



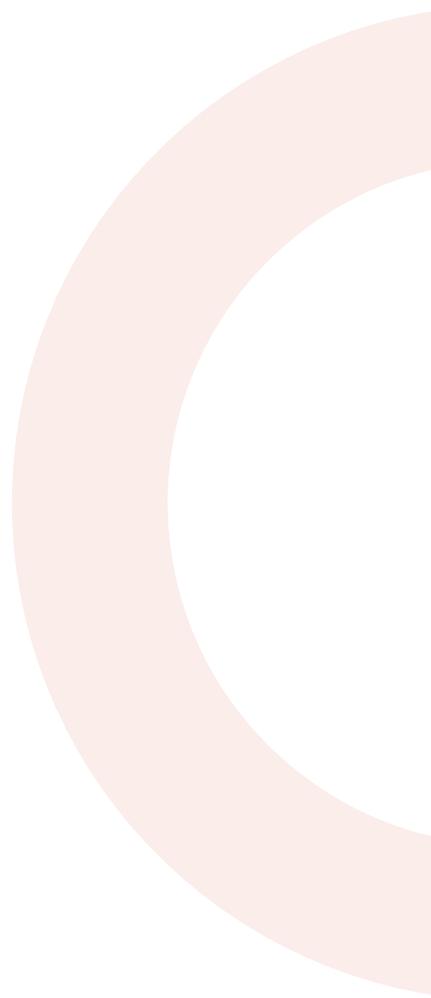
WHITE PAPER

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POWER PLAY: CANADA'S ROLE IN THE ELECTRIC VEHICLE TRANSITION

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EXECUTIVE SUMMARY

Automotive technology continues to evolve at an especially rapid pace due to the continued technical improvements in electric vehicles. Globally, light-duty electric vehicle sales have grown over 60% per year since 2012, to over 2 million in 2018.

Electric vehicles represent the most significant alternative powertrain since the dawn of combustion vehicles in the early 20th century. The annual growth in electric vehicle and electric heavy-duty vehicle sales has averaged 60% and 140% per year between 2012 and 2018, respectively. Nearly all these electric vehicles are in China, Europe, and North America, where clean air and climate change are top priorities and where supporting policies are being continually implemented to accelerate the transition.

This paper evaluates Canada's position in the emerging global electric vehicle industry by analyzing sales and production trends for conventional and electric vehicles and comparing these trends to similar auto markets around the world. By examining Canada's electric vehicle market and assembly developments, and comparing those with activities in other manufacturing countries, we identify underlying policies that Canada could use to ensure they remain an integral part of the rapidly evolving global automobile industry.

Figure ES-1 shows light-duty vehicle production (x-axis) and electric vehicle production (y-axis) by country in 2018. Electric vehicle manufacturing in the countries above the dotted line is greater than 2.3% of their total vehicles produced; conversely, electric vehicles account for less than 2.3% of vehicle production for countries below this line. China leads with 4.2% of its 25 million vehicles produced being electric, and others like Germany and the United States are at the leading edge of the transition to electric vehicle manufacturing. Each of these three countries make more than 5 million vehicles per year, and electric vehicles accounted for 3% to 4% of their production in 2018. At roughly 2 million vehicles manufactured per year, Canada is the 12th largest vehicle producer, but electric vehicle production, at 0.4%, is 80% lower than the global average. As shown, many other high vehicle-producing countries, such as South Korea, France, the United Kingdom, and smaller-producing countries like Slovakia, Austria, Sweden, and the Netherlands, have much larger shares of electric vehicle production than Canada.

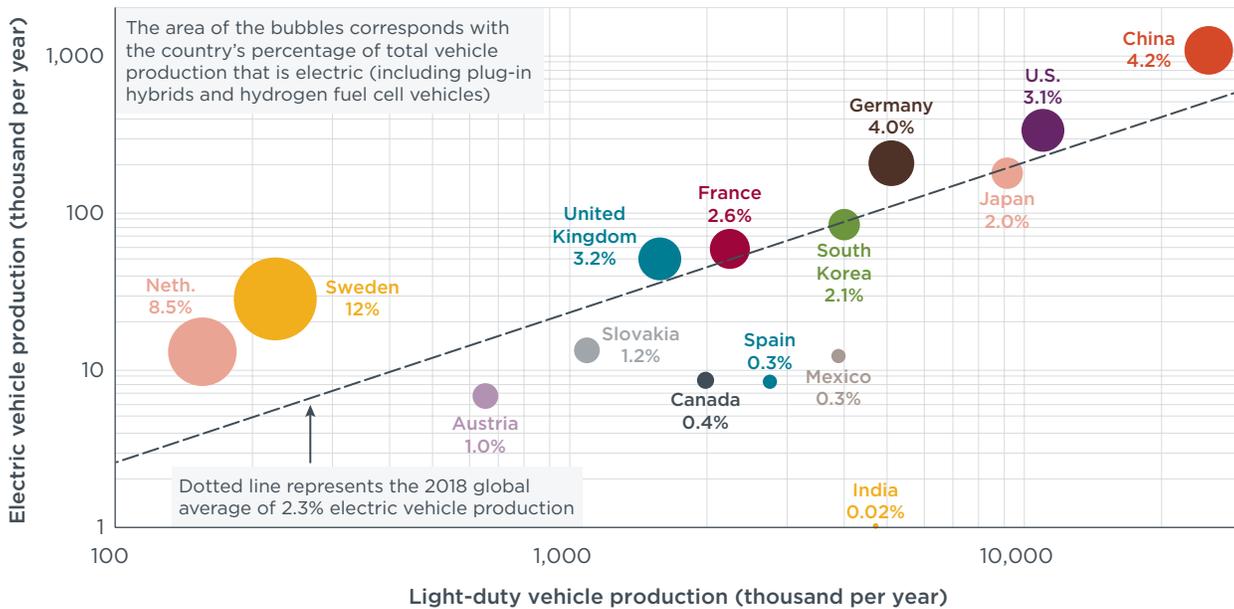


Figure ES-1. Light-duty vehicle production, electric vehicle production, and electric vehicle share of production by manufacturing country in 2018

Canada ranks 5th globally in commercial vehicle production at nearly 1.4 million vehicles produced in 2018, and it exports close to \$3 billion in vehicles from the heavy-duty sector. As with sales for zero-emission commercial trucks and buses, China has dominated the global production of electric heavy-duty vehicles. Canada ranks sixth in the world in electric heavy-duty vehicle production, despite a relatively small share (0.1%). Canada’s overall heavy-duty vehicle manufacturing sector has shown robust growth since the early 2010s, with sharp increases in both exports and revenues.

Based on the findings from this paper, Canada holds a prominent stake in the global automotive industry, but that position could be strengthened with stronger action to support the transition to electric vehicles. The analysis reveals the following conclusions and policy recommendations:

Canada’s auto industry lags behind other auto-manufacturing countries in its preparation for an electrified transportation future. Canada is committed to electrifying its on-road vehicles as part of the country’s overall decarbonization strategy. However, particularly in the light-duty vehicle sector, stronger policies in other countries are driving electrification and attracting electric vehicle investments. Chrysler, Ford, General Motors, Honda, and Toyota production facilities in Ontario are dominated by internal combustion vehicles, while these same companies are making billion-dollar investments to produce electric vehicles in China, Europe, and the United States. Ontario has historically been the center of Canadian light-duty auto production but currently has only one low-volume plug-in hybrid vehicle production plant, making Canada’s light-duty vehicle manufacturing industry quite vulnerable in a global market that is trending toward electrification. If Canada does not find a way to rapidly develop raw materials and a supply base to rapidly accelerate electric vehicle production, it is at risk of losing a major pillar of its economy.

Targeted policy support for electrification can future-proof Canada’s auto industry. The predominant action Canada can take to spur electric vehicle manufacturing is to

grow its domestic electric vehicle sales market. Globally, 80% of electric vehicles are manufactured in the region they are sold. There are many examples of automakers investing in electric vehicle production facilities near cities and regions with growing market demand. Sustained world-class regulatory, incentive, infrastructure, and consumer awareness policies would improve Canada's attractiveness for increased electric vehicle sales and investments. Beyond market-demand policies to ensure affordable models and convenient charging, supply-side policies like research and development funding, loan guarantees, and tax breaks for manufacturing plants are warranted to position Canada's auto industry for the future. Moreover, domestic manufacturing requirements for the procurement of public transit vehicles, which currently exists in Ontario and Quebec, can serve to increase production of electric buses in Canada. While the transition to electrification in trucking is in the early stages, several Canadian-based companies and manufacturing facilities have emerged in recent years, and several zero-emission vehicle models and key components are being produced domestically. A comprehensive suite of policies would encourage further investment in developing electric vehicle supply chains in Canada. In addition to policies to support industry, there is an increasing need for policymakers to provide targeted support for the workers and communities that depend on the auto sector.

Canada can build on its early leadership in developing and producing hydrogen fuel cell technology—especially for heavy-duty vehicles. While battery electric technology has dominated the light-duty zero-emission vehicle market to date, hydrogen fuel cell vehicles are expected to play a larger role in the electrification of the commercial vehicle sector. Fuel cell vehicles' longer-range and quick-fueling capabilities are especially attractive in heavier vehicles such as tractor-trailers, where battery electric technology may not be practical or cost-effective. We identify three key reasons why hydrogen and fuel cell technology are strategically important to Canada's competitive position in the global transition to electric drive. First, the Canadian hydrogen and fuel cell sector is recognized for pioneering new technologies and industry expertise. Second, some regions in Canada have a significant excess of renewably sourced electricity, primarily hydro-electric power, that can be used to produce low-cost, low-carbon hydrogen for powering fuel cell vehicles. Finally, hydrogen fuel cell vehicles are likely to play a critical role in Canada's on-road freight sector, since fuel cells have a lower weight penalty and improved cold temperature performance compared to battery electric trucks.

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INTRODUCTION

Automotive technology continues to evolve, now at an especially rapid pace due to the continued technical improvements in electric vehicles. Figure 1 shows global electric vehicle growth, from just thousands of sales in 2010 to over 2 million in 2018 (EV-Volumes, 2019). Nearly all of these electric vehicles were sold in China, Europe, and North America. At least 13 automakers have announced plans and made billion-dollar investments for a zero-emission future. For heavy-duty vehicles (HDVs), annual electric vehicle sales have been lower but have seen enormous growth, from 2,300 in 2012 to a peak of over 200,000 in 2016. Sales have since declined, to 121,600 in 2018. Sales of electric HDVs have been almost exclusively in China, which represented 98% of the global market in 2018 (EV-Volumes, 2019).

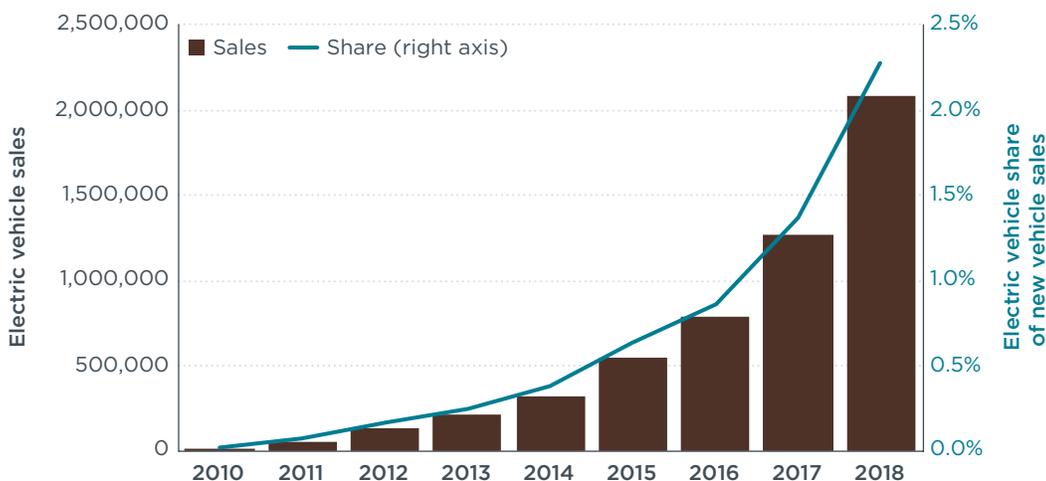


Figure 1. Global light-duty electric vehicle sales and new vehicle share

Although electric vehicles represent just over 2% of new automobiles globally, there are now more than 5 million electric vehicles and significant investments continue to be made. Several automakers have signaled their intention to pursue an all-electric or zero-emission future (Lutsey, 2018a). Governments and automaker announcements alike indicate electric vehicle sales will increase to 10 million to 15 million per year by 2025 (Lutsey, 2018b). Automaker research and development, production plant upgrades, and supply chain investments continue to move toward electric vehicles. Automaker investments to electrify tally to \$300 billion from 2019 to 2028 (Lienert, Shirouzu, & Taylor, 2019; Lutsey, Grant, Wappelhorst, & Zhou, 2018). About 80% of this investment is projected to occur in China, Germany, and the United States (Lienert & Chan, 2019).

Developments in electric buses and trucks indicate that the HDV market will continue to grow (Moultak, Lutsey, & Hall, 2017). The global heavy-duty electric vehicle market is highly concentrated in China, which accounted for 98% of sales in 2018. Chinese-headquartered original equipment manufacturers (OEMs), meanwhile, accounted for 82% of sales (EV-Volumes, 2019). Canada made up 0.03% of global sales in 2018, ranking 21st, while Canadian-headquartered OEMs accounted for 0.1%, ranking sixth (EV-Volumes, 2019).

In Canada, the transportation sector represents a quarter of the country's greenhouse gas emissions (Environment and Climate Change Canada, 2017). To meet climate goals, policymakers in British Columbia, Quebec, and the federal government have

signaled the need to transition to all zero-emission vehicles in the 2040–2050 time frame (British Columbia Ministry of Energy, Mines and Petroleum Resources, 2019; Department of Finance Canada, 2019; International Zero-Emission Vehicle Alliance, 2019). Beyond the environmental goals, Canada is a top vehicle-producing country, making the transition to electric vehicles also consequential for industry.

Where Canada’s auto manufacturing industry fits in the transition to electric vehicles is a top question for industry and policy leaders. This paper evaluates Canada’s position in global electric vehicle sales and manufacturing. We analyze the sales and production trends for conventional and electric vehicles and compare these trends with similar automobile-producing markets around the world. By examining Canada’s electric vehicle market and assembly developments, and comparing those with activities in other manufacturing countries, we identify underlying policies that Canada could use to ensure the country remains an integral part of the global automobile industry.

