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The Supply Chain for Electric Vehicle Batteries

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Abstract

Electric vehicles (EVs) are a growing part of the passenger vehicle industry due to improved technology, customer interest in reducing carbon footprints, and policy incentives. EV batteries are the key determinant of both the range and cost of the vehicle. This paper explains the importance of EV batteries, describes the structure of the EV battery supply chain, examines current limitations in trade data for EV batteries, and estimates the value added to EV batteries for EVs sold in the United States.

Keywords: motor vehicles, cars, passenger vehicles, electric vehicles, vehicle batteries, lithium-ion batteries, supply chain, value chain.

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Introduction

Supply chains spreading across countries have added complexity to tracking international trade flows and calculating the value each country receives from a particular good. This article explores the supply chain of one such good, the lithium-ion battery powering an electric passenger vehicle.[1]

Electric vehicles (EVs) are becoming an increasingly important part of the automotive landscape. According to a 2018 Morning Consult survey, only 23 percent of adults believe gasoline will power a majority of motor vehicles in the year 2050, while 44 percent believe the majority will be powered by electricity.[2] EV sales rose sharply from 2013 to 2017, and these sales will likely grow further as EV investment and government support increase and EV costs decline. According to the 2018 *IEA Global Electric Vehicle Outlook*, new registrations of EVs increased from 111,320 in 2013 to 750,490 in 2017, a 575-percent increase. Still, they accounted for only 0.8 percent of global vehicle sales in 2017.[3] At the same time, EV prices have fallen significantly. Analysts predict that some sizes of EVs will achieve cost parity with internal-combustion-engine (ICE) vehicles by 2024 or 2025, and all EVs will do so by 2030 (assuming no significant increases in material prices).[4] For these reasons, as well as the availability of tax incentives and other policy inducements, passenger vehicle manufacturers have invested substantially in EVs, spending billions of dollars on related research and development and offering new models.

While two Tesla models (the Model S and Model X) accounted for nearly one-half of all U.S. EV sales in 2017, many other brands compete as well. Table 1 lists the 10 models with the most sales in 2017. These 10 models accounted for 94 percent of 2017 U.S. EV sales. The table also lists the assembly location of each model as well as the battery size, battery manufacturer, location of battery pack assembly, and location of cell production. Six of the 10 models are assembled in the United States, as are 7 of the 10 batteries that power the vehicles. But only four of the batteries' cells are produced in the United States.

[1] This article looks exclusively at passenger vehicles, which includes all vehicles under heading 8703 of the Harmonized Tariff Schedule of the United States (2018). This article does not include electric buses, or any vehicle designed for the transport of goods. For more information, see https://hts.usitc.gov/.
[2] Morning Consult, "How People View the Future of Mobility," January 24, 2018, slide 16.
[3] IEA, *Global EV Outlook 2018*, Table A.5, 113; OICA, "2017 Production Statistics," 2017.
[4] Soulopolous, "When Will Electric Vehicles Be Cheaper?" April 12, 2017; Ewing, "What Needs to Happen Before Electric Cars Take Over the World," December 18, 2017.

Table 1: Major electric vehicle models as of 2017

Manufacturer	Model	Range (miles)	Assembly location	Battery size (kWh)	Battery manufacturer	Battery pack assembly location	Battery cell production location
Tesla	Model S	259–335	United States	75 or 100	Panasonic/ Tesla[a]	United States	Japan
Tesla	Model X	295	United States	75 or 100	Panasonic/ Tesla[a]	United States	Japan
Tesla	Model 3	220–310	United States	50–74	Panasonic/ Tesla[a]	United States	United States
Chevrolet	Bolt EV	238	United States	60	LG Chem	United states	South Korea
Nissan	Leaf	151	United States	30	Automotive Energy Supply Corp.	United States	United States
Fiat	500e	84	Mexico	24	SB LiMotive	United States	United States
VW	e-Golf	126	Germany	35.8	Samsung SDI	Hungary	South Korea
Ford	Focus Electric	118	United States	33.5	LG Chem	United States	United States
BMW	i3	114	Germany	22–33	Samsung SDI	Hungary	South Korea
Kia	Soul EV	111	South Korea	27	SK innovation	South Korea	South Korea

Sources: Ayre, "LG Chem," February 21, 2017; BMW, "The BMW i3 and All-New BMW i3s" (accessed March 8, 2018); Bosch, "Bosch Is One-stop Supplier," June 2013; Burke and Silke Carly, "Tesla's Real Capacity Problem?" June 14, 2017; Chevrolet, "Bolt EV" (accessed March 8, 2018); *EV Sales*, "World Top 20," January 31, 2017; Fiat, "2017 Fiat 500e" (accessed March 8, 2018); Ford, "2018 Focus Electric" (accessed March 8, 2018); Herron, "Tesla Motors Battery Suppliers," September 25, 2015; Kia Motors America, "2018 Soul EV" (accessed March 8, 2018); Lee, "Expansion In European Market," March 30, 2017; McCarthy, "Tesla Dominates," August 14, 2017; Nissan, "2018 Nissan Leaf" (accessed March 8, 2018); Pfanner and Landers, "Nissan Considers Shift," July 26, 2015; Reuters, "Samsung SDI, Bosch," November 7, 2010; Tesla, "Model S" (accessed January 10, 2018); Tesla, "Model S and Model 3 Comparison" (accessed March 8, 2018); Tesla, "Model X, The Best SUV" (accessed March 8, 2018); Volkswagen, "e-Golf: Give the City a Jolt" (accessed March 8, 2018).
Note: kWh = kilowatt-hours.
[a] For all three Tesla vehicles, the battery cells are manufactured by Panasonic, and the battery modules and packs are manufactured by Tesla. The battery cells for the Tesla Model 3 are manufactured in the United States, while the battery cells for the other two models are produced in Japan.

