Office of Industries
Working Paper ID-072
January 2021

Supply Chain for EV Batteries: 2020 Trade and Value-added Update

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Abstract

Electric vehicles (EVs) continue to be a growing part of the passenger vehicle industry, and EV batteries remain the key determinant of both the range and cost of the vehicle. This paper expands on the authors' prior work in 2018 by exploring recent changes in the EV supply chain and EV demand, describing and explaining newly available trade data which separates EVs from motor vehicles with internal combustion engines, and providing an updated estimation of the value-added to EV batteries for EVs sold in the United States.

United States International Trade Commission

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Introduction

The electric vehicle (EV) battery supply chain is a relatively new area of global competition in the passenger vehicle industry, and EVs make up an increasingly significant share of passenger vehicle sales. Globally, the top three markets for EV sales are China, the United States and the EU.[1] However, starting in 2017, EV-specific trade data became available internationally, so we are now able to better track the import and export of EVs, in addition to sales. Moreover, the increase in EV sales has led to an increase in demand for the batteries needed to power these vehicles. The EV battery supply chain is an area that is particularly competitive because of a lack of established suppliers, and projected future demand outstrips current supply, both at the cell level and at the material level.[2] Thus, the makeup of this supply chain is very much in flux.

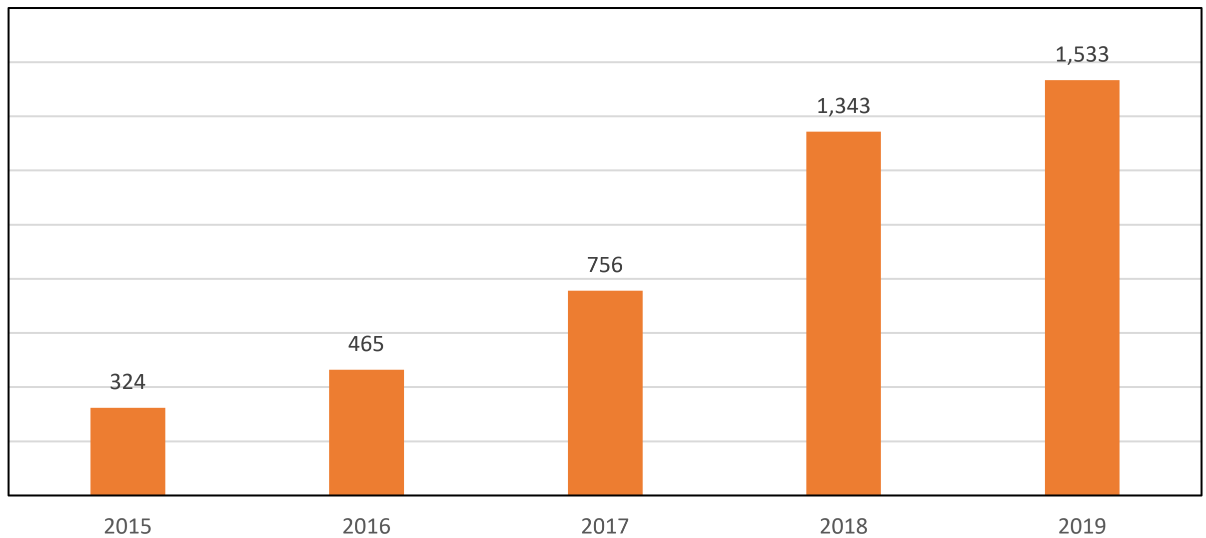
This paper is primarily an update to “The Supply Chain for Electric Vehicle Batteries” by David Coffin and Jeff Horowitz published in the Journal for International Commerce and Economics in 2018 (Coffin and Horowitz (2018)). Commission staff has also previously examined the materials needed for lithium-ion battery production extensively.[3] After a brief overview of the changes to the EV landscape since 2017, this paper summarizes the importance of EV batteries and the EV battery supply chain, describes changes in trade data for both EVs and EV batteries, and provides an updated calculation of the value-added by various countries in the supply chain.

Changes to the EV Landscape

Since 2017, the quantity and variety of EVs produced and sold has expanded rapidly. Global EV sales increased 78 percent from over 754,000 in 2017 to over 1.5 million in 2019 (figure 1).[4] U.S. EV sales more than doubled from 104,490 in 2017 to nearly 245,000 in 2019 (table 1). With Tesla’s Model 3 selling at such high volumes, U.S. production makes up a higher share of U.S. EV sales than in previous years. In 2017 13 different EV models were offered in the United States, but in 2019 that had expanded to 18 (table 1).[5]

[1] IEA, Global EV Outlook 2020 “Table A.5 New Battery Electric Car Sales, 2005-19 (thousands of vehicles,” June 2020, 249.
[2] Boucherat, “The Hardest Part is Scaling,” November 23, 2020; Scott and Ireland, “Lithium-Ion Battery Materials for Electric Vehicles and their Global Value Chains,” June 2020.
[3] Scott and Ireland, “Lithium-Ion Battery Materials for Electric Vehicles and their Global Value Chains,” June 2020; LaRocca, “Global Value Chains: Lithium in Lithium-ion Batteries for Electric Vehicles,” July 2020; Matthews, “Global Value Chains: Cobalt in Lithium-ion Batteries for Electric Vehicles,” May 2020.
[4] IEA, Global EV Outlook 2020 “Table A.5 New Battery Electric Car Sales, 2005-19 (thousands of vehicles,” June 2020, 249.
[5] Loveday, “December 2017 Plug-In Electric Vehicle Sales Report Card,” January 3, 2018; Loveday, “Final Update,” January 17, 2020.

Figure 1 Global EV sales 2015–19 (thousands of units)



Source: IEA, Global EV Outlook 2020, June 2020.

Table 1 U.S. EV sales, by assembly location and model, number of vehicles, 2017–19

Model	Vehicle assembly	2017	2018	2019
Tesla Model 3	United States	1,764	139,782	158,925
Tesla Model X	United States	21,315	26,100	19,225
Chevrolet Bolt EV	United States	23,297	18,019	16,418
Tesla Model S	United States	27,060	25,745	14,100
Nissan LEAF	United States	11,230	14,715	12,365
Audi e-tron	Belgium	0	0	5,369
Volkswagen e-Golf	Germany	3,534	1,354	4,863
BMW i3	Germany	6,276	6,117	4,854
Jaguar I-Pace	Austria	0	393	2,594
Hyundai Kona Electric	South Korea	0	0	1,723
Kia Niro EV	South Korea	0	0	1,166
Honda Clarity BEV	Japan	1,121	0	742
Hyundai IONIQ EV	South Korea	432	345	704
smart ED	Germany	544	1,219	680
Fiat 500e	Mexico	5,380	2,250	615
Porsche Taycan	Germany	0	0	130
Kia Soul EV	South Korea	2,157	1,134	87
Mercedes B250e	Germany	744	135	9
Other		1,846	560	0
Total		106,700	237,868	244,569

Sources: Loveday, "Final Update," January 17, 2020; Wards Automotive Yearbook, 2020 (online, subscription required).

These increased EV offerings lead to higher volumes, which allow battery cell manufacturers to achieve greater economies of scale. In response to this rising demand, the number of global EV battery manufacturers has increased, with new entrants and more cell and pack assembly facilities built.[6] BNEF

[6] The EV battery supply chain is made up of three main parts, the cell, the module, and the pack.

data lists 85 new battery plants or expansions from 2015 to 2019, which added more than 200 GWh of capacity, and increased global capacity to more than 300 GWh.[7] Based on an average battery size of 44 kWh, that is enough of an increase in capacity for an additional 4.5 million electric vehicles per year.[8] China continues to have the most capacity, followed by the United States and South Korea (figure 2). According to BNEF, there are eight EV battery manufacturing plants in the United States.[9] Two battery manufacturers built or added U.S. capacity during this period, adding nearly 21 GWh. Most of this increase was at Tesla's Gigafactory, but Xalt, a manufacturer of batteries for commercial electric vehicles, added 150 MWh as well.[10] Tesla built the Gigafactory jointly with Panasonic (its supplier of battery cells) to supply batteries for its new EVs, as its Japanese supplier did not have sufficient capacity to meet Tesla's rising demand.[11] Global EV battery capacity utilization is relatively high, especially in the United States, thus as EV demand increases new battery manufacturing capacity must be built, as all available capacity is already in use.[12].