ASSESSMENT OF CANADA'S POSITION: LIGHT-DUTY VEHICLES

This section assesses Canada's light-duty automobile industry in 2018 according to a variety of market and production metrics for overall and electric vehicle sales and production, and examines where Canada ranks compared with other nations. The analysis builds upon previous studies (Lutsey et al., 2018), but updates the data through 2018 and focuses specifically on the Canadian market. The analysis relies on global electric vehicle data from EV-Volumes (2019), overall global vehicle sales and production data from the International Organization of Motor Vehicle Manufacturers (OICA, 2019a, 2019b), and vehicle import and export data from several sources (International Trade Administration, 2019a, 2019b; International Trade Centre, 2019).

VEHICLE SALES AND PRODUCTION

Several light-duty vehicle production metrics indicate that Canada's automotive industry is among the largest globally. In 2018, Canada produced 2 million passenger cars and light commercial vans, out of global production of about 91 million vehicles. Canada's light-duty vehicle production declined from 2.4 million, or 3.1% of global production and ninth place globally in 2014, to 2.2% of production and 12th place in 2018—a 29% reduction in the global share. Other countries with similar annual vehicle production include Brazil, France, Mexico, South Korea, Spain, and the United Kingdom, with each country producing between 1.6 million and 4 million vehicles (OICA, 2019a).

Canada also holds a prominent position in global vehicle trade. Canada's car and truck exports, with a value of \$45 billion, rank the country fifth globally, behind Germany, Japan, Mexico, and the United States (International Trade Centre, 2019). Countries with similar export levels to Canada include Belgium, France, South Korea, Spain, and the United Kingdom, each with \$34 billion to \$44 billion in vehicle exports. Canada also ranks 12th globally in automotive parts exports, with \$11 billion in 2018. Over 80% of Canada's vehicle production is exported to the United States, and over 40% of Canada's vehicle sales are imported from the United States (International Trade Administration, 2019b; International Trade Centre, 2019).

Canada's light-duty vehicle sales market is similar in scale to its production, at 2 million vehicles sold per year. National vehicle markets with similar size to Canada include Brazil, France, Russia, South Korea, and the United Kingdom at 1.6 million to 2.4 million annual sales (OICA, 2019b). These statistics help place issues surrounding electric vehicle deployment in a broader industry context. Canada clearly represents a very large market and a very large production region for vehicles. But Canada is also competing with many markets for imports and exports, and with large vehicle-manufacturing markets where new vehicle models are being developed and produced.

ELECTRIC VEHICLE PRODUCTION AND SALES

The growth in the electric vehicle market in Canada has been steady and increasing. Canada's 2018 electric vehicle sales reached 43,000, making it the eighth largest national electric market. Electric markets of similar size include France, Japan, South Korea, and Sweden (from 29,000 to 53,000). Figure 2 shows global light-duty electric vehicle sales growth, including the 10 largest 2018 markets representing 89% of sales. Although Canada makes up only 2% of global electric sales, its average annual

2012–2018 growth rate of 70% was greater than the United States (35%) and global electric sales (60%).

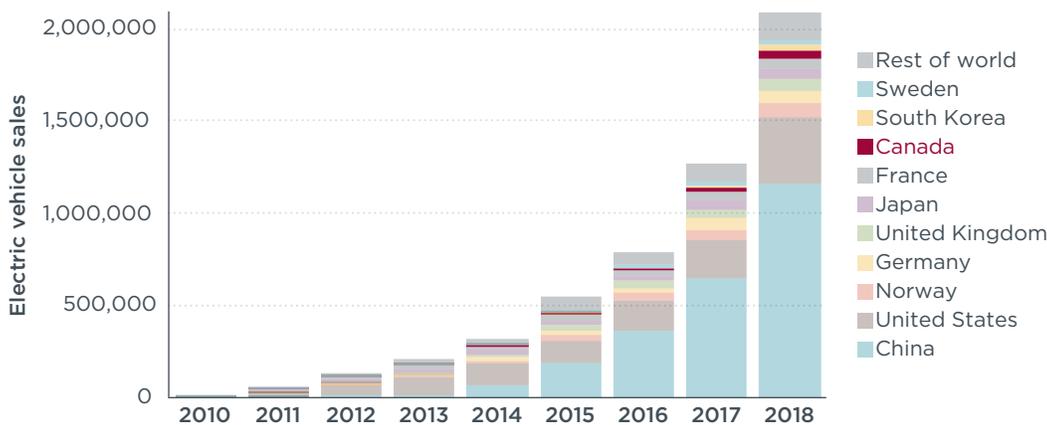


Figure 2. Global light-duty electric vehicle sales from 2010 to 2018, including breakdown of 10 highest-selling markets in 2018. Source: EV-Volumes, 2019

In terms of shares of new vehicles, electric vehicles represent 2.3% of global vehicle sales in 2018. Eleven countries surpassed the global average of 2.3% market share: Norway (49%), Finland (45%), Iceland (19%), Sweden (8%), Netherlands (6%), China (4%), Portugal (4%), Switzerland (3%), Austria (2.6%), the United Kingdom (2.5%), and Belgium (2.5%). Canada’s market has grown from essentially 0% in 2010 to 2.2% in 2018, which is very similar to the share in the United States (2.1%) and globally (2.3%).

Global light-duty electric vehicle production is more concentrated. Approximately 99% of 2018 electric vehicle manufacturing is within 10 countries: China (52%), the United States (17%), Germany (10%), Japan (9%), South Korea (4%), France (3%), United Kingdom (2%), Sweden (1%), Netherlands (1%), and Slovakia (1%). Canada ranks 12th in electric vehicle production. With approximately 9,000 electric vehicles made in Canada, the Chrysler Pacifica plug-in hybrid, the only Canada-made light-duty vehicle model, represents about 0.4% of Canada’s production. High-production markets produce many different electric models. For example, in the United States electric production includes models by Tesla (Model 3, Model S, Model X), Chevrolet (Bolt, Volt), Nissan (Leaf), BMW (X5 40e), and Ford (C-Max, Focus).

Figure 3 shows light-duty vehicle production versus electric vehicle production by manufacturing country in 2018. The plot is shown in log scale due to the large differences in the auto production across the markets, with China having over 25 million vehicles produced and 1.1 million electric vehicles. Countries above the dotted line have electric vehicle production that is greater than the global average. Countries above the global average include Sweden (12% of vehicles assembled), Netherlands (8.5%), China (4.2%), Germany (4%), United Kingdom (3.2%), United States (3.1%), and France (2.6%). Canada has a 0.4% electric share (9,000 electric out of 2 million vehicles) and is 80% lower than the global light-duty electric vehicle production average.

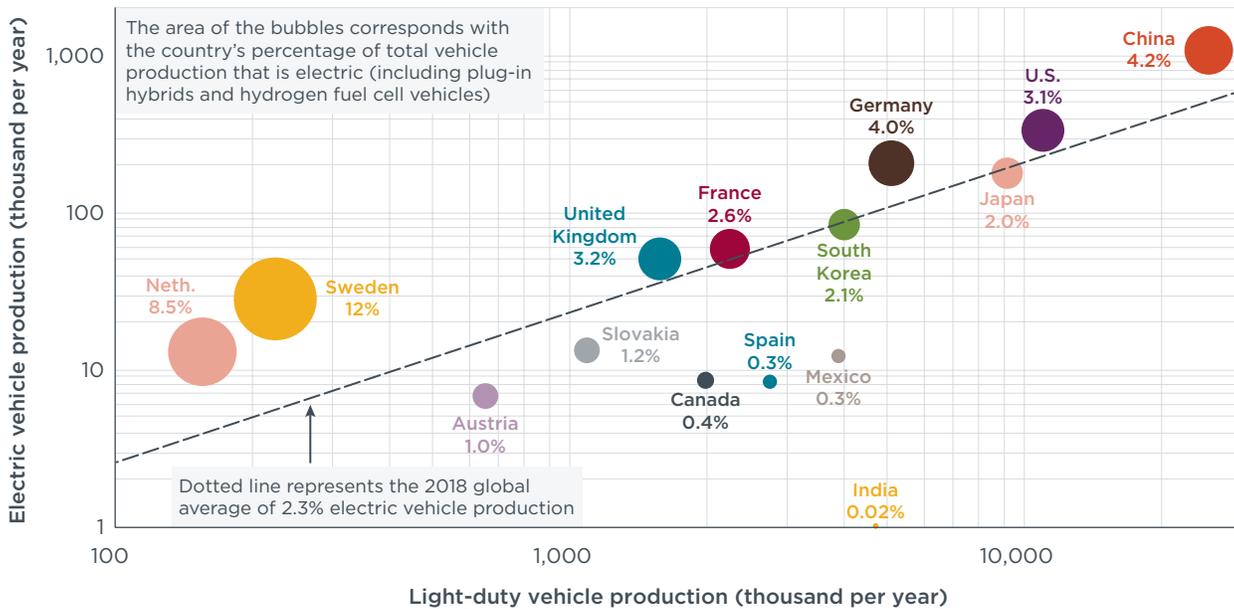


Figure 3. Light-duty vehicle production, electric vehicle production, and electric vehicle share of production by manufacturing country in 2018. Source: EV-Volumes, 2019; Lutsey et al., 2018.

As indicated in Figure 3, there are many high-vehicle-producing countries that have begun to transition to higher electric vehicle production than Canada. Greater electric vehicle production rates, typically from multiple electric models assembled there, are seen in several countries: South Korea (e.g., Hyundai Ioniq, Kona, Sonata; Kia Niro, Optima), France (Renault Zoe, Kangoo; Smart fortwo), and United Kingdom (Nissan Leaf; Geely LEVC black cab; Range Rover). There is also electric vehicle production in smaller markets like Slovakia (Smart forfour, Porsche Cayenne), Austria (Jaguar i-Pace), and much smaller markets such as Sweden (Volvo v60, XC60), the Netherlands (Mini Countryman), and Belgium (which started Audi e-tron at the end of 2018). Not shown in the figure due to having no significant electric production are several major manufacturing nations; Brazil, Iran, Russia, and Thailand are the largest with 1.5 million to 2.7 million vehicles produced in 2018.

Most manufacturers predominantly sell their electric vehicles within the region where they are made, as illustrated in Figure 4. Globally, 80% of electric vehicles produced were sold within their home region: Nearly 100% of China-made electric vehicles are sold there; 81% of Europe-made electric vehicles are sold there; and 74% of U.S. electric vehicles are sold there. In addition to creating large electric markets in their home region, European and U.S. electric vehicles are also exported widely to many markets. Japan, South Korea, and Canada are somewhat different cases in that they export most vehicle production to the larger China, Europe, and U.S. markets and elsewhere.

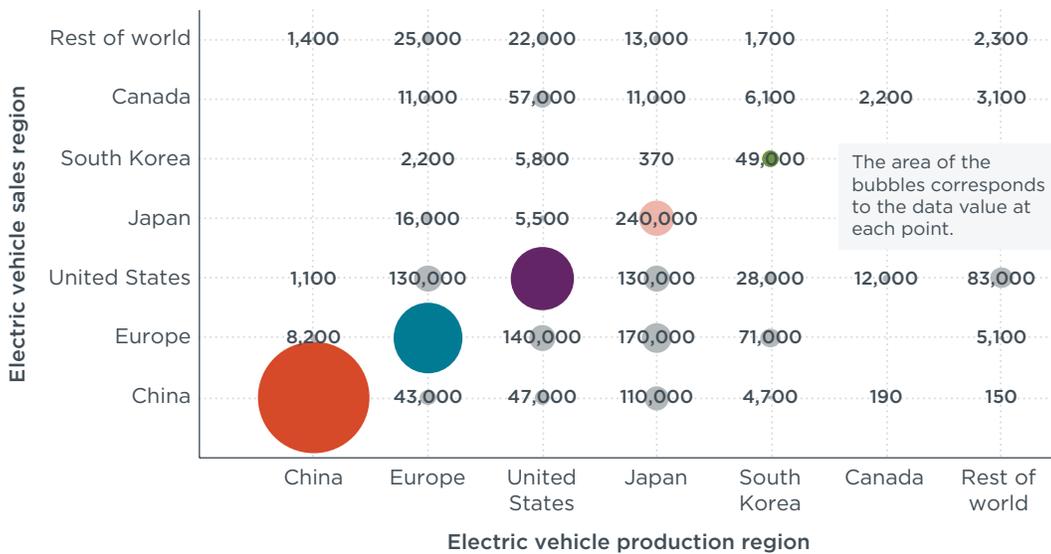


Figure 4. Cumulative 2010-2018 light-duty electric vehicle volume according to production and sales regions. Based on EV-Volumes, 2019; Lutsey et al., 2018.

Table 1 provides more detailed information on the top 15 electric vehicle models sold in 2018 in Canada and the United States, representing 90% of each country's electric vehicle market. The highest volume electric vehicle models in Canada were the Tesla Model 3 (6,300 sales, or 15% of Canada's electric market) and the Nissan Leaf. The U.S. list is similar but was far more dominated by the Tesla Model 3 (139,000 sales, or 39% of the U.S. electric market). The Mitsubishi Outlander and Hyundai Ioniq PHEVs sold more in absolute terms in Canada, despite Canada's market being just 12% the size of the U.S. market. About 97% of Canada's 43,000 2018 electric vehicle sales were imports, and 57% were from the United States. Of U.S. electric vehicle sales, 71% were made in the United States.

Table 1. Fifteen highest-selling electric vehicle models in Canada and the United States in 2018

Canada sales				United States sales			
Rank	Model	Sales	Assembly	Rank	Model	Sales	Assembly
1	Tesla Model 3	6,300	U.S.	1	Tesla Model 3	139,700	U.S.
2	Nissan Leaf	5,700	U.S.	2	Toyota Prius Prime*	27,600	Japan
3	Mitsubishi Outlander*	5,300	Japan	3	Tesla Model X	24,700	U.S.
4	Chevrolet Volt*	4,300	U.S.	4	Tesla Model S	24,500	U.S.
5	Toyota Prius Prime*	3,500	Japan	5	Chevrolet Volt*	18,300	U.S.
6	Chevrolet Bolt	2,500	U.S.	6	Honda Clarity PHEV*	18,200	Japan
7	Ford Fusion Energi*	1,900	Mexico	7	Chevrolet Bolt	18,000	U.S.
8	Tesla Model X	1,600	U.S.	8	Nissan Leaf	14,700	U.S.
9	Chrysler Pacifica*	1,400	Canada	9	Ford Fusion Energi*	8,100	Mexico
10	Hyundai Ioniq PHEV*	1,400	S. Korea	10	Chrysler Pacifica*	7,100	Canada
11	Volkswagen e-Golf	1,200	Germany	11	BMW i3*	6,100	Germany
12	Tesla Model S	1,100	U.S.	12	BMW X5*	4,400	U.S.
13	Kia Soul	1,100	S. Korea	13	BMW 530e*	4,300	Germany
14	Honda Clarity PHEV*	800	Japan	14	Mitsubishi Outlander*	4,200	Japan
15	Hyundai Ioniq BEV	500	S. Korea	15	Kia Niro*	3,400	S. Korea

Based on EV-Volumes, 2019. Values rounded to the nearest hundred; colors distinguish assembly location
 * denotes plug-in hybrid (except some fraction of BMW i3 models are all electric)

The left side of Figure 5 shows the breakdown of electric vehicle sales in Canada by manufacturer. Through the second quarter of 2019, Tesla, General Motors, and Nissan are the leading electric vehicle automakers, with roughly 30,000, 26,000, and 22,000 cumulative electric vehicles sold, respectively. In 2018, these three manufacturers represented nearly two-thirds of Canada's electric vehicle sales, with Ford, Volkswagen, and other companies making up the remaining one-third of the market. In the first six months of 2019, Tesla's market share grew to 40%, followed by Nissan at 15%, General Motors at 12%, and Toyota at 8%.

