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Electrifying the Global BEV Landscape: Top Suppliers and Consumers of BEVs and BEV Batteries

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Abstract

This paper analyzes global sales and trade trends for battery electric vehicles (BEVs) and BEV batteries as well as the U.S. BEV battery supply chain. It finds that global BEV sales and trade in BEVs and BEV batteries have grown significantly since 2018, with China leading in BEV sales, production, and battery exports. U.S. sales of BEVs have grown considerably during this period but continue to trail China and the European Union (EU). Production of U.S. BEVs grew faster than U.S. battery production, leading to increased use of imported battery cells in 2022 and 2023. As of 2023, U.S. BEV battery production relies on imports for cathodes, anodes, and other battery components. This paper also includes evidence that a sharp increase in U.S. investment in BEV, BEV battery, and battery component production—due to increased demand and incentives from the Inflation Reduction Act—will likely lead to U.S. content composing a greater share of content in BEVs produced in the United States.

Keywords: automotive, electric vehicles, BEVs, BEV batteries, lithium-ion batteries, international trade, supply chains.

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Introduction

Global battery electric vehicle (BEV)[1] sales have grown rapidly over the past five years and are predicted to increase in the future.[2] With this sales growth come increased demand for BEV batteries and their upstream inputs. Even though China continues to be the largest producer of BEVs, BEV batteries, and BEV battery components, U.S. production along the entire supply chain is increasing rapidly. For instance, U.S. domestic battery production capacity is projected to meet domestic BEV battery demand in the next five years, though imports will continue to contribute a significant (but decreasing) share of upstream inputs.

These rises in U.S. production throughout the BEV supply chain are occurring as a result of both increases in demand (which encourage further localization of the supply chain) and policy support, including the Inflation Reduction Act. Moreover, BEV adoption in other, earlier-adopting countries like Norway, China, and South Korea (as well as historical trends for adoption of new technologies) suggest that BEV adoption in the United States—and worldwide—will continue to accelerate in the coming years.[3]

This paper will examine trade, sales, and production data for BEVs, BEV batteries, and their components to provide a clearer picture of U.S. participation at each stage of the supply chain, its major competitors, and reliance on foreign inputs. It will also detail recent investment trends in North America and the European Union (EU).

BEV Sales and Trade Trends

Global BEV sales increased 483 percent to 9.5 million vehicles from 2018 to 2023, making up more than 10 percent of new vehicles sold (figure 1).[4] Similarly, BEV imports and exports soared by 850 percent and 752 percent, respectively, during the same period.[5] During that time, U.S. BEV exports stagnated while production, sales, and imports increased. The majority of 2023 global BEV sales were in China, accounting for more than 5.7 million (60 percent) BEV, followed by the EU with 2.15 million units and the United States with 1.18 million units (figure 1).

[1] In this paper, BEVs are defined as vehicles that have a battery as the sole source of power and propulsion. Hybrid vehicles are thus not included in the data for vehicle sales, trade, or production discussed below.