The EV supply chain is similar to the ICE passenger vehicle supply chain. However, instead of competing based on the engine and transmission, EVs compete based on their batteries. Lithium-ion batteries power all EVs sold in the United States and have many different material compositions. For example, lithium-nickel-manganese-cobalt oxide ($Li(NiMnCo)O_2$ or NMC) is the most common composition used in EVs, but lithium-nickel-cobalt-aluminum oxide ($Li(NiCoAl)O_2$ or NCA) is used in the best-selling EVs in the United States (Tesla Models S, X, and 3).[5]

This paper is divided into five parts. The first part explains why understanding the EV battery supply chain is important. The second part breaks down the different stages of the EV supply chain and describes the inputs necessary at each stage. The third section discusses major battery manufacturers supplying the U.S. market. The fourth section examines the available international trade data, and describes (to the extent possible) international trends in EV battery trade, along

[5] For more information on types of lithium-ion batteries, see Battery University, "BU-205: Types of Lithium-ion" (accessed January 10, 2018), and Battery University, "BU-1003: Electric Vehicles (EV)" (accessed January 10, 2018).

with major U.S. import sources and export destinations for lithium-ion batteries and parts. The final section offers a rough estimate of value added by country to batteries for EVs sold in the United States.

The Importance of Batteries

Batteries are the key differentiator between the various 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; most users plug their vehicles into "slow chargers," which can take much longer.[6] Long charging times are likely why most EVs are charged at work or in the home.[7]

The lithium-ion battery is also important in EVs because it makes EVs more expensive than comparable vehicles with ICEs.[8] Battery costs per kilowatt-hour (kWh) declined from roughly $1,000 per kWh in 2010 to $227 in 2016,[9] but EV prices (due to high battery costs) may not fall to the level of ICEs in the larger vehicle segments until 2025 or 2030.[10]

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.[11] 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 risen, and will likely continue to rise as long as lithium-ion batteries are the primary power source for EVs.[12] BNEF projects that global production capacity for lithium-ion batteries will increase from 103 gigawatt-hours (GWh) in the first quarter of 2017 to 273 GWh by 2021.[13]

EV batteries, like many high-technology goods, have a complex supply chain in which production can be separated into stages, and those stages can be completed in different locations. This next section describes the current structure of the EV battery supply chain.

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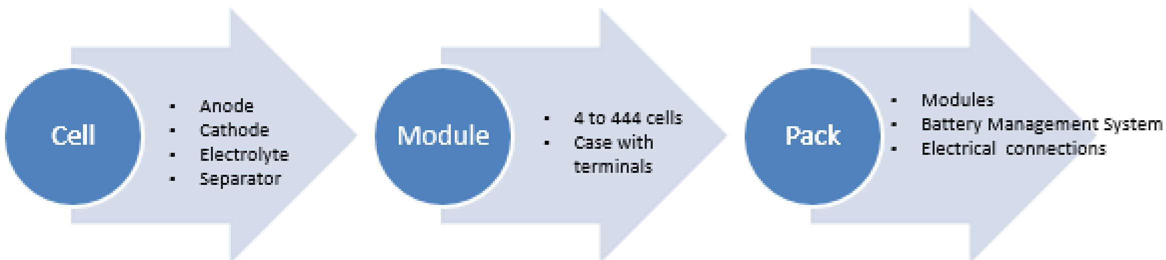
[6] For example, to fully charge a Tesla Model S 100D using a 120V charger would take about four days. Yamauchi, "Tesla Charging," (accessed October 1, 2018).
[7] IEA, *Global EV Outlook 2017*, 2017, 33.
[8] A replacement battery for a 2011 to 2015 Nissan Leaf costs consumers $5,499, but the cost to Nissan may actually be higher. Voelcker, "Nissan Leaf $5,500 Battery Replacement Loses Money," July 24, 2014; McKinsey & Company, *Electrifying Insights*, January 2017, 10.
[9] McKinsey & Company, *Electrifying Insights*, January 2017, 10.
[10] McKinsey & Company, *Electrifying Insights*, January 2017, 13.
[11] Bloomberg New Energy Finance, "Electric Vehicle Outlook 2018," 2018.
[12] Desjardins, "Here Are the Raw Materials We Need," October 27, 2016.
[13] Curry, "Lithium-ion Battery Costs and Market," July 5, 2017, 5.

Structure of the Electric Vehicle Battery Supply Chain

The battery manufacturing supply chain has three main parts: cell manufacturing, module manufacturing, and pack assembly (figure 1). These three stages can be conducted in the same place, or broken up into two or (theoretically) three locations. For example, the Automotive Energy Supply Corporation (AESC) plant in Sunderland, England, produces battery cells and modules, and assembles packs for the Nissan Leaf.[14] However, AESC also sends modules to Spain, where they are put into packs for electric vans. Tesla produces its own modules and packs at both its "Gigafactory," which opened in Nevada in 2017, and at its vehicle assembly plant in Fremont, California. Tesla's battery packs for the Model 3 use cells from the Gigafactory, while cells for the Model S and Model X are produced by Panasonic in Japan.[15] 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 2).