The share of electric vehicles in Canada's light-duty vehicle market has grown from 0.3% in 2014 to nearly 3% in 2019, as shown on the right side of Figure 5. Plug-in hybrid and fully electric (i.e., battery electric or hydrogen fuel cell) vehicle sales are depicted in blue and orange, respectively. While plug-in hybrids made up about half of the electric vehicle market in 2016, 2017, and 2018, their share has decreased to just under 40% thus far in 2019.

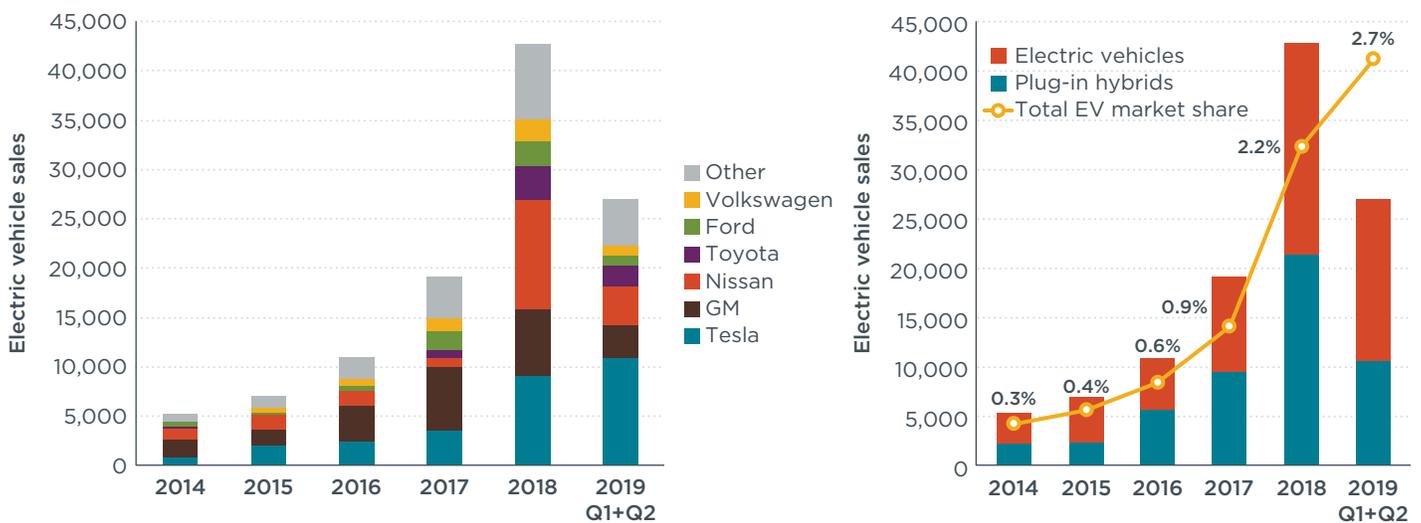


Figure 5. Electric vehicle sales by manufacturer and their share of the overall light-duty vehicle market in Canada

SUMMARY OF THE LIGHT-DUTY VEHICLE INDUSTRY AND MARKET

Table 2 summarizes the relative positions of each country in 2018 according to vehicle production and sales. China, Germany, Japan, and the United States are among the leaders in most categories. China leads in vehicle volume, electric vehicle production, and sales but has not become a leading exporter. Canada's position according to each metric in Table 2 is highlighted in red. Canada accounts for 2.2% of global light-duty vehicles made, but only 0.4% of global electric vehicles made, showing how it lags behind the global industry development trend. The United Kingdom, France, and South Korea have a share of electric production that is proportional to their vehicle production. Smaller auto-producing countries like Sweden, Netherlands, and Slovakia are producing electric vehicles well above their global vehicle production levels. Canada's electric vehicle sales at 2.2% are keeping pace with the global trend.

Table 2. Top 15 countries by vehicle production, export, market, and electric vehicle metrics

Rank	Industry metrics				Market metrics	
	Vehicle production, 2018	Vehicle export value, 2018	Automotive parts export value, 2018	Electric vehicle production, 2018	Vehicle sales, 2018	Electric vehicle sales, 2018
1	China (25.5 m)	Germany (\$167 b)	Germany (\$67 b)	China (1,078,000)	China (24.7 m)	China (1,104,000)
2	U.S. (11 m)	Japan (\$108 b)	U.S. (\$46 b)	U.S. (335,000)	U.S. (17.3 m)	U.S. (358,000)
3	Japan (9.2 m)	Mexico (\$74 b)	Japan (\$36 b)	Germany (205,000)	Japan (4.4 m)	Norway (73,000)
4	Germany (5.1 m)	U.S. (\$67 b)	China (\$35 b)	Japan (181,000)	Germany (3.4 m)	Germany (66,000)
5	India (4.7 m)	Canada (\$45 b)	Mexico (\$30 b)	S. Korea (84,000)	India (3.4 m)	U.K. (60,000)
6	S. Korea (4 m)	U.K. (\$44 b)	S. Korea (\$20 b)	France (59,000)	U.K. (2.4 m)	Japan (53,000)
7	Mexico (3.9 m)	Spain (\$42 b)	France (\$16 b)	U.K. (50,000)	France (2.2 m)	France (46,000)
8	Spain (2.8 m)	S. Korea (\$40 b)	Czech Rep. (\$15 b)	Sweden (28,000)	Brazil (2.1 m)	Canada (43,000)
9	Brazil (2.7 m)	Belgium (\$38 b)	Italy (\$15 b)	Nether. (13,000)	Canada (2 m)	S. Korea (32,000)
10	France (2.3 m)	France (\$34 b)	Poland (\$14 b)	Slovakia (13,000)	Russia (1.8 m)	Sweden (29,000)
11	Thailand (2.2 m)	Italy (\$23 b)	Spain (\$12 b)	Mexico (12,000)	S. Korea (1.6 m)	Nether. (27,000)
12	Canada (2 m)	Slovakia (\$22 b)	Canada (\$11 b)	Canada (9,000)	Spain (1.3 m)	Belgium (13,000)
13	Russia (1.7 m)	Thailand (\$19 b)	Thailand (\$9 b)	Spain (8,000)	Mexico (1.2 m)	Spain (12,000)
14	U.K. (1.6 m)	Turkey (\$18 b)	Romania (\$8 b)	Austria (7,000)	Australia (0.9 m)	Switzerland (9,000)
15	Iran (1.5 m)	Sweden (\$14 b)	U.K. (\$7 b)	India (1,000)	Indonesia (0.9 m)	Austria (9,000)
Global	91.6 million	\$1,730 billion	\$412 billion	2,090,000	91.6 million	2,090,000
Canada share	2.2%	2.6%	2.8%	0.4%	2.2%	2.0%

Notes: due to rounding of the values in the table, the values in the last row are correct to within roughly 0.1 percentage points. Source: International Trade Center, 2019; EV-Volumes, 2019; OICA, 2019a, 2019b

At this stage in the development of electric vehicles, nearly every automaker in the world has committed to multibillion-dollar investments to develop a spectrum of new electric models. Investments in research and development, vehicle and battery manufacturing plants, and supply chain facilities have been concentrated in the leading electric vehicle markets: China, Europe, the United States, Japan, and South Korea. Figure 6 illustrates the flow of these initial electric vehicle investments. The numerical label is the investment amount in billion U.S. dollars. Unsurprisingly, given the sheer size of its vehicle market, China has been the leading country for investment, accounting for 45% of the global total to date. European-based manufacturers have split their investments between Europe (\$84 billion) and China (\$69 billion), whereas virtually all of the \$57 billion in investments from China’s automakers have stayed there. Vehicle manufacturers based in the United States, Japan, and South Korea have primarily made investments in their home markets. Outside of China, Europe, the United States, Japan, and South Korea, investments in other countries—including Canada—have totaled \$7 billion, or 2% of the global total.

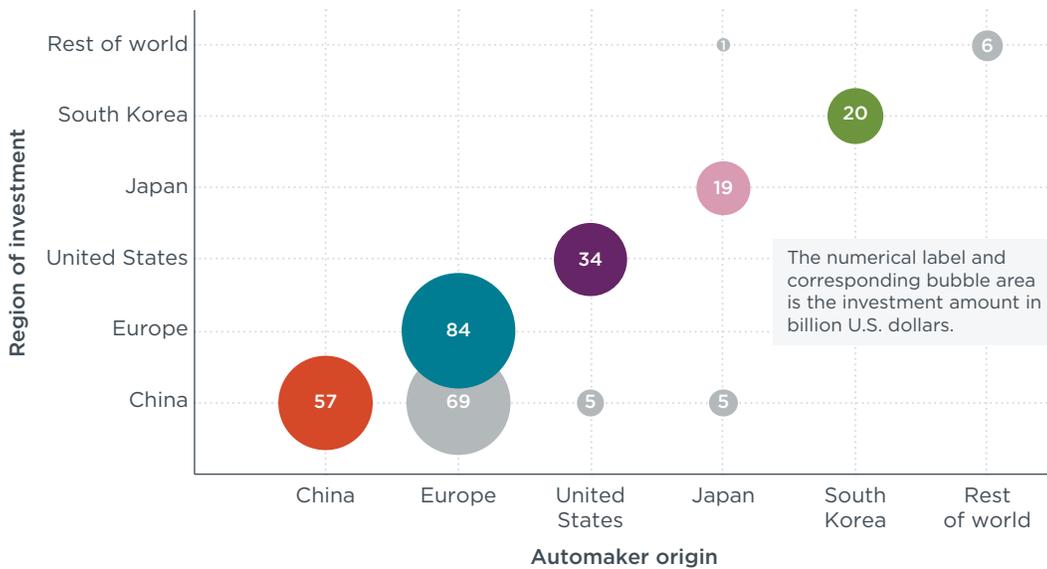


Figure 6. Electric vehicle investment by automaker origin and destination. Source: Adapted from Lienert and Chan, 2019.

BATTERY-ELECTRIC VEHICLE INDUSTRY DEVELOPMENTS

Within the vehicle-level industry developments assessed above, there are relevant supply-chain trends related to raw materials for electric vehicle battery production. For fully battery-electric vehicles, a battery and electric drivetrain displaces the combustion powertrain and aftertreatment system. For plug-in hybrids, a smaller battery pack supplements the combustion powertrain with a more complex drivetrain to use both power sources. For either technology, the changes to the powertrain are dramatic. These changes are evaluated below in the context of overall manufactured vehicle value and relevant suppliers.

Figure 7 shows the breakdown of manufactured vehicle production costs by major component areas for a representative crossover sport utility vehicle, based on Lutsey and Nicholas (2019). The battery pack of the electric vehicle represents a substantial portion of the per-vehicle cost. In 2018, the battery pack made up \$12,000 (200-mile or 322-km electric range) to \$15,000 (250 mile or 402 km) of the cost. This corresponds to 42% to 48% of the electric vehicle production costs. By 2025, the battery share of vehicle cost declines to \$5,800 to \$7,500 per vehicle, or 26% to 31%. The other electric drivetrain components (motor, power electronics, converter, and cables) account for another 12% to 13% of the vehicle cost. Using the same study and assumptions, battery packs represent 11% to 15% of the manufactured content of plug-in hybrid vehicles in 2018, declining between 6% to 9% by 2025.

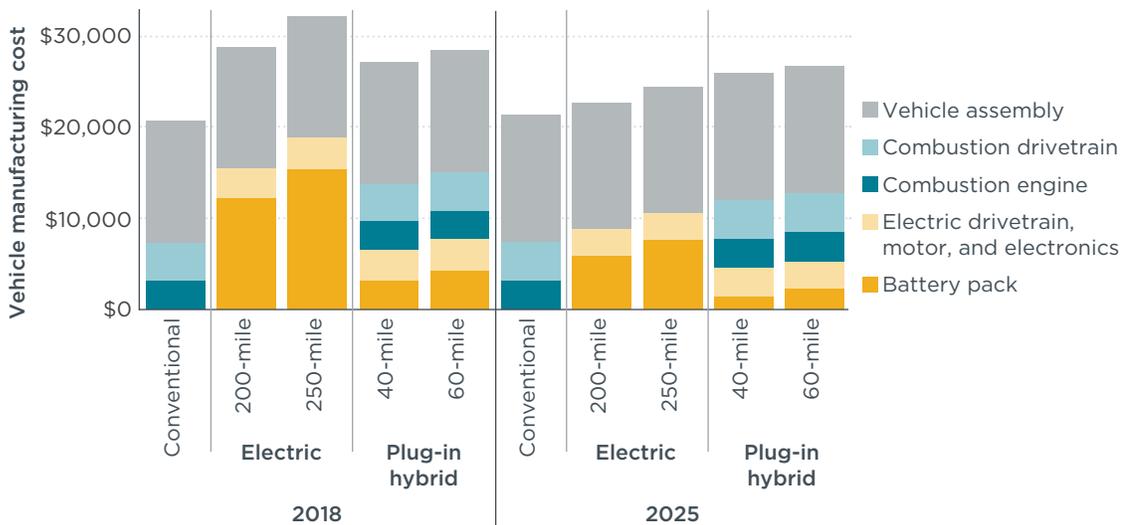


Figure 7. Conventional and electric vehicle manufacturing cost, 2018 and 2025. Source: Lutsey and Nicholas, 2019.

Electric vehicle sales by battery production supplier and their cell manufacturing location are shown in Figure 8. As seen on the left side, battery suppliers continue to move to high-volume production, with five companies now achieving production of more than 200,000 electric vehicles per year. The major battery suppliers for electric vehicle sales in Canada and the United States are Panasonic for Tesla, AESC for Nissan, and LG Chem for Chevrolet. As Figure 8 indicates, China, South Korea, and Japan dominate battery manufacturing. When U.S. and Canada electric vehicle sales grow sufficiently to induce more electric vehicle supply chain creation directly in North America, battery manufacturing in the United States and Canada is expected to become more attractive to companies.