Vehicle and battery manufacturers plan to continue expanding battery manufacturing capacity in the United States, potentially leading to a 160 percent increase in U.S. EV battery cell manufacturing capacity. SK Innovation has begun construction on one 9.8 GWh plant in Tennessee (with production due to begin in 2022) and announced plans to build a second 10 GWh plant in Georgia.[13] GM announced in December 2019 that it planned to open a joint venture plant in Ohio with LG Chem that would have an annual capacity of more than 30 GWh.[14] In January 2020, Volvo announced plans to assemble battery packs at its plant in Charleston.[15]

With the increased supply of EV battery cells, EV battery costs have also declined. In 2017, the average EV battery cost $209 per kWh, with Tesla having the lowest costs at $190 per kWh. In 2019, BNEF estimated that the price per kWh of an EV battery had dropped to $156 per kWh due to increased EV

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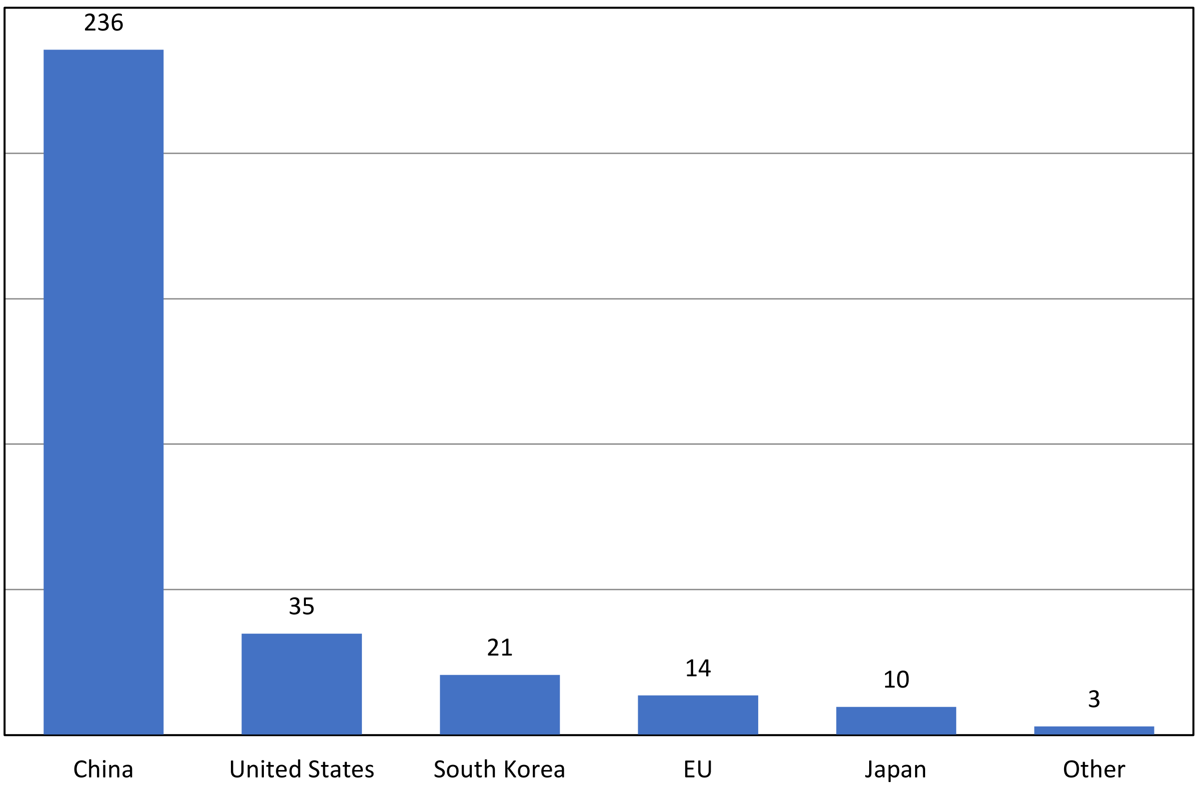
[7] BNEF, Battery Manufacturing, May 30, 2019.
[8] The average battery pack size across all light duty electric vehicles increased from 37 kWh in 2018 to 44 kWh in 2019. IEA, "EV Outlook 2020," 185.
[9] LG Chem Michigan Battery Manufacturing Plant, Tesla Panasonic Reno Battery Manufacturing Plant (Gigafactory), Nissan North America Smyrna Battery Manufacturing Plant, Wanxiang Livonia Battery Manufacturing Plant, Johnson Controls Meadowbrook Battery Manufacturing Plant, Xalt Midland Battery Manufacturing Plant, Saft America Jacksonville Lithium Ion Battery Manufacturing Plant, and Ener1 Indianapolis Battery Manufacturing Plant. BNEF, Battery Manufacturing, May 30, 2019.
[10] BNEF, "Battery Manufacturing," May 30, 2019.
[11] Tesla, "Gigafactory," (accessed December 10, 2020).
[12] For example, the Chevrolet Bolt mostly uses cells produced in South Korea and put into packs in Michigan because cell capacity at LG Chem's Michigan plant is completely used for other EVs. Lambert, "GM recalls 68,667 Chevy Bolt EVs ('17-'19) citing unlikely potential fire risk," November 13, 2020; Boucherat, "The Hardest Part is Scaling," November 23, 2020.
[13] Lee, "SK Innovation Plans Second EV battery Plant in U.S., Expansion in Hungary," January 9, 2020.
[14] GM, "General Motors and LG Chem Team Up to Advance Toward an All-Electric Future, Add Jobs in Ohio," December 5, 2019.
[15] Pack assembly occurs close to the vehicle assembly location because packs are heavy and difficult to transport. Information on whether the cells will be imported is not currently available. Karkaria, "Volvo building U.S. battery assembly plant," January 14, 2020.

sales and spread of high energy density cathodes.[16] Prices have fallen "due to improvements in manufacturing, battery chemistry and tighter supply chain control."[17]

Figure 2 Global EV battery manufacturing capacity (GWh), 2019



Source: BNEF, "Battery Manufacturing," May 30, 2019.

The Importance of Batteries

Batteries are the key differentiator between different EV manufacturers. The amount of energy stored in the battery determines the range of the EV, thought to be a major limitation on EV sales. Consumers tend to worry that an EV with a range of 80 to 250 miles on a single charge would be inconvenient for long trips due to the time it takes to recharge the battery. Manufacturers have spent millions to improve the availability and efficacy of EV chargers, and as a result the fastest ones today take no more than 15 minutes to recharge a vehicle. However, not many of those are available, and instead most users plug their vehicles into "slow chargers," which can take much longer.[18] Long charging times are likely why most EVs are charged at work or in the home.[19] Another reason why the lithium-ion battery is so important in the adoption of EVs is because it makes EVs more expensive than comparable vehicles with

[16] BNEF, "Battery Pack Prices Fall," December 3, 2019.
[17] Stewart, "Battery Prices are Crashing," December 3, 2019.
[18] For example, to fully charge a Tesla Model S 100D using a 120V charger would take about four days. Yamauchi, "Tesla Charging," (accessed October 1, 2018); IEA, Global EV Outlook 2020, 74–75.
[19] IEA, *Global EV Outlook 2017*, 2017, 33.

