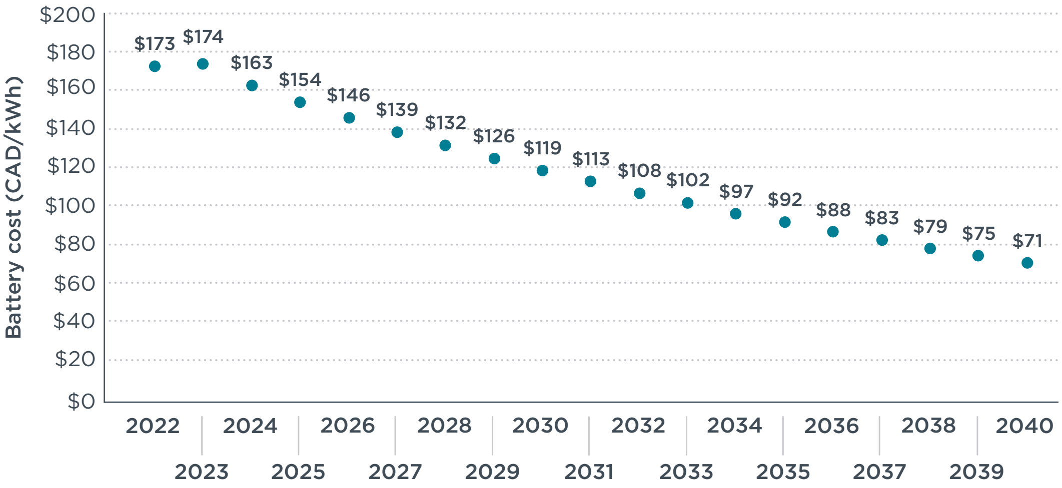

Figure 3. Pessimistic battery cost forecast.

Scenario 3: Optimistic

- Baseline near-term forecast (per scenario 1) and optimistic glide path thereafter at 8% YoY
- C$125/kWh (US$100/kWh) in 2025

Table 20. Scenario 3 (optimistic long-term) cost parity years.

BEV/ICEV Parity		Economy	Mid Range	Luxury
Passenger Car	Powertrain	2025	2030	2039
	Direct cost	2027	2032	Beyond 2040
	Total OEM Cost	**2029**	**2033**	**2040**
CUV	Powertrain	2025	2030	2034
	Direct cost	2027	2032	2037
	Total OEM cost	**2028**	**2033**	**2037**
SUV	Powertrain	N/A	N/A	Beyond 2040
	Direct cost	N/A	N/A	Beyond 2040
	Total OEM cost	**N/A**	**N/A**	**Beyond 2040**
LDT	Powertrain	N/A	2039	Beyond 2040
	Direct cost	N/A	Beyond 2040	Beyond 2040
	Total OEM cost	**N/A**	**2037**	**Beyond 2040**

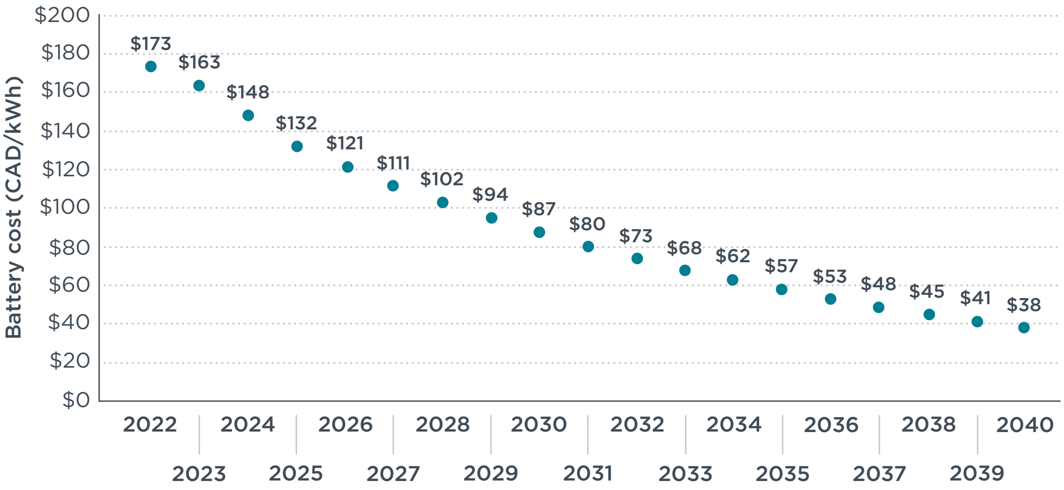

Figure 4. Optimistic battery cost forecast.

Scenario 4: Increased overhead costs for ICEVs

The assumptions allocate higher overhead costs to BEVs initially but with a more aggressive glide path for reductions in overhead cost allocations YoY compared to ICEVs. (There is a 5% YoY improvement for BEVs versus a 1% YoY improvement for ICEVs.) This captures both increased volumes over time of BEVs as well as improved production and corporate efficiencies. ICEVs do display a moderate glide path in the base case, however, at a 1% improvement YoY. An argument could be made that as volumes of ICEVs decline, the allocated overhead allocated to an ICEV could, in fact, increase. Further, increased expenditures in R&D could occur with more stringent fuel-economy regulations before these vehicles are phased out. As such, this scenario increases the allocated overhead YoY by 1% for ICEVs as opposed to the baseline decrease of 1%. All other assumptions are held at the baseline.