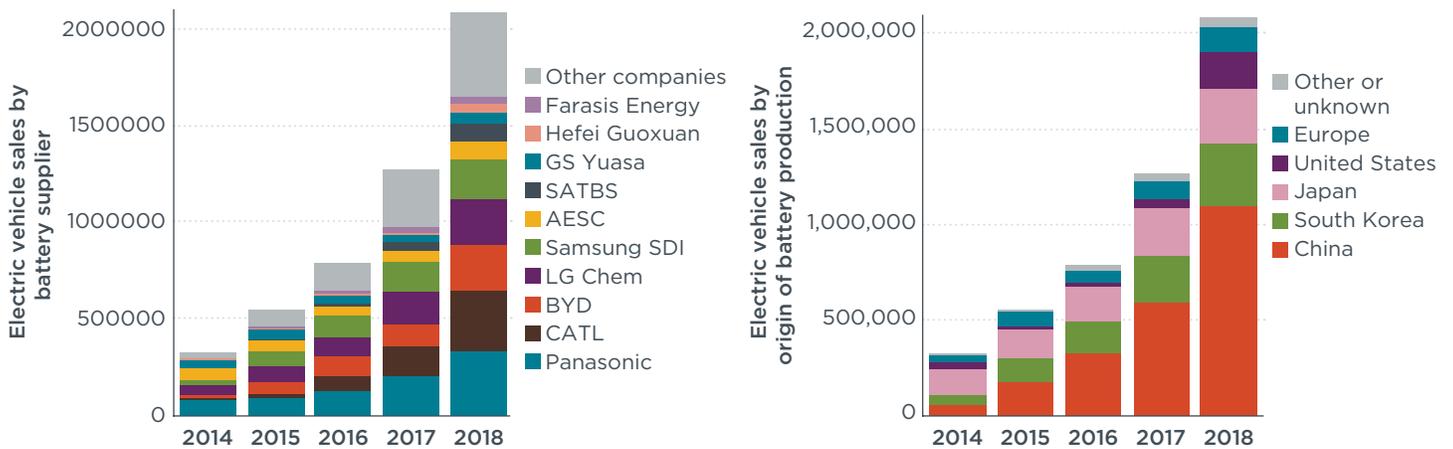


Figure 8. Electric vehicle battery assembly supplier and country, 2014-2018

The major parts of battery production are the raw materials, the cell manufacturing, and the pack-level assembly. Anderman (2018) provides a breakdown of battery pack production that moves from 100,000 units per year in 2020 to 500,000 in 2025. The study indicates that the materials (including lithium, cobalt, nickel, manganese, and graphite) are about half the battery pack raw materials cost, with a quarter from cell manufacturing and a quarter in pack-level manufacturing, including the packaging and

cooling system. These battery cost percentages provide an indication of the relative value for companies and countries to take a strategic interest in the material mining, cell assembly, and battery pack manufacturing.

In addition to these battery-specific materials, there are other automotive content shifts that are likely from electric vehicles. A detailed material comparison of comparable electric and conventional cars (UBS, 2017) indicates the following on a kilogram(kg)-per-vehicle basis: comparable electric vehicles could use 140 kg more active battery materials (lithium, cobalt, nickel, manganese, and graphite), 72 kg more (or 70% higher than conventional) aluminum, 41 kg more (+80%) copper, 55 kg less (-7%) steel, and 62 kg (-60%) less iron.

Although Canada does not have any significant automotive battery pack manufacturing in 2019, the country does have several of the important underlying resources for battery production. Canada is a top-10 country globally for cobalt mining and reserves, graphite production, lithium identified resources, and nickel production and reserves (United States Geological Survey, 2019). In addition, Canada's abundant renewable energy and relatively low-carbon electricity are valuable as manufacturers seek low-carbon battery production. Attracting battery production to Canada is an important way for the country to secure a critical and growing part of the supply chain for electric vehicles sold in North America and around the world.

ASSESSMENT OF CANADA'S POSITION: HEAVY-DUTY VEHICLES

This section assesses Canada's HDV industry up to 2018 according to market and production metrics for total and electric HDV sales and production. The analysis relies on global electric vehicle data from EV-Volumes (2019), overall global vehicle sales and production data from the International Organization of Motor Vehicle Manufacturers (OICA), stakeholder interviews, and publicly available information.

This report uses a broad definition of HDVs, and includes on-road vehicles belonging to Classes 2b through 8 with a gross vehicle weight rating of over 3,856 kg. HDVs include a variety of vehicle sizes and types, including tractor-trailers, delivery trucks, buses, vans, construction equipment, and refuse vehicles.

According to OICA and as shown in Figure 9, Canada is the fifth largest commercial vehicle producing country, behind the United States, China, Mexico, and Japan (OICA, 2019b).¹ The nearly 1.4 million commercial vehicles sold in 2018 represent 5% of global production. In 2010, 1.1 million commercial vehicles were manufactured in Canada, making it the fourth highest producing country and 6% of global production (OICA, 2019c).

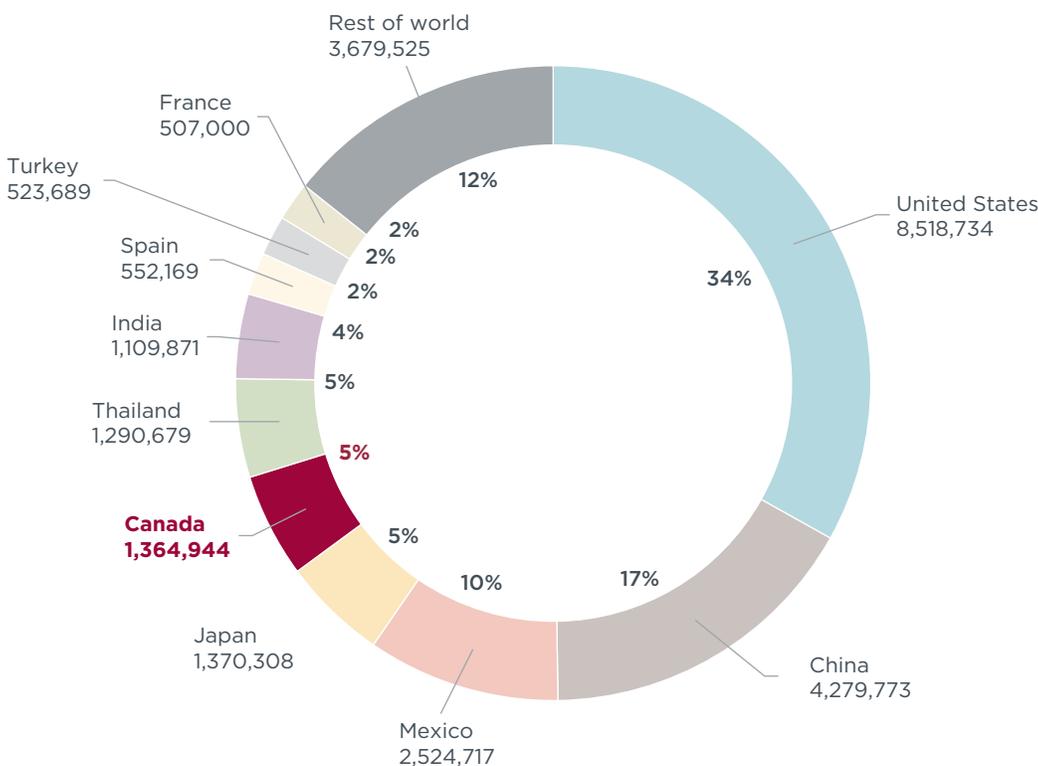


Figure 9. Ten highest-producing countries of commercial vehicles, 2018. Source: OICA, 2019b.

¹ The OICA data set for 2018 does not include entries for the Czech Republic, Finland, Germany, Hungary, Romania, Slovakia, Slovenia, and Uzbekistan. For these countries, 2018 production values are estimated based on 2010 data and average global growth rates between 2010 and 2018.

Figure 10 illustrates a steady growth in HDV sales in Canada as measured by total vehicle registrations² between 2010 and 2018, from 1 million in 2010 to 1.2 million in 2018, with average annual growth of 2.7% between 2011 and 2018. Growth has been driven mainly by the medium and heavy truck sections,³ with 3.3% and 2.5% average annual growth rates, respectively. Passenger buses in this segment, including school, urban transit and inter-city buses, are growing incrementally (Office of Energy Efficiency, n.d.).

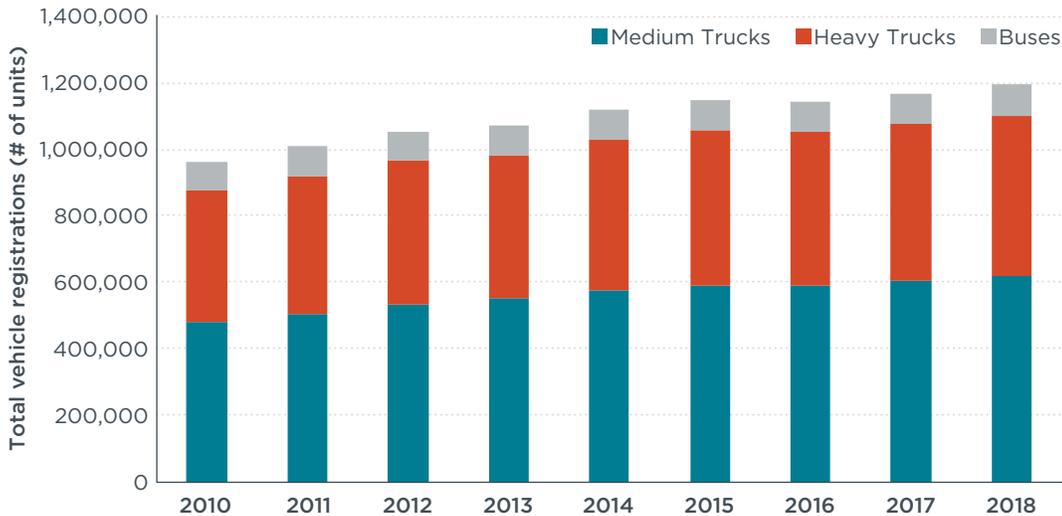


Figure 10. Total medium truck, heavy truck, and bus registrations, 2010–2018. Source: Statistics Canada, 2019a.

HEAVY-DUTY VEHICLE PRODUCTION AND TRADE

Canada’s HDV manufacturing sector has seen robust growth in recent years, with total sector revenues increasing 76% between 2012 and 2017, from \$2 billion to \$3.5 billion (Statistics Canada, 2019c).⁴

Specifically, domestic production of heavy trucks has grown significantly; between 2011 and 2018, Canada’s share of the world’s total heavy truck production increased from 0.25% to 0.49%.⁵ While global production levels have remained relatively steady during this period, Canada’s production of heavy trucks more than doubled. In 2018, Canada produced 20,911 of the 4.2 million heavy trucks produced globally, resulting in Canada ranking 15th in the world (OICA, 2019b). Canada’s exports in the HDV manufacturing sector increased by \$2.1 billion, or 252%, between 2010 and 2018. The United States has consistently been the destination for over 95% of Canada’s exports in the HDV sector, accounting for \$2.9 billion in 2018 (Government of Canada, 2018c). In the same period, Canada imported HDV manufactured products at a greater pace than its exports (an increase of \$4.9 billion or 119%), resulting in an increasing trade deficit

² This paper’s definition of HDV includes some vehicles within the Canadian Vehicle Survey’s definition of “light vehicle.” These are excluded from Figure 10.

³ According to Statistics Canada (2019b), medium trucks are defined as having gross vehicle weights between 4,500 and 14,999 kg while heavy trucks are defined as having gross vehicle weights above 15,000 kg.

⁴ Statistics for Canada’s heavy-duty vehicle manufacturing sector come from the North American Industry Classification System (NAICS) code 33612.

⁵ Per OICA’s definition, “heavy trucks” refers to vehicles intended for the carriage of goods with a maximum authorized mass over 7 metric tons. This definition includes vehicles between 7,000 and 14,999 kg, which are considered “medium trucks” by Statistics Canada (see the previous footnote).

from \$3.3 billion in 2010 to \$6.1 billion in 2018 (Government of Canada, 2019d). This is indicative of a growing domestic market for HDVs and related parts, which could be increasingly served by Canadian production.

Canada's HDV manufacturing sector is heavily concentrated in Quebec and Manitoba, which collectively account for 43% of its production facilities and 89% of its medium and large establishments (Government of Canada, 2018b). This is in contrast to the light-duty vehicle side, which is concentrated in Ontario (Government of Canada, 2018a). Quebec has a cluster of automotive firms specializing in trucks and buses, while Manitoba has several companies specializing in bus production (Global Affairs Canada, 2018).

OEMs with a significant Quebec footprint include the Volvo Group (Nova Bus, Prévost) and PACCAR (Kenworth, Peterbilt). Nova Bus is a manufacturer of a variety of buses, including diesel, natural gas, and electric configurations. Nova Bus's Canadian locations include a plant in St-Eustache, Quebec, where its national headquarters is located, and a plant in St-Francois-du-Lac, Quebec (Nova Bus, 2017b). Prévost, a manufacturer of intercity touring coaches and conversion coaches, has its head office in Sainte-Claire, Quebec (Prevost, 2019). PACCAR has operations in Ste-Thérèse, Quebec, where it produces medium- and light-duty Peterbilt and Kenworth trucks (PACCAR, 2019).

HDV manufacturers with a significant presence in Manitoba include Motor Coach Industries (intercity coaches) and New Flyer (transit buses). Both Motor Coach Industries and New Flyer have a production facility in Winnipeg, Manitoba (NFI Group Inc., 2019b).

HEAVY-DUTY ELECTRIC VEHICLE SALES

While HDV stock and production is growing, the stock of electric HDVs in Canada is quite low. This is slowly changing, however, with businesses and government agencies procuring electric HDVs each year. For the purpose of this report, the definition of electric HDVs includes only electric, plug-in hybrid electric, and fuel cell electric propulsion vehicles. Due to data constraints, total heavy-duty electric vehicle sales do not include hybrid electric heavy-duty vehicles (EV-Volumes, 2019).

Zero-emission trucks and buses have similar environmental and economic benefits as their conventional counterparts, though several barriers have impeded their adoption to date. These barriers to widespread adoption include limited range, high purchase prices, high costs of refueling infrastructure, unproven reliability and durability of the technologies, and reduction in return on investment through reduced payload capacity due to weight of the battery (Wiginton, Smith, Ewing, & Battista, 2019). Given these and other challenges, the large majority of early deployments of zero-emission trucks and buses have been in urban applications and use cases. Public transit buses and freight trucks that operate in urban environments tend to have predictable routes and set downtime at a depot, which makes refueling with electricity or hydrogen easier to operationalize.