Figure 1: The three stages of electric vehicle battery production



Source: Compiled from industry representative, interview with USITC staff, Washington DC, November 14, 2018; industry representative, telephone interview with USITC staff, June 12, 2018.

[14] Gordon-Bloomfield, "How Nissan Makes Its Electric Car Battery Packs," December 2, 2014.
[15] Tesla, "Panasonic and Tesla Sign Agreement for the Gigafactory," July 30, 2014.

Figure 2: Alkaline AA battery cell, Tesla lithium-ion battery cell, and Nissan battery modules and pack

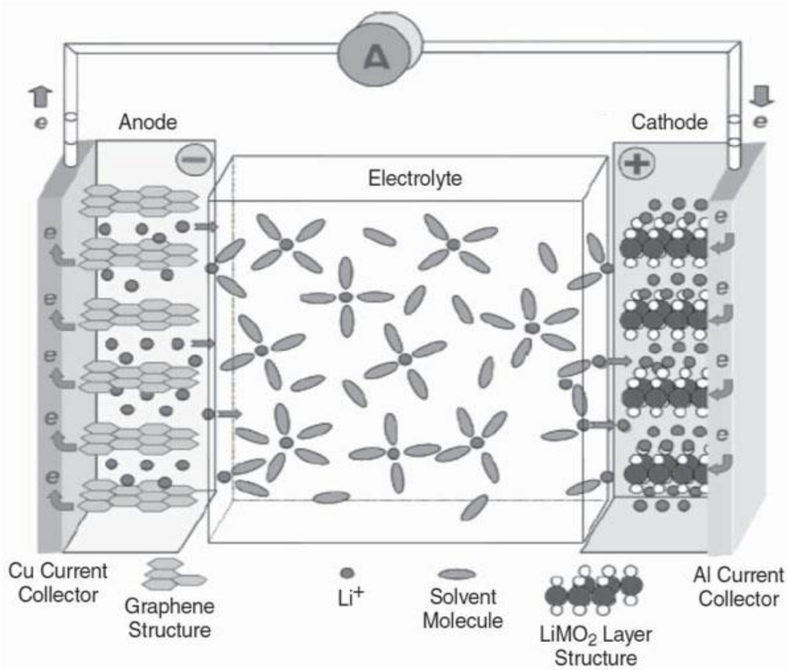
Sources: Wikimedia Commons, "Li-ion-18650-AA-battery," July 2011, https://commons.wikimedia.org/wiki/File:Liion-18650-AA-battery.jpg; Meyer, "Battery-pack of the Nissan Leaf," December 8, 2010, https://commons.wikimedia.org/wiki/File:Battery-Pack-Leaf.jpg.

Battery Cell Composition and Manufacturing

The smallest, but most important, component of the lithium-ion batteries that power EVs is the electrochemical cell, which consists of three major parts: a cathode and an anode separated physically but connected electrically by an electrolyte.[16] A battery's discharge results from the diffusion of lithium ions from the anode to the cathode through the electrolyte, as shown in figure 3.

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

Figure 3: 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.[17] 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 currently sell passenger vehicles in the United States. Based on recent estimates, about 20 percent of the total cost of a finished lithium-ion battery pack comes from the cell stage of production.[18]

Table 2: Cathode component of battery cells in various electric vehicles

Cathode type	Car model example	Notable differences in cathode composition
Lithium-nickel-cobalt-aluminum oxide (NCA)	Tesla models	No manganese present
Lithium-manganese oxide (LMO)	Nissan Leaf	Other than lithium and oxygen, made up entirely of manganese
Lithium-nickel-manganese-cobalt oxide (NMC)	BMW i3	Various compositions which include different ratios of the four metals, 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," September 8, 2017.

[17] Desjardins, "Here Are the Raw Materials We Need." October 27, 2016.

[18] Argonne National Laboratory, "BatPaC," June 28, 2018.

Cells are assembled only as an intermediate good as part of the larger battery assembly process, for insertion into both EV batteries and batteries for other uses.[19] According to Argonne National Laboratory, cells make up 75 percent of the cost of a battery pack, on average.[20] Different cell producers list slightly different specifications and components in their battery cell assemblies, 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.[21]

Cells are classified under statistical reporting number 8507.90.8000 (battery parts) of the Harmonized Tariff System of the United States (HTSUS or HTS).[22] Most cells for lithium-ion batteries in EVs in the United States tend to be imported, but U.S. cell production will increase as Tesla's Gigafactory continues to come online.[23] Although Japan and South Korea are major cell manufacturers, 84 percent of lithium-ion cell production will be in the United States or China by 2020, which would be a 20-percent increase from 2016, based on announced production expansions in the United States and China.[24]

Battery Modules

Multiple cells in a case with terminals attached form a module.[25] The number of cells per module varies by manufacturer and cell type. For example, 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.[26] Modules feature less value added than cells or pack assembly. 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.[27] Modules can be used in battery packs for different vehicles. For example, AESC's Sunderland plant produces modules for Nissan Leafs (for which it assembles the packs on site) and for Nissan's compact cargo van, the NV200.[28] Battery modules are classified under the same HTS statistical reporting number as cells (8507.90.8000). However, since most modules are made in the same facility as the battery pack, there is less trade in this