Table 21. Scenario 4 (increasing allocation to ICEV) cost parity years.

BEV/ICEV parity year		Economy	Midrange	Luxury
Passenger car	Powertrain	2025	2032	Beyond 2040
	Direct cost	2028	2035	Beyond 2040
	Total OEM cost	**2028**	**2033**	**2039**
CUV	Powertrain	2025	2033	2038
	Direct cost	2027	2035	Beyond 2040
	Total OEM cost	**2028**	**2033**	**Beyond 2040**
SUV	Powertrain			Beyond 2040
	Direct cost			Beyond 2040
	Total OEM cost			**Beyond 2040**
LDT	Powertrain		2039	Beyond 2040
	Direct cost		Beyond 2040	Beyond 2040
	Total OEM cost		**2036**	**Beyond 2040**

Note: No comparable BEVs and ICEVs were identified for economy and midrange SUVs and economy LDTs.

Conclusions

Near-term inflationary and raw material cost pressures are impacting battery production costs, and, therefore, cost parity points. How these macroeconomic factors evolve in the coming years will significantly affect the change in ZEV costs. In Scenario 1 (the baseline scenario), we assume that battery costs drop in 2023, coming off an increase between 2021 and 2022, and continue with a consistent 5% annual decline in costs from 2026 onward. In this scenario, total manufacturer costs achieve parity with that of an equivalent ICEV vehicle within the 2035 target timeframe for passenger cars and CUVs within the economy and midrange segments only. In the luxury segment, only CUVs reach parity by 2040. SUVs do not reach parity before 2040 in any of the segments. Midrange LDTs reach parity by 2039 while luxury LDTs do not reach parity by 2040.

In Scenario 2, the more pessimistic outlook, inflationary pressures continue into 2023, resulting in more conservative estimates for costs in 2024 and 2025. This is followed, however, by a 5% YoY decline in costs from 2026 onwards. This yields a scenario in which no luxury segments achieve total OEM cost parity by 2040. Only the economy passenger cars and CUVs reach parity within the 2035 timeframe, while midrange passenger cars and CUVs achieve parity by 2040.

In the optimistic Scenario 3—where battery costs decline in both the near term but at an accelerated rate from 2026 onwards—price parity is reached in all classes and segments within a 2040 timeframe for passenger cars and CUVs, with the economy and midrange segments reaching parity by 2035. The LDT midrange segment reaches parity by 2040. Both the SUV and LDT luxury segments do not reach parity by 2040.

It is worth noting that, in certain cases, the assumptions behind indirect overhead allocations resulted in cost parity for total OEM costs occurring before parity for direct costs. This occurs in Scenario 1 for the LDT midrange and CUV luxury vehicles, as well as in Scenario 2 for passenger car midrange vehicles. This is because indirect overhead costs decline faster for BEVs than ICEVs. In scenarios 1 through 3, the YoY improvement in overhead costs is 5% for BEVs but only 1% for ICEVs, a spread of 4%. Narrowing this spread—such as by lowering BEV YoY improvement to 3%—will result in total OEM cost parity occurring after direct cost parity in all classes and segments. Conversely, as outlined in scenario 4, the overhead costs for ICEVs may in fact increase because of reduced volumes and increased R&D expenditures. If overhead costs for ICEVs increase by 1% YoY, rather than decrease, the spread between BEV overhead costs going down and ICEV costs going up grows wider, to 6%. This results in additional cases where total OEM cost parity is achieved at the same time or even earlier than for direct costs, such as for CUV midrange vehicles. It is evident that the underlying assumptions on indirect overhead cost allocations have a notable impact on the timing of total OEM cost parity.

As noted above, PHEVs do not achieve cost parity with a corresponding ICEV in any of the overlapping classes or segments.

This analysis examines the estimated costs incurred by an OEM before any markups are applied. The analysis focuses on battery pack cost as the key variable, both year-over-year and across vehicle classes segments. Forecasts of other components (except for those supporting the battery packs) were scaled to account for vehicle footprint, class, and battery power as well as range. The assumptions for these components also impacted the cost parity profiles by correspondingly increasing the base year cost. Year-over-year cost variances were either sourced from literature or assumed as specified in Table 20.

Finally, the choice of segment for a given vehicle in the NRCAN database was somewhat subjective. We selected ICEV models within certain price points and then selected BEVs and PHEVs in comparable segments that would compete with the ICEVs. Deciding which class a vehicle belonged to, particularly for SUVs versus CUVs, was also subjective.

Several actions, other than government subsidies, could further accelerate cost parity among top-selling vehicles in Canada, such as the Ford F-Series, RAM pickups, Toyota RAV4, Chevy Silverado, and GMC Sierra (Wallcraft, n.d.). LFP battery technology lowers production costs and would, therefore, accelerate parity should OEMs use this battery type for EVs. However, LFP batteries have a lower range than NMC and NCA batteries. Government support for a robust charging infrastructure would help quell consumer range anxiety, prompting OEMs to bring lower-range and lower-cost versions to market.

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