Growth in Canada's electric HDV⁶ market has occurred mainly in the past three years, with zero sales between 2010 and 2015, and marginal absolute growth until 2018, when Canada's electric HDV sales were reported to be under 50 (EV-Volumes, 2019). Canada

⁶ This section of the paper, in line with EV-Volumes (2019), will define an electric HDV as a small bus, medium bus, large bus, or heavy truck with a battery-electric, plug-in hybrid electric or fuel cell electric propulsion system. It should be noted that this definition excludes hybrid-electric vehicles.

currently sits at 21st place within the global electric HDV market. Electric HDV markets of similar size include Australia, Germany, Belgium, Norway, and Russia, with sales in 2018 ranging from 40 to 50. Based on data from EV-Volumes (2019), global sales have skyrocketed in recent years, increasing from 2,300 in 2012 to a peak of 207,900 in 2016. Passenger buses make up the majority of global electric HDV sales, at 82% in 2018, with heavy trucks making up the majority of the balance. This pace of growth is, in large part, driven by sales in China. As shown in Figure 11, China has dominated the global heavy-duty electric vehicle sales market from 2010 to 2018, making up 98% of global sales in 2018. China has encouraged the sales of electric buses primarily through subsidies, which began in 2009 and applied to battery-electric, plug-in hybrid electric and fuel cell electric buses. Government support was aimed at a number of “pilot cities” and included assistance for charging infrastructure as of 2013 (International Energy Agency, 2018).

Following China, the next leading markets of electric HDVs—albeit all below 1% of global sales—include the United States (0.47%), the Netherlands (0.25%), India (0.17%), and the United Kingdom (0.15%) (EV-Volumes, 2019). Canada makes up a very small portion of global sales at 0.03%. Globally, sales of electric HDVs have been declining since 2016, with sales totaling 121,600 in 2018. This downward trend can be attributed to factors including changes made to subsidies for electric buses from the Chinese national and local governments (Dixon, 2018).

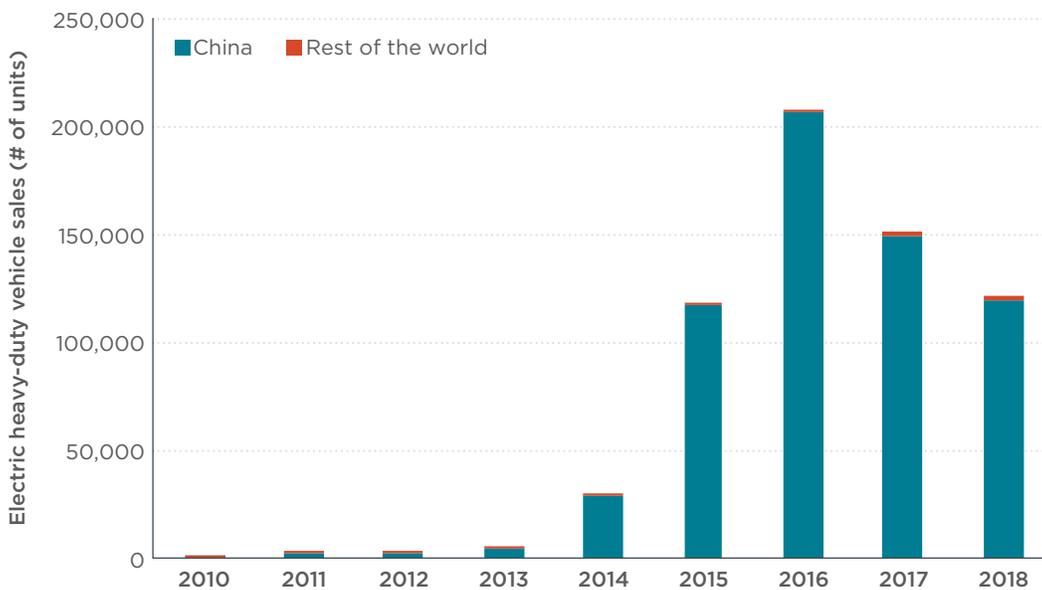


Figure 11. Global heavy-duty electric vehicle sales from 2010 to 2018, China and the rest of the world. Source: EV-Volumes, 2019.

Similar to global trends, electric passenger bus sales in Canada represent a majority of total zero-emission HDV sales (83%) (EV-Volumes, 2019). Much of the growth of the electric passenger bus segment is likely attributed to transit agencies increasing procurement of electric public transit vehicles. Several developments in the deployment of battery-electric transit buses in Canada are summarized in Table 3.

Table 3. Battery-electric bus deployments in Canada

City, transit agency, and other stakeholders	Description	Sources
Toronto, Toronto Transit Commission (TTC)	The City of Toronto has committed to transitioning 50% of its fleet to zero-emission vehicles by 2032 and 100% of the fleet by 2040. TTC announced that a total of 60 electric buses will be delivered by the end of 2019.	Toronto Transit Commission (n.d.)
Montreal, Société de transport de Montréal (STM)	In 2017, STM announced plans to purchase 40 additional electric buses, and has been testing three electric buses between 2017 and 2019 through the City Mobility demonstration project. STM has committed to purchasing only fully electric vehicles for its surface fleet by 2025.	Société de transport de Montréal (n.d.-a)
Vancouver, Translink, Canadian Urban Transit Research & Innovation Consortium (CUTRIC)	TransLink is seeking to increase its battery-electric bus fleet so as to meet a target of 100% renewable energy by 2050. TransLink is running a battery-electric bus pilot in partnership with CUTRIC. This pilot will last 2.5 years and involve the testing of four battery-electric buses from Nova Bus and New Flyer.	Translink (2017)
BC Transit	BC Transit is planning to purchase only electric heavy-duty buses as of 2023. It has a target of a fully electric fleet by 2040. In July 2019, BC Transit announced the acquisition of 10 battery-electric heavy-duty buses. These are intended for deployment in 2021.	BC Transit (2019)

Electrification in the transit sector has been spurred in part by public and private sector programs. The Investing in Canada Plan, a 12-year, \$180 billion plan seeking to invest in areas including public transit and “green Infrastructure” (Infrastructure Canada, n.d.), has resulted in 846 new alternative-fuel buses, including battery-electric and hybrid (Infrastructure Canada, 2019). Investments through the Government of Canada’s Public Transit Infrastructure Fund (PTIF) program has assisted the TTC in purchasing hybrid- and all-electric buses since 2018 (Toronto Transit Commission, 2018).

The City of Brampton and Brampton Transit, the Regional Municipality of York and York Region Transit, and the City of Vancouver and Translink have been participating in the Pan-Canadian Electric Bus Demonstration and Integration Trial in partnership with CUTRIC (Canadian Urban Transit Research & Innovation Consortium [CUTRIC], 2019a). The project, which includes various equipment and charging station manufacturers with a presence in Canada, seeks to test the integration of hybrid-electric and battery-electric buses with overhead charging systems. There has been an uptake of electric school buses, although at a much smaller scale. It has been estimated that there are about 80 electric school buses in operation in Quebec (Dunsky, 2019) and 13 electric buses in Ontario (Dunsky, 2019).

Fleet managers in the private sector in Canada are also beginning to incorporate electric trucks into their operations. In 2017, Loblaw Companies Limited announced a commitment to electrify its corporate-owned trucking fleet and recently ordered 25 electric heavy-duty trucks from Tesla (Saminather, 2017). In September 2018, Walmart Canada announced a target of 100% alternative power for its fleet by 2028. With the company’s purchase of 40 Tesla 18-wheeler semi-trucks, 20% of the company’s fleet will be electric as of 2022 (Walmart Canada, 2018). In April 2019, CN announced a pilot project involving eight Class 8 electric trucks from The Lion Electric Co., to be deployed in CN network cities including Vancouver, Toronto, and Montreal (CN, 2019).

HEAVY-DUTY ELECTRIC VEHICLE PRODUCTION

Global heavy-duty electric vehicle production is heavily concentrated, with 82% of 2018 sales originating from OEMs with global headquarters⁷ in China. Canada ranks sixth in production, at a 0.1% share (EV-Volumes, 2019).

Electric HDV producers with a significant presence in Canada include The Lion Electric Co., Nova Bus, New Flyer, Build Your Dreams (BYD), and GreenPower Motor Company. In 2018, these companies, excluding BYD, sold 130 electric HDVs, of which 23% went to the Canadian market and 77% to the United States.⁸ Canada is one of only a small number of countries with multiple OEMs making electric HDV sales in 2018 (EV-Volumes, 2019).

Table 4 shows the top seven OEMs with electric HDV sales in Canada and the United States in 2018. Canadian firms accounted for 50% of the Canadian market and 17% of the U.S. market. In the United States, U.S. firms accounted for 24% of sales. OEMs headquartered outside of North America account for a significant portion of electric HDV sales in Canada and the United States. In 2018, BYD made up 42% of total electric HDV sales in the United States and 20% of the Canadian market. Daimler AG, headquartered in Germany, accounted for 17% of total electric HDV sales in the United States. The strong position of Canadian OEMs in the North American market is encouraging.

Table 4. Seven highest-selling electric HDV OEMs in Canada and the United States in 2018

Canada sales					United States sales				
Rank	OEM	Sales	Sales %	Global H.Q.	Rank	Model	Sales	Sales %	Global H.Q.
1	Lion Electric	14	35%	Canada	1	BYD	240	42%	China
2	Volvo Group	10	25%	Sweden	2	Proterra	130	23%	U.S.
3	BYD	8	20%	China	3	Daimler AG	97	17%	Germany
4	New Flyer	4	10%	Canada	4	New Flyer	62	11%	Canada
5	GreenPower Motor Company	2	5%	Canada	5	Lion Electric	20	3%	Canada
6	Blue Bird Corporation	1	3%	U.S.	6	GreenPower Motor Company	18	3%	Canada
7	Navya	1	3%	France	7	Blue Bird Corporation	7	1%	U.S.

While only one electric light-duty vehicle model is manufactured in Canada, a number of Canadian OEMs produce multiple models of electric and hybrid-electric HDVs. In 2018, 75% of electric HDVs sold in Canada were built by OEMs with global headquarters in Canada⁹ (EV-Volumes, 2019). These include New Flyer's battery-electric Xcelsior CHARGE bus and fuel cell-electric Xcelsior CHARGE H2 bus (New Flyer, 2019a and 2019b); Nova Bus's LFSe electric bus and LFS HEV hybrid bus (Nova Bus, 2017a and 2017b); and The Lion Electric Co.'s LionC and LionA electric

⁷ This section uses 2018 sales as a proxy for 2018 production and OEM global headquarters as a proxy for production location. For more details, please see Appendix 1.

⁸ Nova Bus, while a subsidiary of the Volvo Group, has its headquarters in Canada and is included in the calculation.

⁹ Nova Bus, which is headquartered in Canada, is owned by the Volvo Group (Sweden). We add the Volvo Group's 25% to the shares of Lion Electric (35%), New Flyer (10%) and GreenPower Motor Company (5%) to get 75%.

school buses (The Lion Electric Company, n.d.-a and n.d.-b). In its December 2018 announcement of the purchase of 12 electric school buses from The Lion Electric Co., Keolis Canada noted that the buses are manufactured and assembled in Saint-Jerome, Quebec (Keolis Canada, 2018). In its June 2018 announcement of a five-year contract for the delivery of nearly 500 hybrid electric buses to a number of Quebec transit authorities, Nova Bus noted that activities at its Saint-Eustache and Saint-Francois-du-Lac plants “help meet Canadian content policies requirements as called for by the Quebec government” (Nova Bus, 2018a). In 2019, The Lion Electric Co. introduced electric truck models, including the Lion8 all-electric urban truck and the Lion8 all-electric waste collection truck (The Lion Electric Company, 2019 and n.d.-c). Finally, Nordresa,¹⁰ headquartered in Laval, Quebec, designs and manufactures electric powertrains for medium-duty vans and trucks (Nordresa, 2019a & 2019b).

The growing Canadian electric HDV production shows potential for Canadian job growth. Nova Bus employs more than 1,000 people across three plants in North America (Nova Bus, 2017a). Since 2017, Nova Bus has created about 200 jobs in its Quebec plants (Infrastructure Canada, 2019). New Flyer employs 1,300 Canadians to manufacture a variety of transit buses including its electric model (McNamara, 2019).

¹⁰ Nordresa was acquired by Dana Inc. in August 2019 (Nordresa, 2019a).

DEVELOPMENTS AND OPPORTUNITIES FOR HYDROGEN FUEL CELL VEHICLES AND INFRASTRUCTURE IN CANADA

To date, plug-in vehicles have captured all but a small portion of the global zero-emission vehicle market, with battery electrics and plug-in hybrids accounting for 99.8% and 99.6% of cumulative light- and heavy-duty electric vehicle sales, respectively, through August 2019 (EV-Volumes, 2019). However, while plug-in electric vehicles are being commercialized more rapidly, hydrogen fuel cell vehicles have two important advantages over battery technology: longer driving ranges and shorter refueling times (Wiginton et al., 2019). The significantly higher energy density of hydrogen compared to batteries ensures that fuel cell electric vehicles remain an appealing zero-emission option, especially for larger vehicles, as well as those that need to travel longer distances.

Despite the advantages of longer range and shorter refueling times, hydrogen fuel cell vehicles have considerable barriers to widespread adoption. Hydrogen refueling infrastructure is limited, the cost of producing and delivering hydrogen fuel to service stations at low volumes is currently high. Moreover, fuel cell vehicle production costs will have to decrease substantially, and consumers' familiarity with the technology and its benefits will need to improve for hydrogen-powered vehicles to reach the mainstream.

There are several reasons hydrogen fuel cell vehicles can be particularly important to Canada's economy and play a role in its transition to a more sustainable on-road transportation future. First, Canada is home to a significant concentration of hydrogen and fuel cell companies that cover all elements of the transport-related supply chain—including hydrogen production and delivery, refueling stations, and fuel cell vehicle engineering and manufacturing. Several of the Canadian firms that are active in these three respective areas are summarized in Table 5. The largest cluster of hydrogen and fuel cell companies in Canada is located in British Columbia, but there also companies based in Ontario, Alberta, New Brunswick, and Manitoba.