internal combustion engines (ICEs).[20] Even though battery costs per kilowatt hour (kWh) have declined from roughly $1,000 per kWh in 2010 to $156 in 2019,[21] it is estimated that EV prices (due to high battery costs) may not fall to the level of ICEs in the larger vehicle segments until 2025 or 2030.[22]

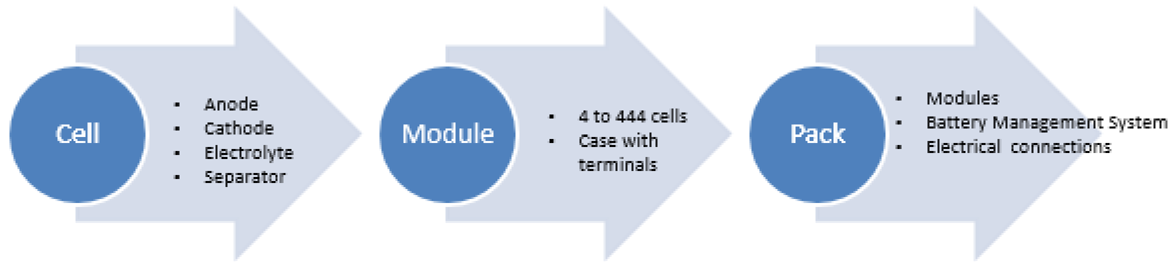
Coinciding with declines in battery costs, Bloomberg New Energy Finance (BNEF) predicts that annual EV sales will increase from 1.1 million in 2017, to 11 million in 2025 and 30 million in 2030.[23] If this is the case, demand for the EV batteries will also surge. Lithium-ion batteries made up 70 percent of the rechargeable battery market in 2016; since then, EV-driven demand for lithium-ion batteries has continued to rise and will likely continue to rise as long as lithium-ion batteries are the primary power source for EVs.[24] These batteries, like many high-tech goods, have a complex supply chain in which production can be broken into stages, and those stages can be completed in different locations. This next section describes the current structure of the EV battery supply chain.

Structure of the EV Battery Supply Chain

The battery manufacturing supply chain has three main parts: cell manufacturing, module manufacturing, and pack assembly (figure 3). These three stages can be conducted in the same place or broken up into two or (theoretically) three locations. For example, the Envision AESC plant in Sunderland, England, produces battery cells and modules, and assembles packs for the Nissan Leaf.[25] However, Envision AESC also sends modules to Spain, where they are put into packs for electric vans. Additionally, Tesla produces modules and packs at its Gigafactory, which opened in 2017 in Nevada, using cells produced by Panasonic at the Gigafactory. However Tesla also produces modules and packs at its Fremont location using cells produced both internally and by Panasonic in Japan.[26] Pack assembly tends to occur near the vehicle assembly location because of the cost of transporting battery packs, which are larger and heavier than cells or modules (figure 4).

[20] A replacement battery for a 2011 to 2015 Nissan Leaf costs consumers $5,499, but the cost to Nissan may actually be higher. For comparison, the unit value of U.S. engine for motor vehicle imports was less than $1,500 in 2019. Voelcker, "Nissan Leaf $5,500 Battery Replacement Loses Money," July 24, 2014; McKinsey & Company, *Electrifying Insights*, January 2017, 10; USITC, Dataweb (accessed December 17, 2020). HS 8407.34.
[21] BNEF, "Battery Pack Prices Fall," December 3, 2019; McKinsey & Company, *Electrifying Insights*, January 2017, 10.
[22] McKinsey & Company, *Electrifying Insights*, January 2017, 13.
[23] BNEF, "Electric Vehicle Outlook 2018," 2018.
[24] Desjardins, "Here Are the Raw Materials We Need," October 27, 2016.
[25] Gordon-Bloomfield, "How Nissan Makes Its Electric Car Battery Packs," December 2, 2014.
[26] Tesla Corporation, "Panasonic and Tesla Sign Agreement for the Gigafactory," July 30, 2014.

Figure 3 The three stages of electric vehicle battery production



Source: Author illustration.

Figure 4 Alkaline AA battery cell, Tesla lithium-ion battery cell, and Nissan battery modules and pack

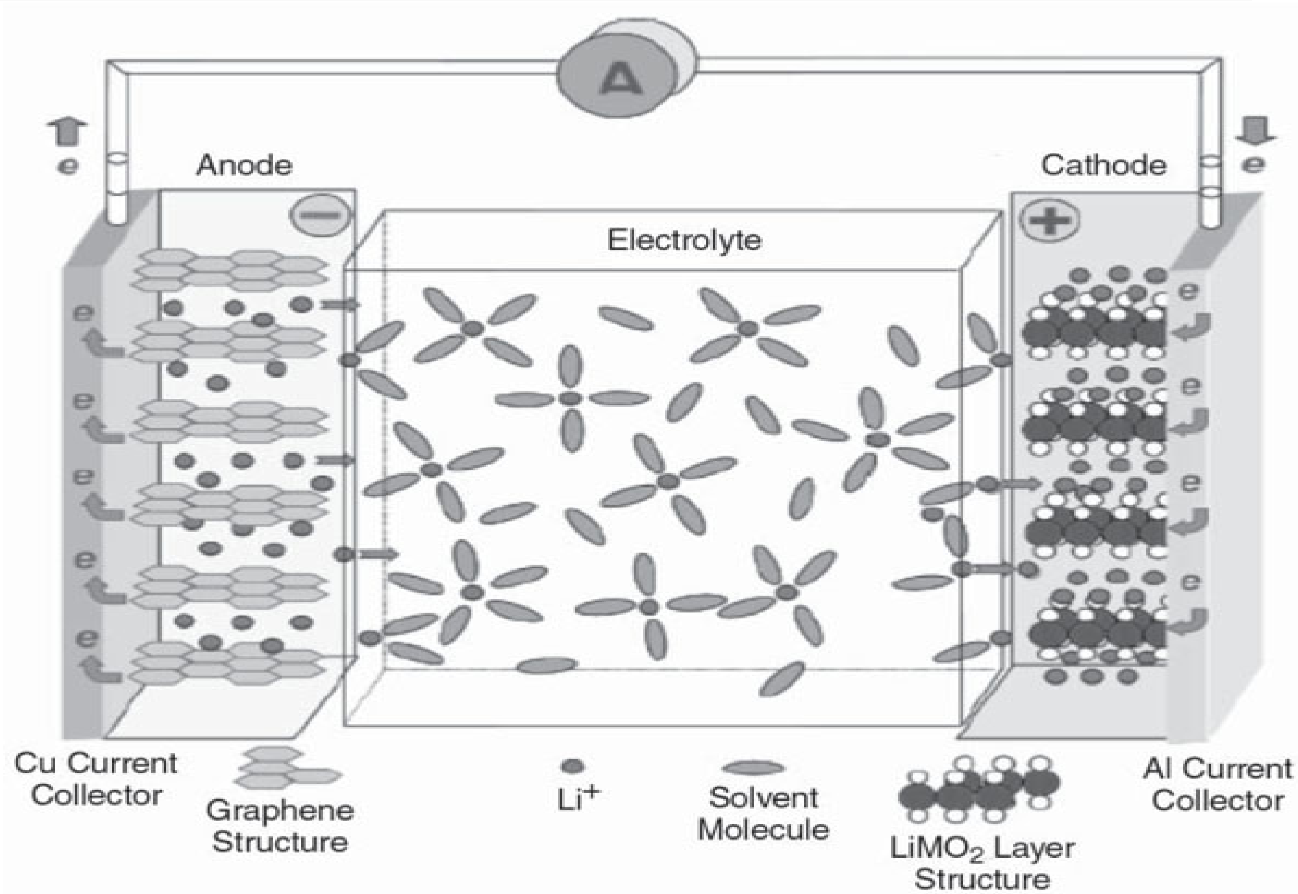
Sources: Wikimedia Commons, "Li-ion-18650-AA-battery," July 2011, https://commons.wikimedia.org/wiki/File:Liion-18650-AA-battery.jpg; Meyer, "Battery-pack of the Nissan Leaf," December 8, 2010, https://commons.wikimedia.org/wiki/File:Battery-Pack-Leaf.jpg.