[19] Most battery manufacturers indicate that, for safety reasons, battery cells cannot be sold separately or individually. See Panasonic, "Overview: Lithium Ion Batteries," June 2007, for features: https://industrial.panasonic.com/ww/products/batteries/secondary-batteries/lithium-ion.
[20] Argonne National Laboratory, "BatPaC," June 28, 2018.
[21] Deutsche Bank. *Lithium 101*, May 9, 2016, 19.
[22] CBP, "Classification of the Battery Management System," June 22, 2011.
[23] Tesla, "Battery Cell Production Begins at the Gigafactory," January 4, 2017.
[24] Dougher, "Breaking Down the Lithium-ion Cell Manufacturing Supply Chain," April 23, 2018; Sanderson, Hancock, and Lewis, "Electric Cars," March 5, 2017.
[25] AESC. "Cell, Module, and Pack for EV Applications" (accessed November 6, 2017).
[26] 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.
[27] Argonne National Laboratory, "BatPaC," June 28, 2018.
[28] Gordon-Bloomfield, "How Nissan Makes Its Electric Car Battery Packs," December 2, 2014.

component of the supply chain. Modules are assembled using cells that were either imported or produced on site.

Battery Packs

EV battery packs are the final stage of EV battery production. Battery packs consist of battery modules, electrical connections, and cooling equipment. Manufacturers can assemble them by hand or by using automated equipment. Based on recent estimates, about 14 percent of the total cost of a finished lithium-ion battery pack comes from the pack stage of production.[29]

Battery manufacturers design EV battery packs for specific vehicle models, and tend to assemble them near the vehicle assembly plant. For example, AESC assembles battery packs in Tennessee and Sunderland, England relatively close to the plants that assemble Nissan Leafs (figure 4). Battery packs, unlike cells and modules, are classified in the international Harmonized Commodity Description and Coding System (HS) under tariff-classification subheading 8507.60, along with all other lithium-ion batteries.[30] The United States has a specific statistical reporting number for imports of lithium-ion batteries for use in vehicles (HTS 8507.60.0010), but imports under that classification may also include modules and packs.

Figure 4: 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).

[29] Argonne National Laboratory, "BatPaC," June 28, 2018.
[30] HS headings that include six digits, such as this one, are called "HS-6" headings; those with eight digits are "HS-8," etc. Classification for battery components is complex and is described in more detail in the "Trade in Batteries" section below.

Lithium-ion Batteries: Chemistry and Sources of Materials

In addition to lithium, lithium-ion batteries tend to contain aluminum, cobalt, graphite, manganese, and nickel. Based on recent estimates, more than one-half of the cost of a finished lithium-ion battery pack is the cost of these materials.[31] Among the common materials, lithium, graphite, and cobalt face supply constraints, while the other metals do not face similar issues. Aluminum, manganese, and nickel have larger end-use markets outside of lithium-ion batteries.[32]

On average, cobalt made up about 30 percent of a lithium-ion battery cathode in 2017, but experts expect cobalt content to decline as batteries become more energy dense.[33] Cobalt supplies are limited and, moreover, are concentrated in only a few countries. The Democratic Republic of the Congo produced more than one-half of worldwide cobalt mining in 2016, followed by China and Canada with less than 6 percent each.[34] China is also the main source of cobalt refining, which is necessary before the cobalt is suitable for battery production. Due to cobalt's relative scarcity, some predict a 20-percent gap between supply and demand in 2025.[35] Cobalt prices increased by 120 percent in 2017; Benchmark Mineral Intelligence's Caspar Rawles expects prices to rise at a slower pace in 2018–25 as EV manufacturers use long-term supply contracts to stabilize prices.[36]

Graphite is used in the anode of many EVs.[37] Benchmark Mineral Intelligence expects that the market for graphite in battery anodes will increase from 80,000 metric tons in 2015 to 250,000 metric tons in 2020, thereby driving up the price.[38] Graphite prices did not increase as rapidly in 2017 as other inputs in EV batteries, but could rise rapidly in future years.[39] Nearly two-thirds of natural graphite is mined in China.[40]

According to Deutsche Bank, lithium-ion batteries for EVs accounted for 14 percent of lithium demand in 2015 (and demand has risen since then).[41] The bank predicts that EVs will generate 38 percent of lithium demand by 2025.[42] Some have predicted a shortfall of 100,000 metric tons for lithium by 2025.[43] This scarcity could drive up the lithium's price and thus the price of battery packs. From January 2016 to January 2018, the price of lithium carbonate in South

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[31] Argonne National Laboratory, "BatPaC," June 28, 2018. A forthcoming paper by the USITC staff in the Natural Resources and Energy Division of the Office of Industries, on the global value chain for lithium-ion batteries cell materials trade, will examine the resources portion of the battery value chain in greater detail.
[32] Desjardins, "Here Are the Raw Materials We Need," October 27, 2016.
[33] Lex, "Electric Vehicles: Assault with Battery," July 26, 2017.
[34] Bochove, "The Canadian Ghost Town," October 31, 2017.
[35] Bochove, "The Canadian Ghost Town," October 31, 2017.
[36] Barrera, "Cobalt Outlook 2018," December 13, 2017.
[37] For example, the battery anode of the Tesla Model S has 54 kilograms of graphite. Desjardins, "Here Are the Raw Materials We Need," October 27, 2016.
[38] Desjardins, "Here Are the Raw Materials We Need," October 27, 2016.
[39] Shaw, "Graphite Outlook 2018," December 12, 2017.
[40] Desjardins, "Here Are the Raw Materials We Need," October 27, 2016.
[41] Deutsche Bank, *Lithium 101*, May 9, 2016, 23.
[42] Deutsche Bank, *Lithium 101*, May 9, 2016, 23.
[43] Jenkins, "Is This the Future of Lithium Mining?" April 1, 2018.