Table 5. Canadian companies in the hydrogen production, refueling infrastructure, and fuel cell vehicle sectors

Area	Company	Headquarters
Hydrogen production	Air Products Canada	Edmonton, AB
	Advanced Flow Systems	Maple Ridge, BC
	Enbridge Gas Distribution	Calgary, AB
	Hydrogenics	Mississauga, ON
	Luxfer Canada Ltd.	Calgary, AB
	Next Hydrogen	Mississauga, ON
	Nu:ionic Technologies	Fredericton, NB
	Quadrogen Power Systems	Burnaby, BC
	Xebec Adsorption Inc.	Blainville, QC
Hydrogen refueling infrastructure	Associated Plastics and Supply Corp.	Vancouver, BC
	Aurora Scientific Corp.	Aurora, ON
	Change Energy Services Inc.	Oakville, ON
	Hydrogen Technology and Energy Corporation	Vancouver, BC
	Hydra Energy Corp.	Delta, BC
	Hydrogen In Motion Inc.	Vancouver, BC
	IRDI System	Richmond, BC
	Kraus Global Ltd. Dispensing Solutions	Winnipeg, MB
	Powertech Labs Inc.	Surrey, BC
Hydrogen fuel cell manufacturing	Ballard Power Systems	Burnaby, BC
	Dana Canada	Oakville, ON
	Loop Energy	Burnaby, BC
	Overdrive Fuel Cell Engineering Inc.	Burnaby, BC
	Palcan Energy Corp.	Vancouver, BC
	Zen Clean Energy Solutions Inc.	Vancouver, BC

Various policies, incentive programs, and industry collaborations have helped initiate hydrogen-related demonstration projects, research initiatives, and commercialization efforts in Canada. Table 6 summarizes some of the developments over the past two years. Part of Natural Resources Canada’s Green Infrastructure Fund was dedicated to the Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (EVAFIDI), a program that supports the construction of a nationwide refueling network for zero-emission and other alternative-fuel vehicles. Specific to hydrogen, Phase 1 deployed three refueling stations, and another 12 stations are planned as part of Phase 2 (Natural Resources Canada, 2019e).

Table 6. Select hydrogen-related projects and policies in Canada's on-road transportation sector, 2017-2019

Timeframe	Description	Sources
March 2017	Federal Budget 2017 expands the Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (EVAFIDI) with an additional \$80 million including 50% funding for hydrogen stations	Natural Resources (2019e)
June 2017	Canadian Hydrogen Fuel-Cell Electric Vehicle Coalition hosted a ride-n-drive event	CNW Group Ltd. (2017)
October 2017-December 2021	Pan-Canadian Hydrogen Fuel Cell Electric Vehicle Demonstration and Integration Trial. The project will deploy and demonstrate on-road the feasibility of at least 10 fuel cell electric buses and one Class 8 fuel cell truck	CUTRIC (2019b)
January 2018	Toyota announces the sale of Mirai light-duty hydrogen fuel cell vehicles in Canada	Toyota Canada Inc. (2018)
June 2018	Shell and HTEC launch Canada's first retail hydrogen refuelling station for vehicles	Shell Canada (2018)
July 2018	Hydrogenics and Enbridge Gas Distribution open North America's first multi-megawatt power-to-gas facility in Markham, ON (suburb of Toronto)	Hydrogenics (2018)
February 2019	Air Liquide announces the construction of the largest proton-exchange membrane electrolyzer in the world (20 MW capacity). The project will increase the current hydrogen output capacity by 50% and will be located in Becancour, QC	Air Liquide (2019)
March 2019	Hyundai introduces the NEXO hydrogen fuel cell sport utility vehicle in Canada	Venetis (2019)
March 2019	The Alberta Zero-Emissions Truck Electrification Collaboration (AZETEC) launches. The project will deploy two heavy-duty, extended-range, hydrogen fuel cell electric-hybrid trucks that will move freight year-round between Edmonton and Calgary. Trimac Transportation and Bison Transport will operate the trucks.	Lowey (2019)
March 2019	Federal Budget 2019 provides \$130 million to accelerate zero-emission vehicle deployment. This includes the first-ever nationwide subsidy for the purchase of battery-electric and hydrogen fuel cell vehicles.	Transport Canada (2019)

British Columbia's Automotive Fuel Cell Cooperation (AFCC), a fuel cell stack developer and joint venture between Daimler, Ford, and Ballard Power Systems created in 2008 (Orton, 2018), was instrumental in establishing the world's first standardized automotive fuel cell stack production facility in Vancouver. The AFCC dissolved in 2018, as Daimler and Ford wanted to bring this fuel cell expertise in-house, but the Mercedes-Benz Fuel Cell plant in Burnaby, BC, continues to produce fuel cell stacks for the automotive industry (Daimler, 2019).

Canada's first retail hydrogen station, a collaboration between Shell and the Hydrogen Technology and Energy Corporation (HTEC), opened in Vancouver in June 2018 (Shell Canada, 2018). Quebec's first hydrogen station was opened in spring 2019 and has the capability to operate the city's fleet of 50 Mirai fuel cell vehicles (CAA-Quebec, 2019). Hyundai introduced its NEXO hydrogen-powered sport utility vehicle to the Vancouver market in March 2019 and is partnering with Modo, a car-sharing cooperative, to make the vehicle accessible to a wider audience (Venetis, 2019).

With respect to HDVs, Canadian manufacturers and fleets have been showcasing hydrogen fuel cell technology for many years, and commercial activity has accelerated. Vancouver-based Ballard Power Systems has been deploying its hydrogen powertrain solutions in commercial vehicles in Canada and several other countries around the world since the early 1990s. The company's fuel cell system has been deployed in transit buses in 15 countries over the past 10 years, with those buses traveling over 10 million kilometers (Ballard Power Systems, 2019). In October 2018, Ballard secured nearly \$6 million in funding from the California Air Resources Board to outfit four UPS delivery trucks in southern California with hydrogen fuel cell modules. In partnership with BAE Systems, Ballard is developing two yard trucks that will be operated by

TraPac in the Port of Los Angeles starting in the spring of 2020 (Ballard Power Systems, 2018).

While Canadian-based manufacturers are supplying hydrogen fuel cell systems to commercial fleet operators around the world, hydrogen buses and trucks are also being deployed in Canada. The Pan-Canadian Hydrogen Fuel Cell Electric Vehicle Demonstration and Integration Trial will deploy and demonstrate the real-world feasibility of at least 10 hydrogen fuel cell transit buses and one tractor-trailer (CUTRIC, 2019b). In March 2019, the Alberta Motor Transport Association launched the Alberta Zero-Emissions Truck Electrification Collaboration (AZETEC) initiative in collaboration with several industry and government partners. The AZETEC project will deploy two hydrogen fuel cell trucks that will haul freight in real-world service between Edmonton and Calgary. Trimac Transportation and Bison Transport will operate the trucks.

Along with the advantage of having a diverse cross-section of industry players active in the hydrogen and fuel cell sectors, hydrogen offers another strategic advantage for Canada. The electrical grid in Canada is powered by a relatively high percentage of renewables and low-carbon sources, including 60% hydro power, 16% nuclear, and 5% other renewables (National Energy Board, 2017). As with electricity, hydrogen can be produced from a variety of lower-carbon and renewable sources. Hydrogen can provide a complement to renewable power generation, as it offers the ability to store excess renewable electricity, thereby enhancing the uptake of lower carbon sources on the grid. As a result, hydrogen fuel presents an attractive opportunity for energy storage and revenue for electrical utilities.

A third strategic benefit of hydrogen in the Canadian context are fuel cells' superior performance when operating with very heavy loads and in colder temperatures. This advantage is likely to manifest most acutely in the heavy-duty trucking sector, as these are the heaviest on-road vehicles, and they must be able to operate in severe winter conditions. In Canada, battery-electric trucks are likely to face performance limitations due to the weight and temperature constraints posed by battery technology. For a battery-electric tractor-trailer with maximum weight of 36,000 kg and a range of roughly 800 km, the battery pack would weigh about 9,000 kg. After accounting for the removal of the diesel engine and associated powertrain component, this 6,000 kg of net additional weight represents over 25% in lost payload, which would be a significant reduction in lost cargo capacity (Sharpe, 2019). With hydrogen being much more energy dense than batteries, weight impacts are expected to be much less of a concern for fuel cell trucks. For example, Nikola's hydrogen model freight truck weighs about 5,000 pounds (~ 2,270 kg) less than the battery-powered variant (O'Dell, 2019). Sharpe (2019) also reviewed the literature to estimate the impacts of cold temperatures on battery performance and driving range. At -20°C, we estimated up to a 25% reduction in available driving range due to degraded battery performance. Data from several years of fuel cell bus evaluations indicate that the range and performance of fuel cell vehicles is not compromised in cold weather, and we estimate similarly robust functionality for hydrogen trucks at low temperatures (Sharpe, 2019).

POLICIES TO SUPPORT ELECTRIC VEHICLES

This section compiles and assesses available information on policies supporting growth in electric vehicle production. Because 80% of light-duty electric vehicle sales originate from assembly in the same region, demand-side market policies are summarized. We also examine supply-side industrial development activities to spur industry electric vehicle research, development, and deployment.

MARKET AND INDUSTRIAL DEVELOPMENT POLICIES

The vast majority of global electric vehicles sales are in relatively few countries; just 11 national markets account for 91% and 99% of electric light- and heavy-duty vehicle sales, respectively, in 2018 (EV-Volumes, 2019). A variety of research studies help identify what underlying policies are encouraging sales in these markets.

Table 7 summarizes electric vehicle policy actions in most of the major national electric vehicle markets. Several light-duty vehicle sales and production statistics are also shown at the top of the table in light blue shading to provide broader market context. The “X” marks denote national programs; “/” signifies smaller local or regional programs. For light-duty vehicles, the markets in the table account for the vast majority of cumulative 2010 to 2018 global electric vehicle sales (94%), electric vehicle production (97%), and electric vehicle battery cell manufacturing (100%) (EV-Volumes, 2019).

Table 7. Summary of government electric vehicle policy actions in selected areas

Area	Action	China	United States	Norway	Germany	United Kingdom	Japan	France	Canada	South Korea	Sweden	Netherlands
Vehicles	Total vehicle sales in 2018 (million vehicles)	25	17	0.1	3.4	2.4	4.4	2.2	2.0	1.6	0.4	0.4
	Total vehicle manufacturing in 2018 (million vehicles)	26	11	0.0	5.1	1.6	9.2	2.3	2.0	4.0	0.23	0.16
Electric vehicles	Global 2010–2018 electric vehicle sales	45%	22%	5%	4%	4%	5%	3%	2%	1%	2%	3%
	Global 2010–2018 electric vehicle production	42%	20%	0%	11%	2%	12%	4%	0.3%	3.0%	2%	0.4%
	Electric vehicle sales 2018 (thousands)	1,100	360	73	66	60	53	46	43	32	29	27
	Electric vehicle production 2018 (thousands)	1,100	345	0	205	50	181	59	9	84	28	13
Industrial policy	Research and development support	X	X	X	X	X	X	X	X	X	X	X
	Battery cell or electric vehicle production incentive	X	/			X						
	Minimum battery production size incentive	X										
	Local manufacturing tax incentives	X	/		/	/	/	/	/	/		
	Battery production minimum capacity mandate	X										
	Vehicle incentives linked to domestic batteries	X										
Regulatory policy	Long-term efficiency or CO ₂ standards	X	X	X	X	X	X	X	X	X	X	X
	Incentive provisions within efficiency regulations	X	X	X	X	X		X	X		X	X
	Electric vehicle deployment requirements	X	/						/			
	Goal for long-term transition to all electric drive	/	/	X	/	X		X	X			X
Consumer support	Vehicle purchase incentive	X	X	X	X	X	X	X	/	/	X	X
	Government purchasing preferences	X	/	/	/	/	X	/	/	X	/	/
	Local registration, lottery, auction preference	X										
	High baseline fuel price (i.e., greater fuel savings)			X	X	X		X			X	X
	Annual vehicle fee exemption or incentive		/	X	X	/	X				X	X
	Discounted or free electric charging	/	/	X	/	/	X		/			X
	Preferential lane (e.g., bus, HOV lane) access	/	/	X	/							X
	Reduced roadway tax or tolls			X		X	X					X
	Preferential parking access	/	/	/	/	/		/	/		/	/
Public outreach campaign	/	/	X	/	X	/	/	/			/	
Charging infrastructure	Carbon pricing system	X	/	X	X	X	X	X	/		X	X
	Low carbon fuel incentive for electricity providers		/	X	X	X	X		/		X	X
	Public charging network funding	X	/	X	X	X	X	X	/	X	X	X
	Home charging equipment tax incentives		/	X				X	/	/	/	Netherlands

Note. Vehicle statistics are for light-duty passenger vehicles. The data in the top two areas of the table (“Vehicles” and “Electric vehicles”) include only light-duty vehicles. The table includes a summary of the three major Asian markets, the two major North American markets, and also five major European markets for electric vehicles. The table is based on a similar table by Lutsey et al. (2018). It also includes updated information from the research above and updates from city-focused studies (Slowik & Lutsey, 2019; Hall, Cui, & Lutsey, 2018).

Table 7 shows how growing the electric light-duty vehicle market requires a broad mix of policy actions. A comprehensive package of policies is also required to support the development and deployment of electric heavy-duty vehicles. Most of the 11 countries shown have implemented the same types of policies to promote electric vehicles with regulatory policy, incentives, charging infrastructure, and other promotion activities. These actions address the barriers of limited electric vehicle supply, high upfront cost, and charging convenience.

Compared with other markets where electric vehicle uptake is high, Canada's electric vehicle policy development has been mixed. Canada has implemented many of the leading policies, but typically in a more limited manner than other major markets. Regulations are the strongest actions, as they can essentially require that electric vehicle models be made available and that the auto industry deploy, market, and sell them in increasing numbers. Canada's vehicle greenhouse gas regulations, like those in the United States, are insufficient to induce broad electrification (Lutsey, 2018b). Zero-emission vehicle requirements are currently implemented only in Quebec, which accounts for about 23% of the Canadian auto market (Statistics Canada, 2019a). British Columbia, which makes up roughly 10% of Canada's passenger vehicle sales, is in the process of adopting a similar zero-emission vehicle regulation. The federal government's Clean Fuel Standard can be expected to encourage electrification, but the regulation is still under development. Canada's federal carbon pricing backstop is also expected to encourage the uptake of electric vehicles nationwide through raising the ownership cost of conventional combustion vehicles (Natural Resources Canada, 2019d).

There are substantial federal and provincial level consumer incentives, particularly in Quebec and British Columbia. British Columbia's Clean Energy Vehicle Specialty-Use Vehicle Incentive provides assistance for the purchase or lease of heavy-duty vehicles (Fraser Basin Council, n.d.). British Columbia, Quebec, and the federal government have each established targets to shift to 100% zero-emission vehicles within the 2040 to 2050 time frame (British Columbia, 2019; Department of Finance Canada, 2019). These could be strengthened through additional, more modest goals for the adoption of zero-emission heavy-duty vehicles.