Battery Cell Composition and Manufacturing

The smallest, but most important, component of lithium-ion batteries is the electrochemical cell, which consists of three major parts: a cathode and an anode separated physically and connected electrically by an electrolyte.[27] A battery's discharge comes from the diffusion of lithium ions from the anode to the cathode through the electrolyte, as shown in figure 5.

[27] Daniel, "Materials and Processing for Lithium-ion Batteries," September 2008.

Figure 5 The structure of a lithium-ion battery cell



Source: Daniel, "Materials and Processing for Lithium-ion Batteries," September 2008.

The anode is typically made of graphite, while the electrolyte typically consists of organic carbonate solvents with dissolved lithium salts (often lithium hexafluorophosphate, $LiPF_6$). The anode is physically and electronically isolated from the cathode by a separator, often a thin porous plastic film through which the liquid electrolyte permeates. The cathode has the most variation in its different forms.[28] Table 2 lists the chemical compositions for a few different lithium-ion vehicle battery cell cathodes. The relatively low cost of manganese has helped Nissan keep the cost of its battery down, allowing it to produce one of the least expensive EVs for the U.S. market. Globally, BYD, based in Shenzhen, China, produces a cheaper lithium-ion battery, but does not sell passenger vehicles in the United States. Based on recent estimates, about 21 percent of the value-added of a finished lithium-ion battery pack comes from the cell stage of production.[29]

[28] Desjardins, "Here Are the Raw Materials We Need." October 27, 2016.
[29] Argonne National Laboratory, "Batpac 4.0," 2019.

Table 2 Cathode component of battery cells in various electric vehicles

Cathode type	Car model example	Notable differences in cathode composition
NCA (Lithium nickel cobalt aluminum oxide)	Tesla models	No manganese present
LMO (Lithium manganese oxide)	Nissan Leaf	Aside from lithium and oxygen, entirely manganese
NCM (Lithium nickel manganese cobalt oxide)	BMW i3	Various compositions which include different ratios of the four elements, with nickel normally being the most abundant

Sources: Desjardins, "Here Are the Raw Materials We Need," October 27, 2016; Lima, "LG Chem Will Introduce NCM 811 Battery Cells," December 22, 2017.

Cells are an intermediate good in the larger battery assembly process.[30] Different cell producers list slightly different specifications and components in their battery cell assembly, but the general ideas remain the same. Tesla uses cylindrical small-format Panasonic 18650 and 2170 battery cells (similar to laptop batteries) to reduce cost, while other vehicle manufacturers have worked with suppliers to create larger prismatic "automotive-grade" battery cells to reduce complexity and increase reliability.[31] Cells are classified under the statistical reporting no. 8507.90.8000 (battery parts) of the Harmonized Tariff System of the United States (HTS).[32]

Battery Modules

Multiple cells in a case with terminals attached form a module.[33] The number of cells per module varies by manufacturer and cell type. For example, Envision AESC uses four cells in the modules it produces for battery packs used by the Nissan Leaf, but Samsung SDI puts 12 cells into its modules.[34] Module production adds less value-added than the cell stage of production. Based on recent estimates, about 11 percent of the total cost of a finished lithium-ion battery pack comes from the module stage of production.[35] Modules can be used in battery packs for different vehicles. As mentioned previously, Envision AESC's Sunderland plant produces modules for the Nissan Leaf (for which it assembles the packs on site), but it also uses these modules in Nissan's compact cargo van, the NV200.[36] Battery modules are classified under the same statistical reporting no. as cells (8507.90.8000- battery parts). However, since most modules are made in the same facility as the battery pack, there is less trade in this component of the supply chain. Modules are assembled using cells that were either imported or made on site.

Battery Packs

EV battery packs are the final stage of EV battery production. Battery packs are made up of battery modules, electrical connections, and cooling equipment. Manufacturers can assemble them by hand or

[30] Most battery manufacturers indicate that, for safety reasons, battery cells cannot be sold separately or individually. For more information, see Panasonic, "Overview: Lithium Ion Batteries," June 2007.
[31] Deutsche Bank, *Lithium 101*, May 9, 2016, 19.
[32] CBP, "Classification of the Battery Management System," June 22, 2011.
[33] AESC, "Cell, Module, and Pack for EV Applications," (accessed November 6, 2017).
[34] AESC, "Cell, Module, and Pack for EV Applications," (accessed November 6, 2017); Samsung SDI, "The Composition of EV Batteries: Cells? Modules? Packs?" September 25, 2017.
[35] Argonne National Laboratory, "Batpac 4.0," 2019.
[36] Gordon-Bloomfield, "How Nissan Makes Its Electric Car Battery Packs," December 2, 2014.

by using automation. Based on recent estimates, about 7 percent of the total cost of a finished lithium-ion battery pack comes from the pack stage of production.[37] Battery manufacturers design EV battery packs for specific vehicle models and tend to assemble them near the vehicle assembly plant. For example, Envision AESC assembles battery packs in Tennessee and the UK relatively close to the plants that assemble the Nissan Leaf (figure 6). Battery packs, unlike cells and modules, are classified in the Harmonized Commodity Description and Coding System (HS) of tariff classification under no. 8507.60, along with all other lithium-ion batteries. [38] Additionally, the United States has a specific statistical reporting number for imports of lithium-ion batteries for use in vehicles (8507.60.0010).

Figure 6 Nissan leaf battery pack

Source: Wikimedia, "Nissan Leaf Battery Pack DC 03 2011 1629.jpg," https://commons.wikimedia.org/wiki/File:Nissan_Leaf_battery_pack_DC_03_2011_1629.jpg (accessed December 7, 2017).

Electric Vehicle Trade 2017–19

Perhaps the biggest change in analyzing the electric vehicle industry is that, starting in 2017, the HS added a specific subheading for electric vehicles.[39] This means it is now possible to more empirically examine and analyze trends in global EV trade, which is the furthest downstream aspect of the EV supply chain. Table 3 displays the top global importers of electric vehicles. Each of the top six largest

[37] Argonne National Laboratory, "Batpac," June 28, 2018.

[38] HS headings that include six digits, like this one, are called "HS-6" headings; those with eight digits are "HS-8," and so on. Classification for battery components is complex and is described in more detail in the "Trade in Batteries" section below.

[39] There are also breakouts for hybrid vehicles (8703.40 and 8703.50), and plug-in hybrid vehicles (8703.60 and 8703.70). Note that the new subheadings only account for passenger electric vehicles and does not include commercial electric vehicles. The majority of commercial electric vehicles are electric buses.

importers have experienced a substantial growth in imports over the last three years, and total imports have more than tripled.

Table 3 Imports of electric vehicles, by country, 2017–19 (million $)

Importer	2017	2018	2019	% growth
Netherlands	293	436	3,152	974
Belgium	261	864	3,048	1070
Norway	1,532	2,250	2,811	84
China	1,469	1,198	2,467	68
Germany	614	849	1,619	164
United States	364	322	1,571	332
Rest of World	3,084	4,606	9,580	211
Total	7,617	10,524	24,248	218

Source: IHS Markit, Global Trade Atlas (HS 8703.80; accessed December 9, 2020).