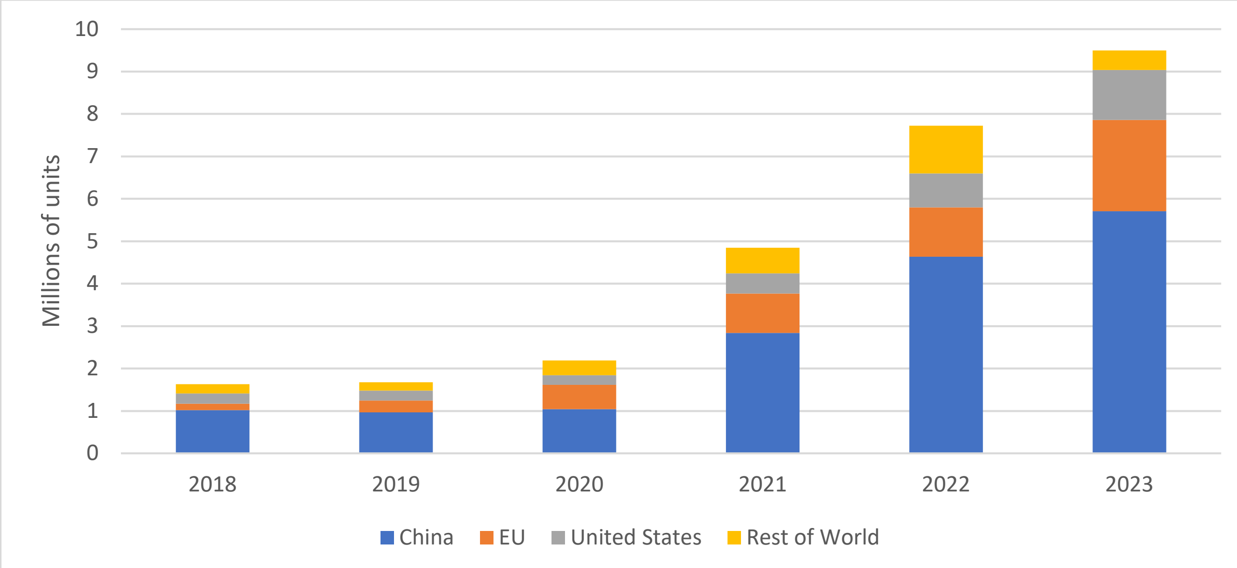
[2] IEA, "Global EV Outlook 2023 – Analysis," April 2023, 8. Spell it out in the bib.

[3] Adoption of new technologies often follows what is referred to as the "S-shaped adoption curve," which posits that 5 percent is the threshold at which early adoption is replaced by mass adoption and the adoption of the technology becomes more standard for consumers. These adoption trends held true for BEV adoption in Norway in 2013, China in 2018, and South Korea in 2022. For more information see Randall, "U.S. Crosses the Electric-Car Tipping Point for Mass Adoption," July 9, 2022.

[4] More than 79 million vehicles (cars, sport utility vehicles, light trucks, and medium/heavy trucks) were sold worldwide in 2022. IEA, Global EV Data Explorer, April 26, 2023; Wards Intelligence, "World Vehicle Sales by Company and Country, 2022," May 1, 2023.

[5] S&P Global, Global Trade Atlas, accessed February 25, 2024. Electric Vehicles are primarily classified in HS subheadings 8703.80 and can also be classified in HS 8701.24, 8702.40, and 8704.60. For more information on imports and exports, see figures 4 and 5 below.

Figure 1 Global BEV sales, by country, in millions of vehicles, 2018–23



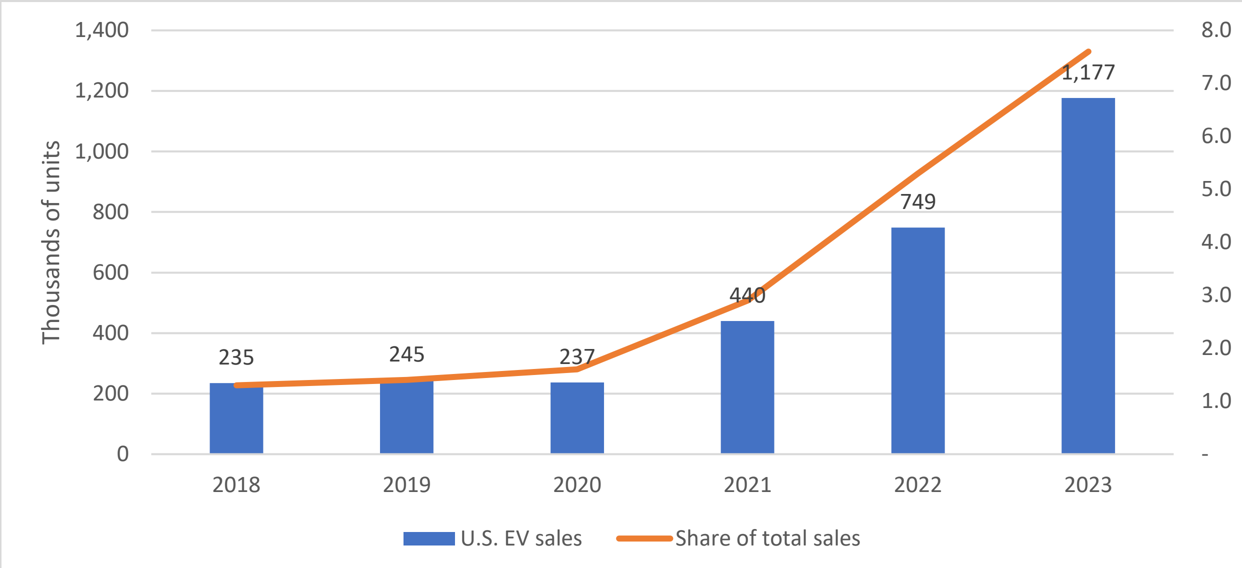
Source: IEA, Global EV Data Explorer, April 26, 2023; Carey, "Global Electric Car Sales Rose 31%," January 11, 2024. Sales data include sales of cars, trucks, buses, and vans.