There has been significant commitment by the Government of Canada to invest in electric vehicle supportive infrastructure—including the EVAFIDI, the Electric Vehicle Infrastructure Demonstration (EVID) program and the Zero-Emission Vehicle Infrastructure Program (ZEVIP) (Natural Resources Canada, 2019a, 2019b, 2019d). The Government of Canada's Investing in Canada Plan, while not specifically focused on electrification, has supported the uptake of electric vehicles. Additional federal incentives should be made available specifically to support the uptake of electric buses by Canadian transit agencies. These incentives would ideally be paired with additional support for electrification, including infrastructure funding and workforce re-training programs. The federal government and sub-national jurisdictions including Quebec and British Columbia have made strong commitments toward the procurement of electric vehicles for their fleets (Treasury Board of Canada Secretariat, 2019; Transports Quebec, 2019; Government of British Columbia, 2018). In addition to the policies discussed above, further investigation is warranted on the deployment of public-private partnerships, which can help mitigate the risk associated with investment in electric heavy-duty vehicles and related infrastructure.

In Canada, Ontario and Quebec have established Canadian content requirements for public transit procurements. The Ontario Ministry of Transportation amended its

Canadian Content for Transit Vehicle Procurement policy in June 2017 to comply with the Canada-European Union Comprehensive Economic and Trade Agreement (CETA). The amended policy stipulates a 25% maximum on the amount of Canadian content that transit entities and operators can require when using funding from the province to procure transit vehicles (Toronto Transit Commission, 2017). Prior to CETA, Quebec had issued a requirement in 2008, in concert with the STM, that 60% of content in rolling stock must be Canadian-supplied and that final assembly be done in Canada (Sinclair et al., 2014). More recently, Quebec implemented a requirement of 25% Canadian content and final assembly in Canada (Société de transport de Montréal, 2018).

Canadian content requirements for transit operators can provide a significant boost to Canadian bus production. Nova Bus indicated that activities at its Saint-Eustache and Saint-Francois-du-Lac plants help meet the Quebec government's Canadian content requirements (Nova Bus, 2018a). Domestic content requirements are also useful for job creation and economic value generation. Relevant examples are the "Buy America" provisions for transit bus procurements in the United States, which apply to procurements above \$100,000 that make use of grants administered by the Federal Highway Administration or the Federal Transit Authority. These provisions include requirements of 100% United States content for manufactured products and iron and steel (Canadian Trade Commissioner Service, 2016). Further examination would be valuable regarding the extent to which Canadian content policy requirements encourage domestic heavy-duty vehicle manufacturing—especially electric HDVs—and protects the industry from the loss of jobs and investment in the face of "Buy America" policies across the border.

It is critical that federal, provincial, and local governments commit to creating policies that support vehicle manufacturing supply chains to better ensure that Canada has a strong domestic industry to meet increased electric vehicle demand over time. Moreover, during this transition there will be an increasing need to provide well-designed support for the Canadians who depend on the auto industry.

AUTOMAKER INVESTMENTS AROUND THE WORLD

An additional way to investigate the relative impacts of policies to develop global electric vehicle markets is to identify where auto industry investments and announced electric vehicle deployments are going. This includes tallying electric vehicle investments by origin, typically the headquarters of the automobile manufacturer, and the destination, or the location of the manufacturing plant of the investment, as well as available information on announced electric vehicle deployment plans by automakers.

These various metrics related to electric vehicle investment are shown in Figure 12. We first show the most recent full calendar year 2018 vehicle market data for context related to the overall light-duty vehicle market and electric vehicles in 2018. These metrics, for production location and sales market, are shown in the left side of the figure. These show how China plays an outsized role in electric vehicles relatively to its overall vehicle market: China represents 27% to 28% of light-duty auto sales and production and 52% to 56% of global electric sales and production. North America and Europe each represent around one-fifth of the global light-duty vehicle and electric markets. As seen in Table 2, Canada's light-duty vehicle sales and production each represent 2% of the global market of 91 million annual vehicles. Canada's light-duty electric vehicle production represents 0.4% of global production, and Canada's electric vehicle sales represent 2% of the 2 million global electric sales.

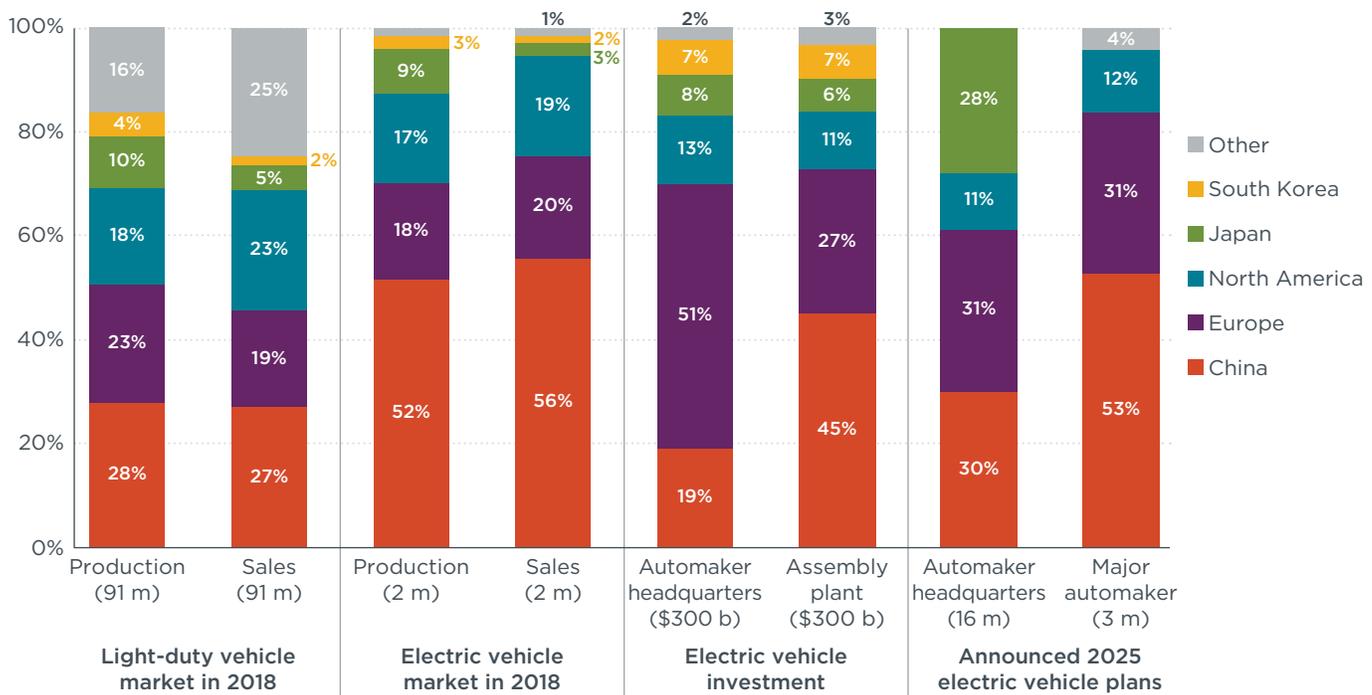


Figure 12. Breakdown of various market metrics related to electric vehicle investments by major region. Source: OICA, 2019a, 2019b; EV-Volumes, 2019

The right half of Figure 12 indicates the origin and destination of electric vehicle investments (Lienert & Chan, 2019) in several ways. Of the publicly announced \$300 billion on automaker investments in electric vehicles, many automakers that are headquartered in Germany, Japan, and the United States will direct much of their investments to China. Just 19% of the \$300 billion in announced electric vehicle investments originate from China-headquartered companies and 45% of the investment total is destined for China. Conversely, about 51% of the electric investments originate from European companies, with just 27% destined for European production.

The right two columns refer to the total number of projected electric vehicles sold in 2025 based on announced plans from all automakers through 2017 (Lutsey et al., 2018). From 2 million electric vehicles sold in 2018, sales are projected to increase to 16 million based on announcements by all automakers. Of the announcements, 31% are by auto companies headquartered in Europe (Volkswagen, Renault, Mercedes, and BMW), 30% in China (Chang'an, BAIC, Geely, and Dongfeng), 28% in Japan (Nissan, Mitsubishi, and Toyota), and 11% in the United States (Tesla and General Motors). Many automakers have not publicly announced their electric vehicle sales, so these offer an imperfect approximation of electric vehicle deployment and do not match the percentages of the announced \$300 billion in investments by automaker headquarters.

The right-most column shows the breakdown of 3 million electric vehicles from the largest automaker announcements on battery-electric vehicles. Volkswagen, along with being the largest announced goal, is also the only one for which a global sales breakdown for 2025 was attached to the public announcements (Witter, 2018). Investments are primarily from the four main automobile production markets (China, Europe, Japan, and North America) and, again, much of the projected sales are expected to be in China.

There are many examples of the various electric vehicle investments and production plans that align with the Figure 12 findings where electric vehicle production is moving toward the markets where there is greater growth. Germany-based automakers Volkswagen and Mercedes are constructing new electric vehicle assembly plants in the United States. All western automakers are increasing electric production in China (e.g., Volkswagen Group in joint ventures with China-based FAW, JAC, and SAIC). Japan- and South Korea-based battery suppliers including LG Chem, SKI Innovation, and Panasonic are adding battery cell production facilities in China, Europe, and the United States.

AUTOMAKER INVESTMENTS IN CANADA

The information above provides an imperfect picture, yet it illustrates where the companies are projecting the largest market and policy developments through 2025 in the largest markets. Although the data in Figure 12 is shown in a manner that groups Canada in the North America data, in our investigation none of the \$300 billion electric vehicle investments or 2025 electric vehicle production plans were explicitly slated for Canada.

To provide some context for how automotive investments could better serve electric vehicle developments in Canada, Table 8 summarizes several aspects of the light-duty vehicle market. There were 19 vehicle models assembled in Canada; one of these, the Chrysler Pacifica, is available as a plug-in hybrid electric. Although electric vehicle models made up only 2% of domestic vehicle sales in 2018, there were 37 electric models imported into Canada, showing the deficit in Canada's auto industry in meeting demand for electric vehicles.

Table 8. Canada vehicle sales by company, models assembled in Canada, and electric vehicle models imported from other regions

Automaker group	Percentage of Canada sales market	Company electric share in Canada	Models assembled in Canada in 2018 ^a	Electric models imported from other regions
Ford	15%	0.8%	Ford Edge, Flex; Lincoln MKX, MKT (Oakville, Ontario)	Ford C-Max, Fusion Energi, Focus
General Motors	14%	2.4%	Chevrolet Equinox, <i>Impala</i> , <i>Silverado</i> ; <i>Cadillac XTS</i> ; <i>GMC Sierra</i> (Oshawa and Ingersoll, Ontario)	Chevrolet Bolt, Volt; Cadillac CT6
Toyota	12%	1.5%	Toyota Corolla, RAV4; Lexus RX350, RX450h (Cambridge and Woodstock, Ontario)	Toyota Prius Prime
Fiat Chrysler	11%	0.6%	Dodge Grand Caravan, Charger, Challenger; Chrysler Pacifica ^b (Brampton and Windsor, Ontario)	Fiat 500e
Hyundai Kia	10%	1.5%	—	Hyundai Kona, Ioniq, Sonata, Soul; Kia Niro, Optima
Honda	10%	0.4%	Honda Civic, CR-V (Alliston, Ontario)	Honda Clarity
Nissan	9%	3.3%	—	Nissan Leaf; Mitsubishi Outlander
Volkswagen	6%	1.8%	—	Volkswagen eGolf; Porsche Cayenne, Panamera; Audi A3 e-tron
Mazda	4%	0.0%	—	—
Subaru	3%	0.0%	—	—
Daimler	2%	1.2%	—	Smart fortwo; Mercedes GLC, GLE
BMW	2%	2.6%	—	BMW 330e, 530e, i3, i8, X5; Mini Countryman
Tesla	0.7%	100%	—	Model 3, Model S, Model X
Jaguar Land Rover	0.5%	0.3%	—	Jaguar I-Pace
Volvo	0.5%	5.6%	—	Volvo S90, XC60, XC90

Sources: Based on Marklines, 2019; EV-Volumes, 2019; Government of Canada, 2019e

^a Models in italics are from Oshawa plant, which General Motors announced will close

^b Chrysler Pacifica, available as a plug-in hybrid electric vehicle, is the only electric vehicle assembled in Canada

INDUSTRIAL DEVELOPMENT POLICIES

There are several international examples and policy practices that could ensure that Canada benefits from the shift to electric vehicles over time. As mentioned, perhaps the most constructive broad action is to grow the electric market to attract automaker investments in the Canadian supply chain. In addition, more narrowly targeted actions on electric vehicle supply chain development, in line with other proactive countries, would also spur investments. There are several such examples in battery supply and vehicle investments in other areas.

Some policies and programs already exist to support Canada’s electric vehicle supply chain. Canada’s 2018 Fall Economic Statement provided \$800 million in added funding for the Strategic Innovation Fund. The 2019 federal budget noted that automotive manufacturers and parts suppliers could access the fund to invest into Canadian zero-emission vehicle manufacturing (Canada Ministry of Finance, 2019). The Strategic Innovation Fund describes itself as providing “financial support to projects that will improve Canada’s innovation performance while providing economic, innovation and public benefits to Canadians” (Innovation, Science and Economic Development Canada, 2018). In Quebec, Develop the Industry was one of the three strategic directions of the ‘Plan d’action en électrification des transports 2015-2020’ (TEAP). Quebec plans to develop its electric transportation industry through interventions in research and development, marketing, exports, private investment, and workforce

training (Transports Quebec, 2015). In British Columbia, the Advanced Research and Commercialization Program supports the development of the province's clean energy vehicle sector and encourages international investment therein. It supports investment in product development and commercialization activities (Government of British Columbia, n.d.).

Although relatively small-volume electric vehicle production requires exports to reach other markets, companies seek to co-locate assembly nearer to sales as they increase volume. The highest-selling global electric vehicle, the Nissan Leaf, with 429,000 sales through June 2019, is manufactured in Tennessee for North America markets, in the United Kingdom for Europe, and in Japan for Asian markets.

In the early electric vehicle market, with electric vehicles just 2% of global sales, opportunities to attract automakers to assemble electric vehicles have been relatively limited. However, as the market grows, opportunities continue to emerge involving incumbent automakers converting older plants or constructing new ones, new companies taking over idled plants, and major parts suppliers developing battery production facilities.

Table 9 summarizes some examples of automaker investments in electric vehicle manufacturing facilities in North America and the government policies that have encouraged these ventures. These production plants for plug-in vehicles are primarily located in the United States, with Ford's facility in Cuautitlan, Mexico, and the Nova Bus plant in Quebec being the two exceptions. Established automakers and startups have made investments in brand new assembly locations (Proterra and Tesla), expanded plants with new production lines for electric vehicles (Blue Bird, Ford, GM, Mercedes-Benz, Nissan, Nova Bus, and Volkswagen), and repurposed facilities for electric vehicle manufacturing (Rivian). The most common policy instruments to support these investments are property tax credits from state/provincial and local governments, but there are also examples of job training support, federal loans, and other types of incentives.