Most of the largest increases in imports are in Europe, with Belgium and the Netherlands increasing the most. The Netherlands, who leads the way in terms of import volume, has announced a ban on all sales of vehicles with internal combustion engines by 2030.[40] This coincides with the Netherlands' commitments under the EV30@30 Campaign, which was launched in 2017.[41] To this end, the Dutch government is disincentivizing the use of traditional gas vehicles and instead incentivizing the purchasing and owning of electric vehicles. The Netherlands' strategy includes high taxes on gasoline (which are scheduled to rise in coming years and are among the highest in Europe), a company car tax that is substantially higher for non-EVs, and an exemption from both the purchase tax and ownership tax when purchasing/owning an EV.[42] Moreover, the availability of charging stations more than doubled in recent years.[43]

Belgium, whose imports have increased the most (in percentage terms) over the last three years, has several purchase incentives in place, including purchase grants of 3,500-4,000 euros in some provinces, and tax breaks in the form of exemptions from ownership, registration, and company taxes. Multiple European companies have also invested in EV charging station capacity over the last few years in Belgium.[44] Additionally, Belgium has a charging station incentive in which 75 percent of the cost of charging can be deducted from individual income taxes, and companies receive a 13.5 percent deduction on investments in charging infrastructure.[45] It is also worth noting that some imports into the

[40] Lambert, "The Dutch government confirms plans to ban new petrol and diesel cars by 2030," October 10, 2017.
[41] The EV30@30 Campaign is an initiative launched by the Clean Energy Ministerial in 2017, with the objective of reach a 30 percent share for EVs sales, relative to total automotive sales, by 2030. The participating countries are Canada, China, Finland, France, India, Japan, Mexico, Netherlands, Norway, Sweden and the United Kingdom. For more information, see http://www.cleanenergyministerial.org/campaign-clean-energy-ministerial/ev3030-campaign.
[42] Balzhäuser, "EV and EV Charger Incentives in Europe," December 4, 2019; DutchNews.nl, "After a €30 rise in January, Dutch energy prices among highest in EU," May 7, 2019.
[43] Netherlands Enterprise Agency, "Statistics Electric Vehicles in the Netherlands," June 2020. A forthcoming paper will expand upon the EV supply chain in foreign markets and will expand until these EU policies and as well as investments in EV infrastructure.
[44] Autovista Group, "Europe's EV infrastructure expands thanks to investment," December 23, 2019; EV-Box, "EV-Box enters Belgium and Luxembourg" Press Release, December 15, 2016.
[45] Balzhäuser, "EV and EV Charger Incentives in Europe," December 4, 2019.

Netherlands and Belgium may be due to the *Rotterdam-Antwerp effect,* and may actually be imports intended for final consumption in other EU member states.[46]

Table 4 shows the top exporters of electric vehicles, with exports from top exporters growing significantly over the last three years. In Europe, new manufacturing locations for EVs led to significant increases in exports for Belgium (Audi e-tron) and Austria (Jaguar I-Pace).[47] Moreover, investments in EV battery production in these countries have also led to increased vehicle production (and therefore exports). In Austria, Samsung SDI acquired the battery pack business of Magna International in 2015, which has helped bolster Austrian EV production.[48] Germany, which is where the Volkswagen e-Golf, BMW i3, smart ED, Porsche Taycan, and Mercedes B250e are produced (see Table 1), increased its battery production from 2017 to 2019, driving increased EV exports. ACCUMOTIVE, a subsidiary of Daimler, invested 500 million euros in a new plant that began producing EV batteries in 2017 for Mercedes-Benz and Smart's German EV production.[49] Daimler opened a second EV battery plant in Kamenz, Germany in 2018.[50] Outside of Europe, the export growth in South Korea is likely due to investments made by Korean firms. For example, Hyundai and Kia both announced plans to substantially increase their EV production (the Kia Niro EV and Hyundai Kona EV, respectively) as they look to increase their market share in this segment of the automotive sector.[51] In total, Kia and Hyundai's market share of global EV production ranked fourteenth in 2014, but was ranked fourth as of the first quarter of 2020.[52]

Table 4 Exports of electric vehicles, by country, 2017–19 (million $)

Exporter	2017	2018	2019	% growth
United States	3,194	3,418	7,873	147
Belgium	170	537	5,580	3,186
Germany	1,544	1,801	3,900	153
South Korea	421	1,093	2,354	459
Austria	50	643	1,253	2,411
Netherlands	1,294	1,247	1,166	-10
Rest of World	1,707	2,793	4,115	141
Total	8,380	11,532	26,241	213

Source: IHS Markit, Global Trade Atlas (HS 8703.80; accessed December 9, 2020).

[46] The *Rotterdam-Antwerp effect* refers to a trade trend that distorts trade between EU and non-EU countries due to imports to the Netherlands or Belgium being inflated due to the two countries possessing the two largest ports among EU countries. This creates the appearance of higher consumption in the two countries, when many of imports are actually destined for another market via intra-EU trade. For more information, see Economics Online, "The Rotterdam effect," (accessed December 14, 2020).
[47] Wards Automotive Yearbook, 2020 (online, subscription required).
[48] Kim, "Samsung SDI to Open SDIBS for Strengthening Battery Pack Business," May 12, 2015.
[49] Daimler, "Daimler invests 500 million Euros in new battery factory in Germany," March 1, 2016.
[50] Daimler, "Under the microscope: Battery production: Daimler to build global production compound for batteries," (accessed May 28, 2020).
[51] Szymkowski, "Electric Hyundai Kona, Kia Niro production to rise again: report," November 8, 2017.
[52] Herh, "Hyundai and Kia Expand Presence in Global EV Market," June 8, 2020.

Global Lithium-Ion Battery Trade 2017–19

For lithium-ion battery trade, the United States and Germany are beginning to import almost as much as China in recent years, but China still holds a large share of the world's exports. The situation regarding the HS classification remains unchanged over the last few years; HS subheading 8507.60 is where lithium-ion batteries for all uses are categorized for purposes of tracking international trade.[53] However, the U.S. Harmonized Tariff System (HTS) has additional 10-digit statistical reporting numbers for imports that separate EV batteries from other lithium-ion batteries which makes it possible to analyze U.S. trade in EV batteries at a more precise level.[54] As mentioned previously, battery cells are traded under a broader statistical reporting number for battery parts, which makes it difficult to track imports and exports of battery cells at a global level, since that trade data includes a lot of other products as well.

Internationally, while China (excluding Hong Kong) continues to lead the way in terms of imports of lithium-ion batteries in 2018 and 2019, German and U.S. imports grew significantly in recent years, and nearly equaled Chinese imports in 2019 (table 5). The rest of the top five importers include Hong Kong and Vietnam, and together the top five importers account for over 51 percent of all imports worldwide. However, it is difficult to know what portion of imports under this HS subheading were batteries for EVs versus lithium-ion batteries for some other purpose, because the HS subheadings do not differentiate on an international level. One way of perhaps seeing some evidence of different imports across countries though, is looking at unit prices for the value of imports in each country. China and Hong Kong have imports with unit prices of $2.58 and $3.26 respectively, while German and the U.S. imports are valued at $16.09 and $17.25 per unit in 2019.[55] While neither of those prices correspond to entirely battery packs, it does suggest that the composition of Chinese imports are more skewed towards lower cost batteries for non-EVs.

Table 5 Imports of lithium-ion batteries, by country, 2017–19 (million $)

Importer	2017	2018	2019	% growth
China	3,265	3,883	3,724	14
Germany	2,248	2,858	3,708	65
United States	2,522	3,166	3,630	44
Hong Kong	2,078	2,484	2,715	31
Vietnam	([a])	([a])	2,087	N/A
Rest of World	8,229	12,161	15,172	84
Total	18,342	24,551	31,036	69

Source: IHS Markit, Global Trade Atlas (HS 8507.60; accessed December 9, 2020).[a] Vietnam's import data for 8507.60 in 2017 and 2018 is not available.