America (one of the major sources) more than doubled.[44] Chile and Argentina are the top two global exporters of lithium carbonate.[45]

Battery Manufacturing Competition

Several battery manufacturers assemble battery packs for vehicles sold in the United States. More vehicles in the United States were sold with Tesla battery packs installed in them than those of any other battery pack assembler (table 3). While Tesla historically assembled its battery packs using cells from Japan supplied by Panasonic, its new Gigafactory in Nevada has begun producing cells in cooperation with Panasonic for use in Tesla vehicles.[46] LG Chem batteries were the second-most common brand of batteries among vehicles sold in the United States in 2017 (table 3). LG Chem assembles packs in Michigan and South Korea for Ford, General Motors, and Chrysler using Korean or U.S.-made cells, depending on the model.[47] AESC has assembled cells, modules, and packs for the Nissan Leaf and NV200 in Tennessee and Sunderland, England.[48] Samsung SDI produces cells and assembles packs for BMW and Volkswagen at a plant in Hungary.[49] Those packs are then installed in vehicles in Germany. Bosch assembles batteries in Michigan for Fiats produced in Mexico.[50]

Table 3: Battery pack assembly and cell production locations for vehicles sold in the United States

Battery pack manufacturer	Number of battery packs installed in U.S. vehicles, 2017	Pack assembly location	Cell production location
Tesla/Panasonic	50,147	United States	United States and Japan
LG Chem	26,113	United States	United States and South Korea
AESC	11,230	United States[a]	United States
Samsung SDI	9,810	Hungary	South Korea
Bosch (formerly SB LiMotive)	5,380	United States	United States
SK innovation	2,157	South Korea	South Korea

Sources: Ayre, “LG Chem,” February 21, 2017; BMW, “The BMW i3 and All-New BMW i3s” (accessed March 8, 2018); Bosch, “Bosch Is One-stop Supplier,” June 2013; Burke and Silke Carly, “Tesla's Real Capacity Problem?” June 14, 2017; Chevrolet, “Bolt EV” (accessed March 8, 2018); *EV Sales*, “World Top 20,” January 31, 2017; Fiat, “2017 Fiat 500e,” (accessed March 8, 2018); Ford, “2018 Focus Electric” (accessed March 8, 2018); Herron, “Tesla Motors Battery Suppliers,” September 25, 2015; Kia Motors America, “2018 Soul EV” (accessed March 8, 2018); Lee, “Expansion In European Market,” March 30, 2017; McCarthy, “Tesla Dominates,” August 14, 2017; Nissan, “2018 Nissan Leaf” (accessed March 8, 2018); Pfanner and Landers, “Nissan Considers Shift,” July 26, 2015; Reuters, “Samsung SDI, Bosch,” November 7, 2010; Tesla, “Model S” (accessed January 10, 2018); Tesla, “Model S and Model 3 Comparison” (accessed March 8, 2018); Tesla, “Model X, The Best SUV” (accessed March 8, 2018); Volkswagen, “e-Golf: Give the City a Jolt of Energy” (accessed March 8, 2018).

[a] While AESC produces cells and packs in Tennessee and Sutherland, this paper assumes that vehicles produced in Tennessee for the U.S. market use cells and packs produced in Tennessee and not from Sutherland.

[44] Sanderson, “Sale of $5bn Lithium Stake,” February 17, 2018.
[45] IHS Markit, Global Trade Atlas database (accessed July 25, 2018).
[46] Tesla, “Battery Cell Production Begins at the Gigafactory,” January 4, 2017.
[47] Ayre, “LG Chem,” February 21, 2017.
[48] Pfanner and Landers, “Nissan Considers Shift,” July 26, 2015.
[49] Reuters, “Samsung SDI, Bosch,” November 7, 2010.
[50] Reuters, “Samsung SDI, Bosch,” November 7, 2010.

International Trade in Batteries[51]

Because of the lithium-ion battery's complex supply chain, international trade data are a complicated puzzle to understand. Lithium-ion batteries for EVs are categorized in an HS 6-digit subheading (8507.60) that includes lithium-ion batteries for all uses, with separate statistical suffixes for batteries for EVs versus all other uses. But different stages of the lithium-ion battery supply chain seem to be imported under both statistical suffixes, as well as an additional HTS 8-digit subheading (8507.90.80). This section explores the available trade data.

By value, China (not including Hong Kong) reported the highest amount of imported lithium-ion batteries from 2013 to 2017, followed by the United States, Hong Kong, and Germany (table 4). During this period, though, Chinese lithium-ion battery imports declined, possibly owing to increased Chinese lithium-ion battery production. Moreover, 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, with the HTS subheadings don't differentiate on an international level.