From 2018 to 2023, U.S. BEV sales increased 391 percent (figure 2). During the first three years, 2018–20, U.S. sales were relatively stagnant, before nearly doubling in 2021 and significantly increasing again in 2022 and 2023. Moreover, U.S. BEV sales surpassed 5 percent of total vehicles sales in 2022, which, as mentioned above, is historically an important milestone for adoption of new technologies. U.S. BEV sales continued to grow in 2023, but at a slower pace than many expected. Some U.S. vehicle manufacturers and battery suppliers responded by slowing BEV production and scaling back battery production plans. For example, GM delayed its production of BEV pickup trucks, while Ford, Rivian, and Lucid lowered their BEV production forecasts.[6] Ford also scaled back planned capacity for a previously announced battery plant in Michigan, while Panasonic announced it would not build a previously announced battery plant in Oklahoma.[7]

[6] Shepardson and Klayman, "GM Delays EV Truck Production at Michigan Plant by Year," October 17, 2023; Shepardson and Gomes, "Ford Cuts F-150 Lightning Production as EV Demand Softens," January 19, 2024; Sriram, Roy, and Sriram, "Rivian, Lucid's 2024 Production Targets Disappoint as EV Demand Wanes," February 22, 2024.

[7] White, "Ford Scales Back Michigan Battery Plant, Restarts Construction," November 21, 2023; Katsumura et al., "Panasonic Says Oklahoma No Longer Candidate for New Battery Plant," December 20, 2023.

Figure 2 U.S. BEV sales, in thousands of vehicles and as a share of total sales, 2018–23



Sources: Wards Intelligence, "U.S. Vehicle Sales by Model, 2018–2022," February 9, 2023; Wards Intelligence, "U.S. Car and Light Truck Sales by Model by Month 2023," January 30, 2024; Wards Intelligence, "% Powertrain Installations," various years.