China's increased lithium-ion battery exports also suggest increased Chinese lithium-ion battery production (table 6). However, similar to the situation with imports, it appears that the makeup of these

[53] While international trade data for lithium-ion batteries cannot be separated based on final use, a majority of demand for Li-ion batteries is for passenger vehicles, and this share is expected to increase to over 70 percent by 2030. For more information, see BNEF, "Long-Term Electric Vehicle Outlook," 2019.
[54] For a more detailed explanation of these data restrictions, see Coffin and Horowitz, "The Supply Chain for Electric Vehicle Batteries," December 2018.
[55] IHS Markit, Global Trade Atlas (HS 8507.60; accessed December 11, 2020). Note that unit prices for Vietnam are unavailable.

exports differs greatly across countries as well. It may be that Chinese production and exports of lithium-ion batteries is for different types of batteries (e.g., power drills, cell phones, etc.) that are typically less expensive than EV batteries. This can be seen in the difference in the unit prices of these exports; Chinese, South Korean, and Japanese exports are all valued at less than $6.25 per unit in 2019, whereas U.S. exports are valued at $95.96 in the same year.[56]

Table 6 Exports of lithium-ion batteries by country, 2017–19 (million $)

Exporter	2017	2018	2019	% growth
China	8,048	10,825	13,031	62
South Korea	3,518	4,388	4,678	33
Hong Kong	2,174	2,877	3,099	43
Japan	2,572	2,580	2,054	-20
Poland	269	821	2,030	656
United States	1,292	1,396	1,499	16
Rest of World	3,242	5,222	6,760	108
Total	22,077	29,438	35,134	59

Source: IHS Markit, Global Trade Atlas (HS 8507.60; accessed December 9, 2020).

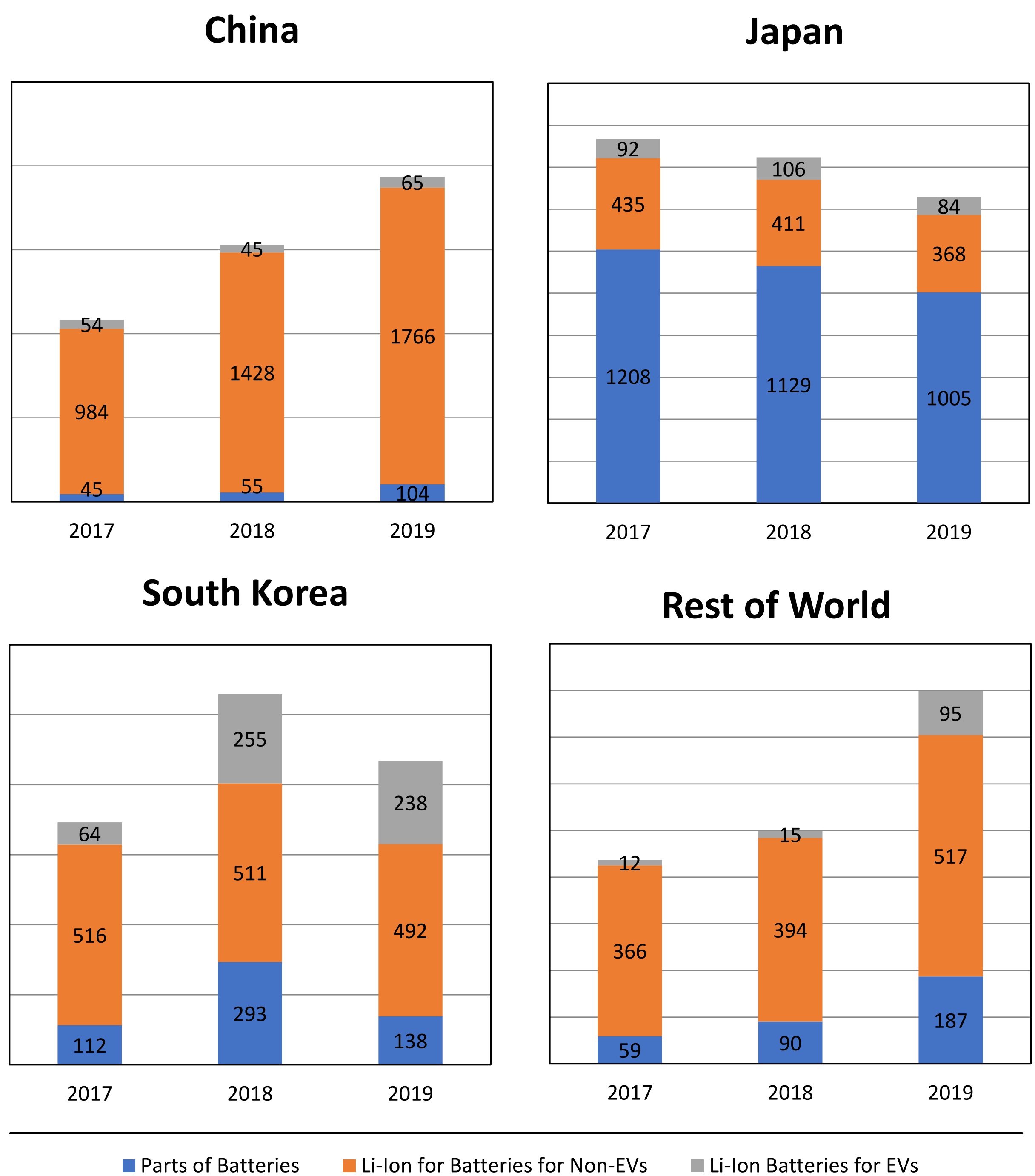
U.S. Lithium-ion Battery Trade 2017–19

For the United States, the majority of assembled EV battery imports continue to be imported from South Korea and the majority of battery parts are imported from Japan, while the majority of exports of lithium-ion batteries from the United States are destined for the Netherlands, Mexico and the United Kingdom (figures 7 and 8). For imports, the HTS breaks out HS 8507.60 into two 10-digit statistical reporting numbers, 8507.60.0010 and 8507.60.0020, to separate lithium-ion batteries for EVs from lithium-ion batteries for all other uses. CBP classifies only battery packs under 8507.60, and specifically should be imported under HTS 8507.60.0010. Battery cells and modules should enter under HTS 8507.90.8000 (battery parts).[57]

Figure 7 shows the leading U.S. import sources for lithium-ion battery components under these three classifications, and the composition of each. Based on these data, the United States continues to appear to import most of its battery parts (some of which are lithium-ion cells and modules) from Japan and, to a lesser extent, South Korea. Moreover, the United States continues to import a high number of lithium-ion battery components not specifically intended for EVs (some of which may be cells and/or modules) from China, South Korea, and Japan, but imports relatively few completed EV battery packs from China and Japan. The data also appears to support the list in Table 1, which shows that the majority of pack assembly for U.S.-sold EVs occurs in the United States.

[56] IHS Markit, Global Trade Atlas (HS 8507.60; accessed December 11, 2020).
[57] CBP, "Classification of the Battery Management System," June 22, 2011. For a more detailed description of HTS classifications, see Coffin and Horowitz, "The Supply Chain for Electric Vehicle Batteries," December 2018.