Table 4: Imports of lithium-ion batteries by country, 2013–17 (million $)

Importer	2013	2014	2015	2016	2017
China	3,314	3,421	3,298	3,055	3,262
United States	1,673	1,691	1,674	1,954	2,527
Germany	684	988	1,314	1,614	2,244
Hong Kong	1,558	1,501	1,629	1,747	2,078
Japan	653	537	633	748	808
Subtotal	7,882	8,138	8,548	9,118	10,919
Other	3,539	4,712	5,132	6,058	7,254
Total	11,421	12,851	13,680	15,176	18,173

Source: IHS Markit, Global Trade Atlas (HS 8507.60; accessed June 4, 2018).

China also exported the most lithium-ion batteries (and components) of every country during 2013–17 (table 5). China's increased lithium-ion battery exports also suggest increased Chinese production of lithium-ion batteries, implying that the high volume of its imports may be more cells and modules (components) than packs (finished products).

Table 5: Exports of lithium-ion batteries by country, 2013–17 (million $)

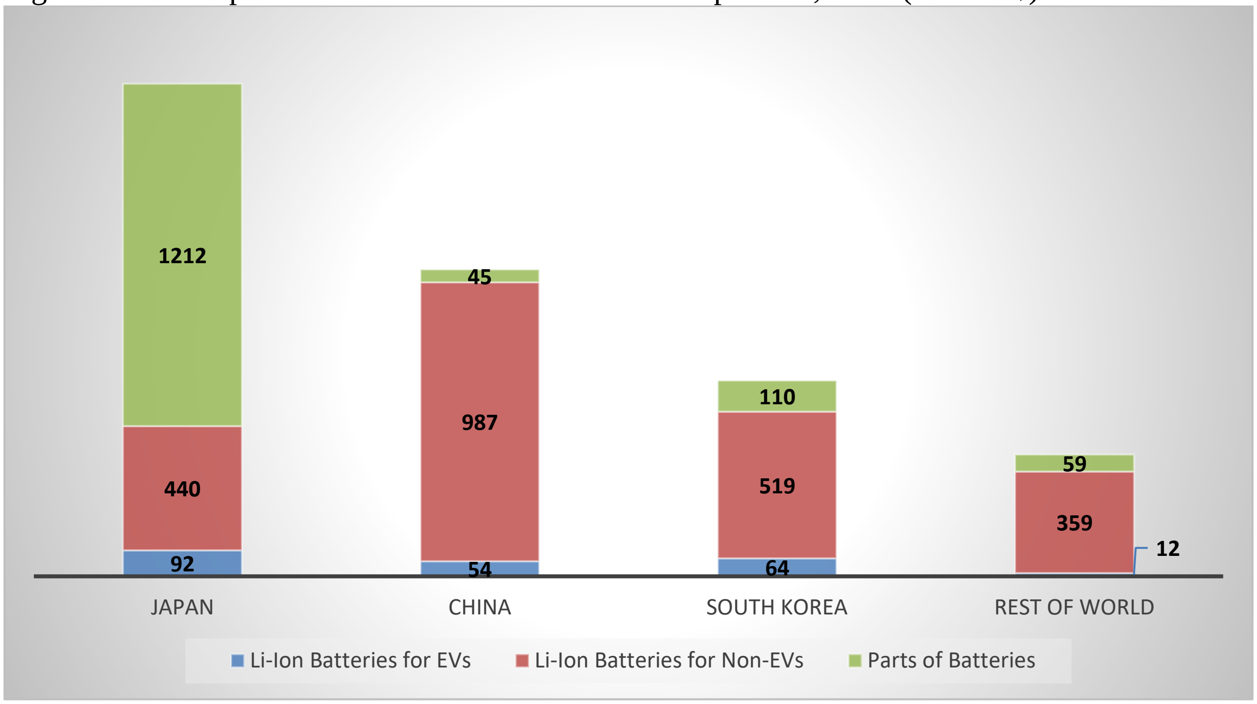
Exporter	2013	2014	2015	2016	2017
China	4,800	5,475	6,494	6,780	7,987
South Korea	2,265	2,268	2,030	2,328	3,518
Japan	2,052	2,032	2,034	2,615	2,572
Hong Kong	1,480	1,394	1,429	1,512	2,174
United States	660	765	797	1,114	1,289
Subtotal	11,257	11,935	12,784	14,348	17,540
Other	1,963	2,344	2,706	3,130	4,400
Total	13,220	14,279	15,490	17,799	21,940

Source: IHS Markit, Global Trade Atlas (HS 8507.60; accessed June 4, 2018).

[51] This section discusses trade in lithium-ion batteries for all uses, because there are no globally harmonized EV battery-specific classifications.

For U.S.-specific trade data, the picture is somewhat clearer. For imports, the HTSUS 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. Since only battery packs are supposed to be classified under 8507.60 as previously discussed, we know that only U.S. imports of EV battery packs should enter under HTS 8507.60.0010. As mentioned above, battery cells and modules enter under HTS 8507.90.8000 (battery parts). Figure 5 reports the leading U.S. import sources for lithium-ion battery components under these three classifications, and the composition of each.

Figure 5: U.S. Imports of lithium-ion batteries and components, 2017 (million $)



Source: USITC, DataWeb (accessed February 13, 2018).
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.