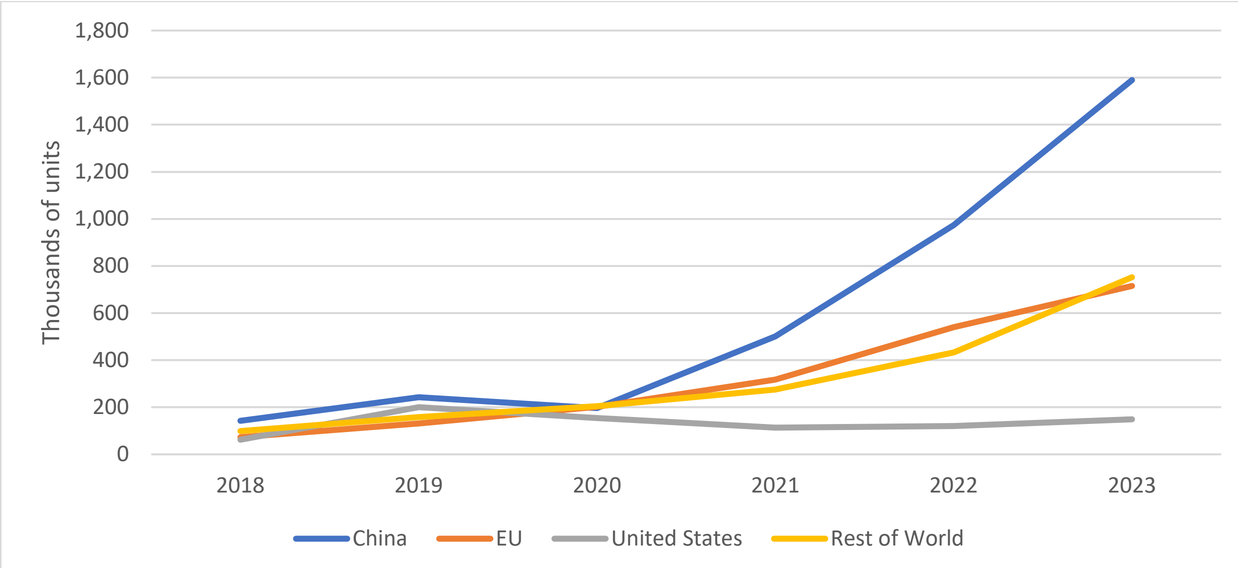
Tesla continues to be the leading seller of U.S. BEVs. Tesla accounted for 61.5 percent (649,700) of U.S. sales in 2023, though its share of the BEV market has declined nearly 27 percentage points since 2018 as BEVs from other vehicle manufacturers have entered the market. In 2023, 54 different models of BEV light vehicles (which includes cars, sport utility vehicles, pickup trucks, and some vans), across 28 different vehicle brands, were sold in the United States.[8] For comparison with a preceding year, only 25 models, representing 19 different brands, were sold in the United States in the fourth quarter of 2021.[9] Additional brands with new BEV models sold in the United States after 2021 include BrightDrop, Cadillac, Genesis, Subaru, and Toyota in 2022, followed by Lexus and Vinfast in 2023.

China was also the world's leading exporter of BEVs, with nearly half (1.6 million vehicles, or 49.6 percent) of all exports in 2023 (figure 3). China's exports of BEVs made up one-third of total Chinese vehicle exports in 2023.[10] It is also worth noting that the top exporter (by brand) from China was not a Chinese manufacturer but Tesla (a U.S. company), making up 39 percent of Chinese BEV exports in the first half of 2023.[11] The EU ranked second in 2023, with 715,128 vehicles exported, while South Korea ranked third with an estimated 360,000 and the United States ranked fourth with 148,692.[12] The United States, however, ranked second in 2019, when it had volumes comparable to China. Since then, U.S. exports declined, while exports from other countries rose significantly. This decline in U.S. exports appears to be entirely caused by declines in exports to two locations—Belgium and China—and is likely

[8] Kelley Blue Book, *Electric Vehicle Sales Report: Q4 2023*, January 9, 2024.
[9] Kelley Blue Book, "Electrified Light-Vehicle Sales Report: Q4 2021," accessed August 18, 2023.
[10] S&P Global, Global Trade Atlas, accessed February 28, 2024.
[11] Mazzocco and Sebastian, "Electric Shock," September 14, 2023.
[12] South Korea's exports are estimated because Global Trade Atlas data lists 700,000 units exported with a unit price of $96. S&P Global, Global Trade Atlas, accessed February 28, 2024.

due (at least in part) to the opening of two Tesla production facilities, one in Shanghai in January 2019 and the other near Berlin in March 2022.[13]

Figure 3 Global BEV exports, by country, in thousands of vehicles, 2018–23



Source: S&P Global, Global Trade Atlas, accessed February 25, 2024. HS subheadings 8701.24, 8702.40, 8703.80, and 8704.60. Note: Two of these subheadings—8701.24 and 8704.60—were established in 2022. Additionally, EU exports include only exports to outside the EU.