Figure 7 U.S. imports of lithium-ion batteries and components, top countries (million $)



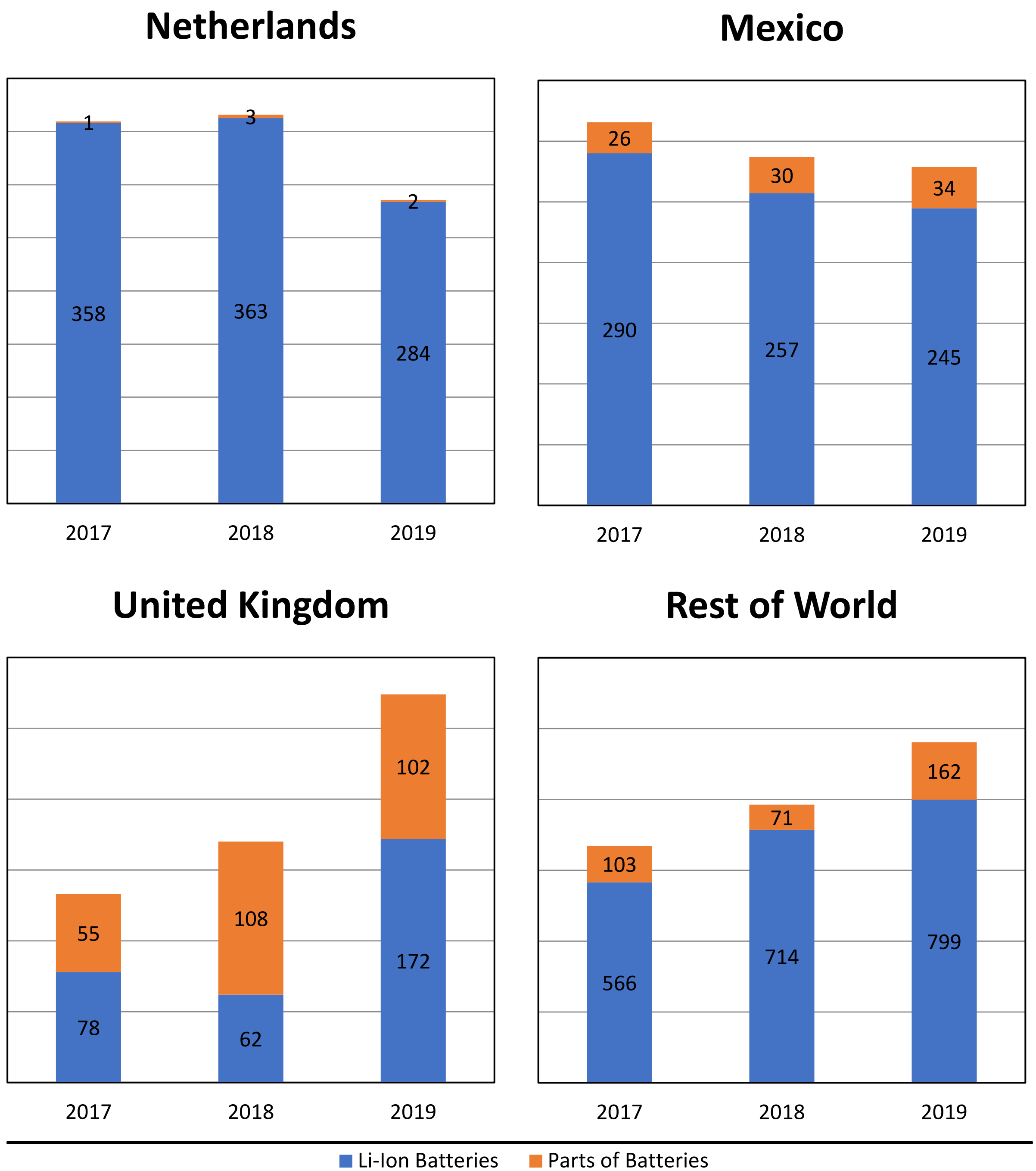
Source: USITC, DataWeb (accessed December 9, 2020).
Note: HTS 8507.60.00.10 denotes lithium-ion batteries for use in EVs, HTS 8507.60.00.20 denotes lithium-ion batteries for all other uses, and HTS 8507.90.80.00 denotes parts of batteries.

It is worth nothing however that there has been a significant increase in imports of EV battery packs from South Korea, which increased from $64 million in 2017 to $238 million in 2019, coinciding with growing sentiment in South Korea that lithium-ion batteries may be a key portfolio of its export driven economy in the future.[58] However, the increase could be a matter of misclassification in whole or in part. These imports appear to be cells or modules even though they were imported under 8507.60.0010 since official trade statistics suggest that the quantity imported into the United States was over 8.1 million units in 2019, a volume far higher than the number of packs used in electric vehicles manufactured in the United States in that year.[59] Furthermore, of the EVs sold in the United States and produced in the United States, none of them report using a battery pack assembled in South Korea, though the Chevrolet Bolt uses cells from South Korea.[60]

As for U.S. exports, separate subheadings for lithium-ion batteries used in EVs do not exist, but in some cases, it appears that the trade flow is EV-related. Figure 8 shows the leading U.S. export destinations for lithium-ion battery components under the two existing classifications, and the composition of each. The leading destination remains the Netherlands, where Tesla likely exports batteries (or modules) to support its EV plant in the Netherlands (opened in 2013).[61] However it is worth noting that exports to the Netherlands have actually decreased in recent years, perhaps, in part, due to Tesla's expansion of its European production operations in Tilburg, Netherlands.[62] Similarly, the Fiat 500e is assembled in Mexico (table 1), so a significant share of exports of lithium-ion batteries to Mexico likely supports that production.

[58] Su-hyun, "Lithium-ion batteries rising as new pillar of Korea's exports," January 21, 2019.
[59] IHS Markit, Global Trade Atlas (HS 8507.60.0010; accessed May 19, 2020).
[60] Further, EVs that do not qualify as light vehicles may also use South Korean batteries, including buses or off-road vehicles. Replacement packs for Hyundai or Kia EVs made in South Korea may also account for some of the imports.
[61] Tesla, "Tesla Motors Opens Assembly Plant in Tilburg, Netherlands," August 27, 2013.
[62] Lambert, "Tesla set up anew large facility near its European factory," September 24, 2018. It's also worth noting that Tesla's sales in the Netherlands were down significantly to start 2020, For more information see: Collins, "Tesla's Sales Fell 68% in The Netherlands and 92% in Norward in February," March 2, 2020.

Figure 8 U.S. exports of lithium-ion batteries and components, top countries (million $)

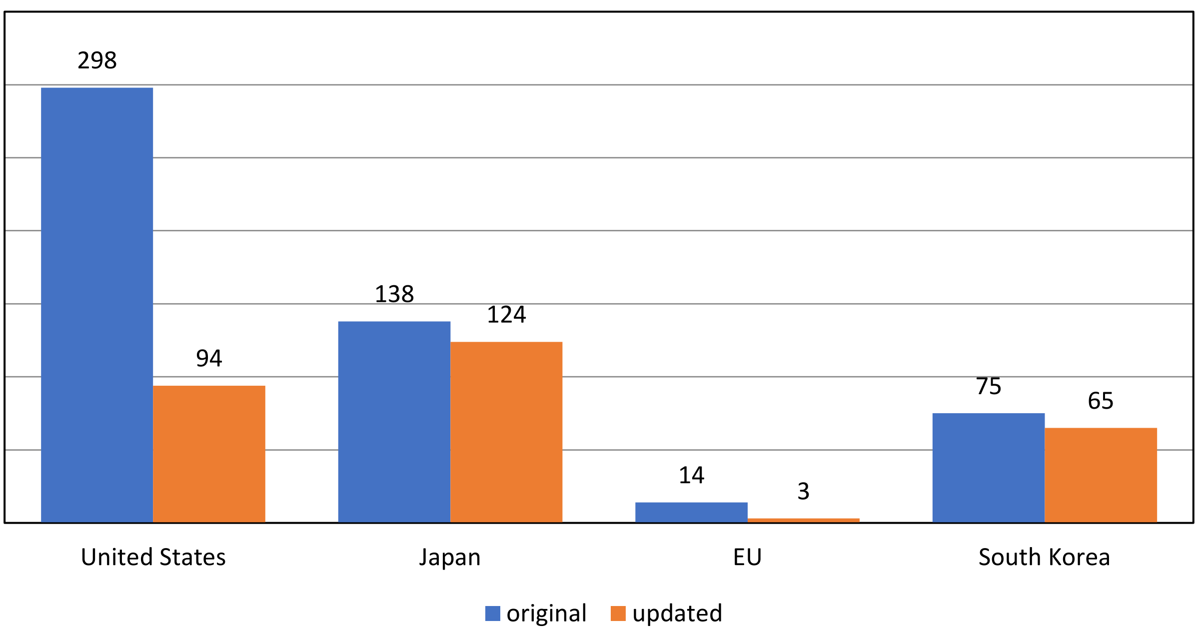


Source: USITC, DataWeb (accessed December 9, 2020).
Note: HTS 8507.60 denotes lithium-ion batteries and HTS 8507.90.8000 denotes parts of batteries.