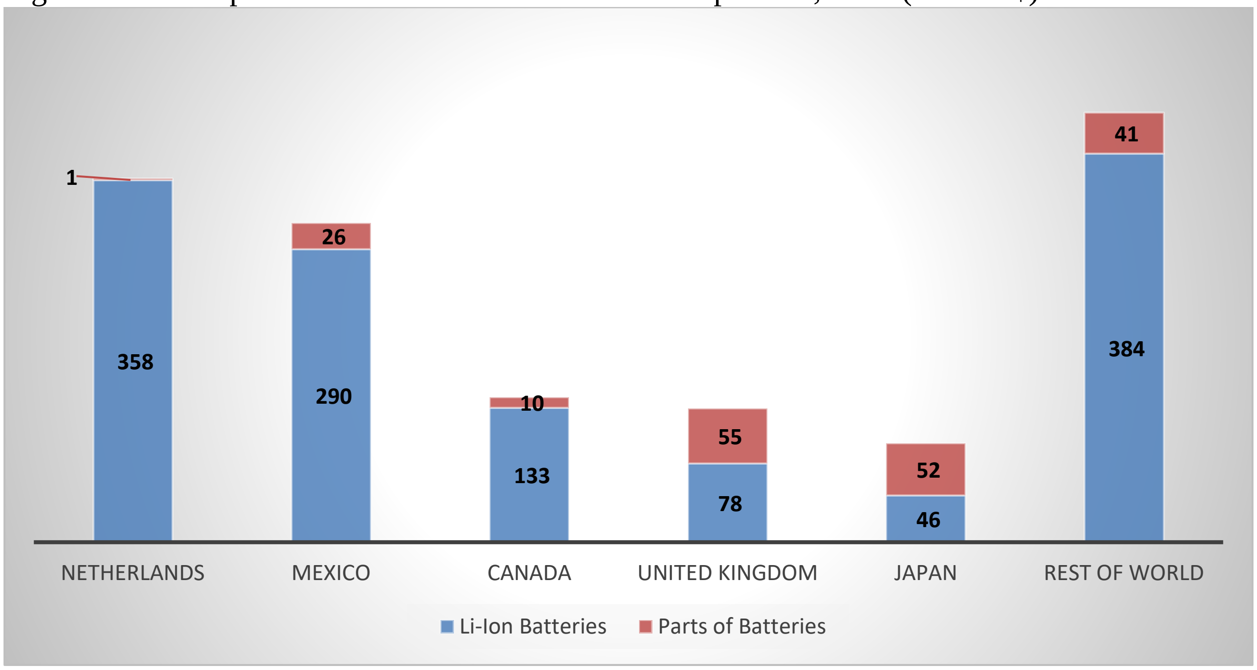
Based on these data, the United States appears to import almost all of its battery parts (some of which are lithium-ion cells and modules) from Japan. It seems to import a high number of lithium-ion battery components not specifically intended for EVs (some of which may be cells and/or modules) from China, South Korea, and Japan, and imports relatively few completed EV battery packs. This supports the table-3 list, which shows that the majority of pack assembly for U.S.-sold EVs occurs in the United States.

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. Tesla likely exports batteries (or modules) to support its EV plant in the Netherlands (opened in 2013), which may be the reason that the Netherlands is the leading destination for U.S. lithium-ion battery exports (figure 6).[52]

[52] Tesla, "Tesla Motors Opens Assembly Plant in Tilburg, Netherlands," August 27, 2013.

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. For the limited battery parts that the United States does export, it is impossible to know what share of these are lithium-ion cells, and what share are parts of batteries for other uses.

Figure 6: U.S. Exports of lithium-ion batteries and components, 2017 (million $)



Source: USITC, DataWeb (accessed February 13, 2018).
Note: HTS 8507.60 denotes lithium-ion batteries and HTS 8507.90.80.00 denotes parts of batteries.

Electric Vehicle Battery Value Chain Estimation

This section estimates the value that has been added at the country level for the manufacture of EV batteries used in EVs sold in the United States. The authors rely on company-specific information, because the trade data do not offer enough specificity, as detailed earlier. Instead, the authors used publicly available company-specific data, as well as estimated values for the two most important stages of EV battery production. The data collected included U.S. 2017 EV sales by model, the size of the battery in the EV, the battery pack assembly location, and the cell manufacturing location (table 6). Combining this information with information on the U.S. dollar cost per kWh in battery packs allowed the authors to estimate battery value-added by country.

Table 6: Data used to estimate value added by country for the manufacture of batteries used in electric vehicles sold in the United States

Vehicle model	2017 unit sales	Battery size	Battery pack assembly	Cell manufacturing	Battery cost per vehicle ($)	Total value added ($)[d]
Tesla Model S	27,060	75.0	United States	Japan	14,250 [a]	6,413
Tesla Model 3	1,772	50.0	United States	United States	9,500 [a]	4,275
Tesla Model X	21,315	75.0	United States	Japan	14,250 [a]	6,413
Ford Focus Electric	1,817	33.5	United States	United States	7,002 [b]	3,151
Chevy Bolt	23,297	60.0	United States	South Korea	12,500 [c]	5,625
Fiat 500e	5,380	24.0	United States	United States	5,016 [b]	2,257
VW e-Golf	3,534	35.8	Hungary	South Korea	7,482 [b]	3,367
BMW i3	6,276	22.0	Hungary	South Korea	4,598 [b]	2,069
Nissan Leaf	11,230	26.0	United States	United States	5,434 [b]	2,445
Kia Soul EV	2,157	27.0	South Korea	South Korea	5,643 [b]	2,539

Sources: Field, "UBS Analyst Dubs Model 3 Unprofitable, Tesla Responds with Battery Pricing," April 27, 2016; Zart, "Batteries Keep Getting Cheaper," December 11, 2017; *EV Sales*, "World Top 20," January 31, 2017; Argonne National Laboratory, "BatPaC," June 28, 2018.