The EU is by far the largest importer of BEVs. Even excluding intra-EU trade, the EU imported more than 800,000 BEVs in 2022, more than a quarter of global imports (figure 4). The United States was the 3rd-largest importer, importing almost 400,000 BEVs in 2023. Conversely, China (the world's largest purchaser and exporter of BEVs) was the 15th-largest importer, importing only 30,000 BEVs in 2023.[14] Almost 60 percent of the EU imports from non-EU members in 2023 were from China, and China's top export destination for BEV exports was the EU.[15] Chinese companies have focused on tightening costs and rapidly creating similar new models.[16] Historically, China has produced smaller, short-range BEVs These vehicles are noticeably cheaper than the larger, longer-range vehicles typically in higher demand in the United States, but may not appeal to the U.S. consumer.[17] Some Chinese companies, however, now offer a full range of BEVs in the EU, and others have announced plans to enter the EU market with more premium models.[18] Also, the EU began an anti-subsidy investigation in September 2023 that could

[13] Exports of U.S. BEVs to Belgium plunged from 94,410 vehicles in 2019 to 5,084 in 2022. Similarly, U.S. BEV exports to China dropped from 40,476 to 1,492 during the same period. This is likely explained by the opening of Tesla's Shanghai factory, which began exporting vehicles in December of 2019, including to Europe. For more information, see Sun and Goh, "Tesla to Export China-Made Model 3 Vehicles to Europe," October 19, 2020; Automotive News Europe, "Tesla Drives China EV Export Rebound," June 21, 2022; Zhang, "Tesla Delivers 41,926 Vehicles in China," January 10, 2023.

[14] The United Kingdom is the second-largest importer of BEVs, with 416,000 vehicles imported in 2023.

[15] Mazzocco and Sebastian, "Electric Shock," September 14, 2023.

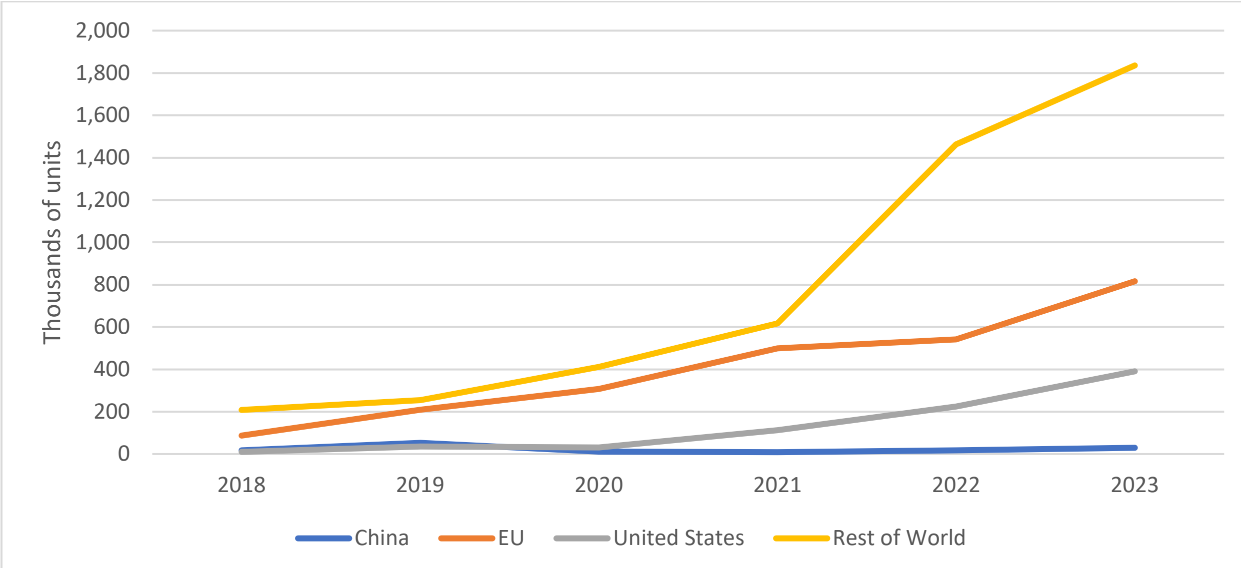
[16] Federal Reserve, "The Coming Cost Crunch," January 18, 2024.

[17] Waldersee, "China's EV Makers Face Cost and Consumer Challenges to Conquer Europe," August 20, 2023.