EV Battery Supply Chain Value-added

This paper uses an updated methodology based on Coffin and Horowitz (2018) to calculate value-added in the EV battery supply chain. This paper calculates the value-added of the EV battery (value of the battery less the cost of materials and purchased items) by splitting value between the country where the battery is assembled and the country where the battery's cells were made based on the split from the most recent version of the Argonne National Laboratory's estimates of EV battery costs (BATPAC).[63] Further, the value-added of cell assembly (cell cost minus materials and purchased items) and pack assembly (cost of final pack to OEM less materials and purchased items) are calculated. Coffin and Horowitz (2018) removed the cost of materials, but not the cost of purchased items, and first removed the cost of materials and purchased items before making value-added comparisons of cells and batteries. This change in methodology reduces the share of value-added at the pack level in comparison to the cell level (figure 9). The main difference is in the value-added calculated for pack assembly, which was 25 percent of the cost of the battery under the old methodology and seven percent under the updated methodology.

Figure 9 EV battery value-added using both original and updated methodology, 2017 (millions $)



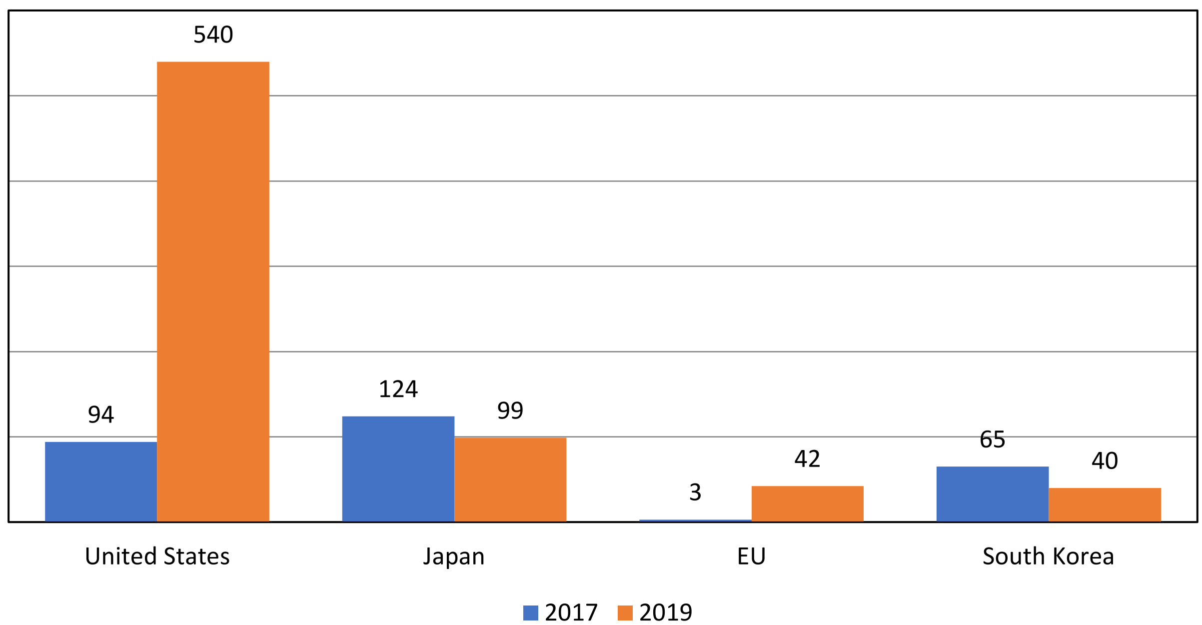
Source: Author's estimates based on Coffin and Horowitz (2018) and BatPac 4.0.

[63] ANL, BatPac 4.0, 2019.

The paper assumes a value of $156/kWh for EV batteries, unless a vehicle manufacturer has released specific data for that vehicle's battery pack.[64] This methodology does not consider the value-added that occurs in purchased items (e.g. the production of cathodes, electrodes, separators, electrolyte, etc.) or in other parts used in the production of a battery pack, as the country sources of those items are not known. The cost of materials makes up 72 percent of the cost of a battery, so the value-added from these materials and inputs could be significant. Lack of an estimate for this portion of the battery may underestimate the value-added share of producers of these inputs (e.g., Chinese production of cathodes and anodes used to make cells in the United States is not taken into account).

In 2019, the value-added to EV batteries from pack assembly and cell production primarily came from the United States (figure 10). Over 90 percent of U.S. value-added came from the sale of Tesla vehicles, some of which have cells produced in the United States (the Model 3), and all have their packs assembled in the United States. For non-Tesla vehicles, only 18 percent of the value-added originates in the United States.

Figure 10 EV Battery Value-added from 2017 and 2019 U.S. EV Sales, using updated methodology (millions $)



Sources: Authors calculation with data drawn from: BatPac 4.0, Loveday, "Final Update" January 17, 2020; Holland, "Powering The EV Revolution," December 4, 2019; Eisenstein, "May the Chevy Volt RIP," February 28, 2019; BNEF, "Battery Pack Prices Fall," December 3, 2019.
Note: Due to methodological changes that change the value-added calculations, the 2017 numbers differ from those in Coffin and Horowitz (2018).

[64] $156/kWh is the average cost of a battery pack according to a BNEF survey published in December 2019. BNEF, "Battery Pack Prices Fall," December 3, 2019. Holland, "Powering the EV Revolution," December 4, 2019; Eisenstein, "May the Chevy Volt RIP," February 28, 2019.

Aggregate value-added numbers show the majority of value-added from EV battery manufacturing in U.S. EVs coming from the United States (table 7). Most of the foreign value-added came from cell production. As mentioned previously, pack assembly tends to be near vehicle production because transportation costs of EV packs after final assembly are quite high considering the dimensions and weight of EV battery packs.[65]

Table 7 Value-added in U.S. EV Sales by Country and Type (millions $)

Stage	United States	Japan	EU	South Korea
Cell production	373.3	98.5	31.9	37.9
Pack assembly	166.4	0.2	10.3	2.0
Total	539.7	98.7	42.2	39.9

Sources: Authors calculation with data drawn from: ANL, BatPac 4.0, 2019; Loveday, "Final Update" January 17, 2020; Holland, "Powering The EV Revolution," December 4, 2019; Eisenstein, "May the Chevy Volt RIP," February 28, 2019; BNEF, "Battery Pack Prices Fall," December 3, 2019.

Conclusion

U.S. EV sales and the U.S. EV battery supply chain have expanded significantly in recent years, while battery costs have continued to decline. U.S. cell and battery assembly accounts for a significant share of the value-added in vehicles produced in the United States. Future research should look at how much U.S. value-added is consumed in electric vehicles sold in other markets. Additionally, attempting to extract value-added from the cost of materials used in the making of cells and battery packs would provide a more thorough and complete view of the EV battery supply chain, and reveal which countries are most competitive at different points in the supply chain. Finally, research in later years will also have a better ability to look at value-added over time, allowing for an analysis of how investment in battery plants affects value-added.

[65] All EVs produced in the United States used battery packs assembled in the United States, sometimes even in the same plant. All EVs produced in the EU had pack assembly in the EU. All EVs produced in Asia had packs that were assembled in Asia. Cell production was more globally distributed, with both U.S. and EU-produced EVs using cells from outside the region.

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