[a] Authors' calculations based on $190 per kWh from reports of the cost for Tesla battery packs.

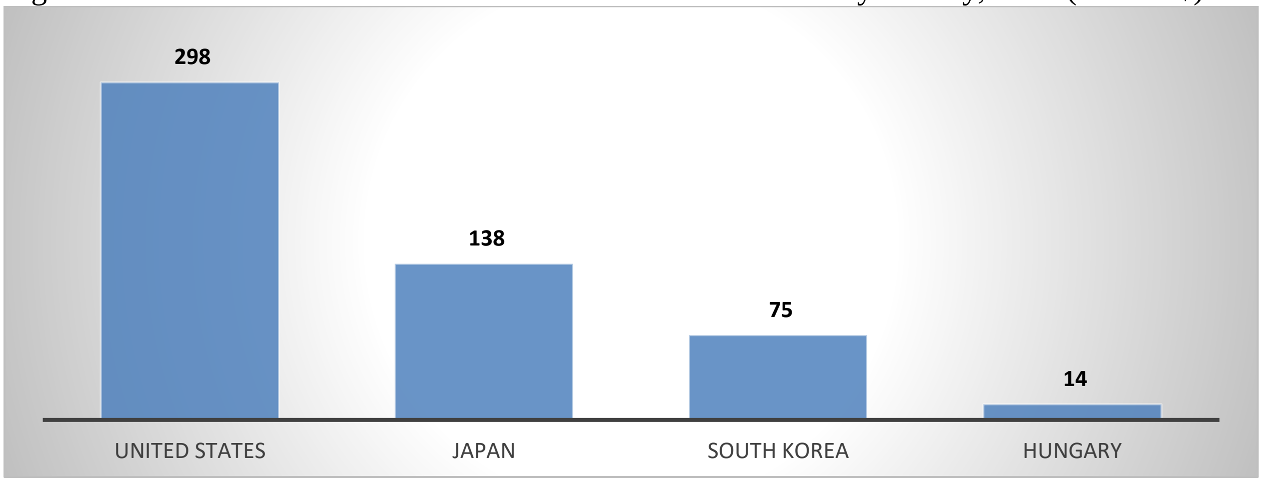
[b] Authors' calculations based on $209 per kWh, which was the average price in 2017 according to a Bloomberg report.

[c] Authors' calculations based on $12,500 for the price of the pack, as reported in a UBS breakdown.

[d] Total value added is the cost of the battery less the cost of materials.

Combining this data with BatPaC cost estimate data from the Argonne National Laboratory, the authors estimate that 57 percent of the total value added[53] of batteries used in EVs sold in the United States originates in the United States (26 percent of total cost, which includes raw materials), followed by Japan (12 percent of value added) (figure 7). Manufacturers assemble 7 of the 10 battery packs in the United States, and of those 7, 4 also use cells manufactured in the United States.

Figure 7: Total value added for batteries in U.S. electric vehicles by country, 2017 (million $)



Source: Authors' estimates based on data from table 1 and table 7 above.
Note: Total value added is the cost of the battery less the cost of materials.

[53] Total value-added is the cost of the battery less the cost of materials.

Conclusions

It is possible that some other battery type that packs more energy per pound will be developed in the future, but until then, lithium-ion batteries will be the most important part of an EV. As EVs take an increasing share of motor vehicle sales, the battery supply chain will become increasingly important. Understanding the supply chain can help businesses and governments understand how trade flows and resources will be affected by increased demand for EVs and thus, their inputs.

China and the United States appear to be the largest suppliers of lithium-ion battery cells in the future, with competition from Japan and South Korea.[54] Moreover, since cells are more easily imported/exported longer distances, they are likely to continue to be internationally traded. Conversely, due to the higher cost of transporting battery packs, international trade in EV battery packs is likely to remain low compared to trade in battery cells. Vehicle manufacturers' decisions about where to produce EVs (and in what quantities) are likely to be the primary determinants in lithium-ion battery module and pack production locations.

Due mostly to the lack of more detailed international trade data for lithium-ion batteries, it is challenging to separate out information from components of the battery supply chain. However, based on the authors' estimates, the United States and Japan appear to provide the most value-added to lithium-ion batteries used in EVs sold in the United States. Much of the estimated U.S. value comes from pack assembly. Based on this research, due to China's high level of sales of domestically produced EVs with domestically produced batteries and cells, China likely accounts for the vast majority of the value added from lithium-ion batteries in Chinese EV sales and is likely the world leader in value added for EV batteries.

[54] Dougher, "Breaking Down the Lithium-ion Cell Manufacturing Supply Chain," April 23, 2018; Sanderson, Hancock, and Lewis, "Electric Cars," March 5, 2017.

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