Table 9. Selected electric vehicle assembly plants and policy support actions in North America

Facility and location	Electric vehicle models (production ^A through Q2 2019)	Examples of industrial policy support actions	Sources
Blue Bird Georgia, United States	<ul style="list-style-type: none"> All-American RE Electric School Bus Vision Electric School Bus 	<ul style="list-style-type: none"> \$4.4 million from the Department of Energy for the development of a zero-emission electric school bus 	Blue Bird (2017, 2019a, 2019b, 2019c)
Ford Michigan, United States Cuautitlan, Mexico	<ul style="list-style-type: none"> Mach E (expected MY 2020) F-150 electric (expected MY 2021 or 2022) Two mid-size crossover EV models (expected MY 2023) 	<ul style="list-style-type: none"> 10-year tax abatement from the City of Flat Rock 	Martinez (2019a, 2019b) Cousino (2017)
General Motors Michigan, United States	<ul style="list-style-type: none"> Volt (178,000; production ended in Feb. 2019) Bolt (65,000) New EV model 	<ul style="list-style-type: none"> Michigan Economic Growth Authority tax credits: undisclosed amounts^B 	EV-Volumes (2019) Wichter (2019) Livengood (2018)
Mercedes-Benz Alabama, United States	<ul style="list-style-type: none"> EQC crossover (expected MY 2022) EQA sedan (expected MY 2022) 	<ul style="list-style-type: none"> \$80 million non-educational sales and property tax abatements over 20 years \$20 million in pre-employment screening and job-training services over 10 years 	Falkenberg-Hull (2018) Tomberlin (2018) Alabama Department of Commerce (2019)
Nissan Tennessee, United States	<ul style="list-style-type: none"> Leaf (429,000 total; ~ 250,000 from Smyrna, TN plant) 	<ul style="list-style-type: none"> \$98 million property tax abatement for the Smyrna plant expansion \$35 million state grant and \$18 million county property tax abatement for supplier facility in Smyrna \$52.5 million in job training or infrastructure grants 	EV-Volumes (2019) Cole (2013) Reicher (2017)
Nova Bus Quebec, Canada	<ul style="list-style-type: none"> LFSe (production totals unknown) 	<ul style="list-style-type: none"> \$15 million in non-repayable financial contributions from Investissement Quebec for operational automation, digital technologies, and energy-efficient processes 	Nova Bus (2017c)
Proterra California, United States	<ul style="list-style-type: none"> Proterra Catalyst 	<ul style="list-style-type: none"> \$3 million grant from The California Energy Commission for facility construction, design, and development 	Proterra (2015, 2019a, 2019b)
Rivian Illinois, United States	<ul style="list-style-type: none"> Electric pickup truck (production expected to begin in 2020) 	<ul style="list-style-type: none"> \$49 million state tax credit \$4 million in incentives from Normal, Illinois 	Channick (2018) Channick and Zumbach (2019)
Tesla California, United States Nevada, United States	<ul style="list-style-type: none"> Model S and X (400,000) Model 3 (291,000) 	<ul style="list-style-type: none"> \$465 million federal loan \$106 million tax break to support Model 3 assembly (California) \$1.25 billion tax exemptions (Nevada) 	U.S. Department of Energy Loan Programs Office (2010) Lambert (2016) Randall and Halford (2019) Tesla (2018a, 2018b, 2018c, 2019a, 2019b, 2019c)
Volkswagen Tennessee, United States	<ul style="list-style-type: none"> Various EV models (production expected to begin in 2022) 	<ul style="list-style-type: none"> \$2.5 million grant from Hamilton County for plant expansion to produce electric vehicles is under consideration Additional tax abatements under Payments-in-lieu-of-tax (PILOT) program under consideration 	Halvorson (2019) Sharp (2019)

A: For electric vehicle models that are not yet in production, information is provided about when production is expected to begin.

B: In 2015, General Motors signed a deal with the governor of Michigan that shields the automaker's tax credits in the state from public disclosure

Encouraging a battery manufacturer to make batteries in a major auto-assembly market is the next-most consequential way to maintain a strong stake in the automotive industry. Many companies and countries have successfully attracted Asia-based battery suppliers to manufacture in North America and Europe. Table 10

provides some recent examples of battery production facilities in the United States and Europe and the policies that have facilitated these investments. Together, these battery manufacturing plants are expected to add roughly 65 gigawatt hours (GWh) to global annual production capacity over the next two to three years. As with the vehicle assembly facilities in Table 9, the policies that have encouraged these battery plant investments include tax abatements, grants, and other monetary and non-monetary incentives.

Table 10. Selected electric vehicle battery production plants, auto companies, and support actions in North America and Europe

Facility and location	Battery production and auto companies	Examples of industrial policy support actions	Sources
CATL Erfurt, Germany TBD, United States	<ul style="list-style-type: none"> \$2 billion investment; production expected to begin in 2021 Targeting 14 GWh/year by 2022 and 60 GWh/year by 2026 BMW, Daimler, Volkswagen, Groupe PSA 	<ul style="list-style-type: none"> German government plans to make up to 1 billion euros available for subsidies to promote domestic battery cell production 	Shuiyu (2019) Hampel (2019a, 2019c) Steitz (2019)
Envision AESC Tennessee, United States Sunderland, United Kingdom	<ul style="list-style-type: none"> 7.5 GWh/year total capacity at three sites in the U.S., UK, and Japan (2019) Nissan 	<ul style="list-style-type: none"> \$62 million property tax abatement (Tennessee) £20.7 million grant from the UK government 	Hampel (2019b) Broden (2018) Swerdlow (2010)
LG Chem Michigan, United States Wroclaw, Poland	<ul style="list-style-type: none"> 3 GWh/year (U.S.) 6 GWh/year and expanding to 15 GWh/year (Poland) New U.S. plant (Kentucky or Tennessee). Production to begin in 2022 with 10 GWh/year expected New European plant (Poland or elsewhere) GM, Ford, FCA, Hyundai, Volvo 	<ul style="list-style-type: none"> \$151 million federal stimulus grant to finance 50% of \$303 million plant (U.S.) \$125 million in state tax credits, with the condition of employing at least 300 people (U.S.) Exemption from income tax on activity conducted in Special Economic Zones (SEZ) SEZ encouraged \$350 million foreign direct investment from LG Exemption from real estate tax (often offered by local communities to new foreign investors) Investment grant from state authorities Subsidies from local employment offices Additional utility and infrastructure benefits 	Werwitzke (2018) Byung-yeul (2019) Lambert (2019b) Harger (2013) Clifford Chance (2017)
Samsung SDI Göd, Hungary	<ul style="list-style-type: none"> 3 GWh/year BMW, Volkswagen 	<ul style="list-style-type: none"> Grants through subsidies, job creation subsidies, and EU co-financed tenders to support \$353 million investment Local subsidy granted by municipality Development tax allowance (regional aid) Training and workshop establishment subsidies 	Gibbs (2019) Ésik (2016)
Tesla / Panasonic Nevada, United States	<ul style="list-style-type: none"> 23 GWh/year (35 GWh/year expected by the end of 2019) Tesla 	<ul style="list-style-type: none"> Investment-dependable transferable tax credits 20-year 100% sales tax abatement 10-year 100% property tax abatement 10-year 100% modified business tax abatement 	Lambert (2019a) Damon (2014)

SUMMARY AND POLICY RECOMMENDATIONS

Canada holds a prominent stake in the global automotive industry, but that position could be strengthened through increased action to support the transition to electric vehicles.

Canada's auto industry is falling behind other auto-manufacturing countries in transitioning to electric vehicle production. Canada's global 2018 position for light-duty vehicle production with 2 million vehicles is 12th, having fallen from fifth in 2000. Ontario has been the historical center of Canadian vehicle production but has only one low-volume electric vehicle production plant, making it vulnerable to a global market that is trending toward electric. Production facilities in Ontario by Chrysler, Ford, General Motors, and Toyota are dominated by conventional combustion vehicles, while these companies are making billion-dollar electric vehicle investments in other markets. Stronger policies elsewhere drive electrification and attract electric vehicle investments, especially in China, Europe, and the United States.

If Canada does not find a way to rapidly develop raw materials, supply base, and electric vehicle production for both its light- and heavy-duty sectors, it is at risk of losing a foundational pillar of its economy. This is especially true in the passenger vehicle sector, which has had a net loss of five vehicle assembly plants over the past 20 years. In addition to the global transition to electric, other high-level trends such as trade agreements and increased automation in manufacturing will have significant impacts on Canada's automotive industry and its competitiveness globally.

In the light-duty space, auto companies and their suppliers are making significant investments in vehicle electrification, but to date the large majority of activity has been in markets outside Canada where there are stronger electric vehicle policies in place. The predominant action Canada can take is to grow its domestic electric vehicle market. Most electric vehicles, 80%, are made in the region they are sold. There are many examples of automakers investing in production location near their growing markets. Most U.S. electric vehicle sales are made in the United States, and Germany-based automakers are shifting electric vehicle production to the United States. Japan- and South Korea-based battery suppliers are shifting their production to the two largest markets of Europe and China, and all automakers are disproportionately investing in China electric vehicle production. In 2018, 97% of Canada's light-duty electric vehicle sales were imported, so sustained regulatory, incentive, infrastructure, and consumer awareness policies are needed to improve Canada's attractiveness for electric vehicle sales and production.

For commercial trucks and buses, Canada's position in electric vehicle manufacturing is much stronger than in the passenger car sector. At present, several heavy truck and bus makers that are producing electric vehicle models and components have assembly plants in Canada. These include companies headquartered in Canada (Ballard Power Systems, GreenPower Motor Company, Hydrogenics, The Lion Electric Company, NewFlyer, Nova Bus, Nordresa, and Prévost), as well as global automakers (Blue Bird Co., BYD, Proterra, PACCAR, Motor Coach Industries, Naya, and Volvo Group) that have established manufacturing locations in Canada.

Targeted policy support can future-proof Canada's auto industry for electrification. There are many ways for Canada to re-invest in the auto industry to position it for the future. Beyond market-demand policies to ensure affordable models and convenient

charging, supply-side policies like research and development, loan guarantees, and tax breaks for manufacturing plant are warranted.

Based on our analysis, the following are our key findings and policy recommendations:

Canada's auto industry lags behind other auto-manufacturing countries in its preparation for an electrified transportation future. Canada is committed to electrifying its on-road vehicles as part of the country's overall decarbonization strategy. However, particularly in the light-duty vehicle sector, stronger policies elsewhere are driving electrification and attracting electric vehicle investments in other countries. Chrysler, Ford, General Motors, and Toyota production facilities in Ontario are dominated by conventional combustion vehicles, while these same companies are making billion-dollar investments to produce electric vehicles in China, Europe, and the United States. Ontario has historically been the center of Canadian light-duty auto production but has only one low-volume electric vehicle production plant. Canada's passenger vehicle manufacturing industry is quite vulnerable to a global market that is trending toward electrification. If Canada does not find a way to rapidly develop raw materials, supply base, and electric vehicle production, it is at risk of losing a major pillar of its economy.

Targeted policy support for electrification can future-proof Canada's auto industry. The predominant action Canada can take to spur electric vehicle manufacturing is to grow its domestic electric vehicle sales market. Globally, most electric vehicles (80%) are made in the region they are sold. There are many examples of automakers investing in electric vehicle production facilities near cities and regions with growing market demand. Sustained world-class regulatory, incentive, infrastructure, and consumer awareness policies in Canada would improve Canada's attractiveness for electric vehicle sales. Beyond market-demand policies to ensure affordable models and convenient charging, Canada's auto industry can be positioned for the future through supply-side policies like research and development, loan guarantees, and tax breaks for manufacturing plants. Canadian content policy requirements for the procurement of public transit vehicles, which currently exist in Ontario and Quebec, can serve to increase domestic production of electric buses. While the transition to electrification in trucking is in the early stages, several Canadian-based companies and manufacturing facilities have emerged in recent years, and there are several zero-emission vehicle models and key components that are being produced domestically. A comprehensive suite of policies would encourage investment in building up supply chains in Canada. Moreover, there is an increasing need for policymakers to provide targeted support for the workers and communities who depend on the auto industry.

Canada can leverage its early leadership in developing and producing hydrogen fuel cell technology—especially for heavy-duty vehicles. While battery-electric technology has dominated the light-duty zero-emission vehicle market to date, hydrogen fuel cell vehicles are expected to play a larger role in the electrification of the commercial vehicle sector. Fuel cell vehicles' longer-range and quick-fueling capabilities are especially attractive in heavier vehicles such as tractor-trailers, where battery electric technology may not be practical or cost-effective. We identify three key reasons hydrogen fuel cell vehicles and infrastructure are strategically important to Canada's competitive position in the global transition to electric drive. First, the Canadian hydrogen and fuel cell sector is a global leader recognized for pioneering new technologies and industry expertise. Second, some regions in Canada have significant excess of renewably sourced electricity (primarily hydro-electric power)

that can be used to produce low-cost, low-carbon hydrogen for powering fuel cell vehicles. Finally, hydrogen fuel cell vehicles are likely to play a critical role in Canada's on-road freight sector because fuel cells have a lower weight penalty and improved cold temperature performance relative to battery electric trucks.

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APPENDIX A

ELECTRIC HEAVY-DUTY VEHICLE PRODUCTION: PROXIES FOR PRODUCTION AND PRODUCTION LOCATION

The *Electric heavy-duty vehicle production* section uses proxies to estimate the production levels and location of electric heavy-duty vehicles. Sales data as measured by new registrations from EV-Volumes (2019) are used as a proxy for production data. This is imperfect as production may not equal sales in a given year. Global headquarter locations are used as a proxy for production location. This, too, is imperfect, as production locations and global headquarter locations are not always in the same country.

Canadian producers are often subsidiaries of larger firms or have a Canadian presence that is linked into a larger, multi-national production chain. This can make it difficult to isolate Canadian production. For example:

- » Build Your Dreams (BYD), headquartered in Shenzhen, China, announced the opening of a bus assembly plant in Newmarket, Ontario, in June 2019 (Build Your Dreams, 2019).
- » Nova Bus is part of the Volvo Group, a global manufacturer based in Gothenburg, Sweden, and has a plant in the United States (Plattsburgh, New York) (Volvo Group, 2019).
- » GreenPower Motor Company has a corporate office in Canada (Vancouver, British Columbia) but does its manufacturing in the United States (Porterville, California) (GreenPower Motor Company Inc., 2019).
- » New Flyer—operating as New Flyer of America Inc. and New Flyer Industries Canada ULC—is a subsidiary of NFI Group Inc. (NFI Group Inc., 2019a). The NFI Group has its head office in Canada—Winnipeg, Manitoba. New Flyer’s Winnipeg, Manitoba, bus manufacturing facility, however, is integrated into a North American production chain (NFI Group Inc., 2019b).