[18] Westerheide, "BYD Kicks off EV Sales in Italy," June 20, 2023.

result in the imposition of countervailing duties on imports of BEVs from China to counteract Chinese state subsidies for BEVs.[19]

Figure 4 Global BEV imports, by country, in thousands of vehicles, 2018–23



Source: S&P Global, Global Trade Atlas, accessed February 27, 2024. HS subheadings 8701.24, 8702.40, 8703.80, and 8704.60. Note: Two of these subheadings—8701.24 and 8704.60—were newly established in 2022. Additionally, EU imports include only imports from outside the EU.

U.S. imports trailed significantly behind European imports in 2023 but have increased significantly in recent years. U.S. imports totaled more than 390,000 vehicles that year, compared to more than 10,000 vehicles in 2018. The top sources of U.S. imports in 2023 were South Korea (112,000), Germany (83,000), and Mexico (80,000), which together accounted for 70.5 percent of U.S. imports for the year.[20]

BEV Production, Import Share, and Export Share Calculations

Table 1 combines vehicle sales, imports, and exports to estimate production, and calculates import and export shares. These calculations reveal interesting differences in approaches that countries are taking to vehicle electrification. Looking first at import shares, China is an outlier because it imports very few BEVs. Excluding China, however, the United States has the smallest import share of the major vehicle producers worldwide and is relatively in line with Japan. Meanwhile, nearly half the vehicles sold in the EU market were imported from outside the EU in 2022, and South Korea imported nearly as many vehicles as were sold in the country.

[19] Blenkinsop, "EU to Investigate 'flood' of Chinese Electric Cars, Weigh Tariffs," September 13, 2023.

[20] Source: S&P Global, Global Trade Atlas, accessed February 28, 2024. HS subheadings 8701.24, 8702.40, 8703.80, and 8704.60.

Table 1 Sales, imports, exports, and production of major vehicle producers, 2022

Country	Sales	Imports	Import share	Exports	Production	Export share
China	4,632,000	18,200	0.4%	974,266	5,588,066	17.4%
EU	1,167,300	543,659	46.6%	522,866	1,146,507	45.6%
United States	800,000	224,643	28.1%	119,555	694,912	17.2%
Japan	89,020	26,227	29.5%	76,403	139,196	54.9%
South Korea	156,640	140,680	89.8%	239,601	255,561	93.8%
Rest of World	795,850	1,293,272	162.5%	116,039	(381,383)	-30.4%

Source: Author calculations using data from IEA, Global EV Data Explorer, April 26, 2023, and S&P Global, Global Trade Atlas, accessed August 18, 2023. HS subheadings 8701.24, 8702.40, 8703.80, and 8704.60. Production is the sum of sales and exports, minus imports. The import share is the quotient of sales and imports, and the export share is the quotient of exports and production.

Note: U.S. sales in table 1 do not perfectly match those in figure 3 above. This is because the data on U.S. sales at the national level from Wards Intelligence are more disaggregated than the data from IEA Global EV Outlook, which have sales data for additional countries but also include sales of BEV buses and vans. Relatedly, the import share being greater than 100 percent and export share less than zero for the rest of the world is likely because of differences in country-level sales data for some smaller, non-vehicle-producing countries to match to their official trade statistics.

Because BEV production data by country are not readily available, table 1 uses a basic production estimation methodology. The estimates are calculated using a reworking of a basic consumption function (consumption = production + imports − exports). To find production, add sales of vehicles in a country/region, minus that country's imports, plus that country's exports.[21] This method produces an estimate of nearly 5.6 million BEVs produced in China in 2022, which is in line with China's self-reported BEV production, which was 5.47 million BEVs in 2022.[22]

The BEV Battery Supply Chain

As explained in more detail in Coffin and Horowitz (2018), the presence of a battery as the source of propulsion is the main differentiator when comparing BEVs and traditional internal combustion engine vehicles.[23] Lithium-ion batteries help determine vehicle range, which is the main source of competition between BEVs. Batteries are also the most expensive component in a BEV, making up anywhere from 13 percent to 31 percent of the cost of a BEV.[24] A simple representation of the supply chain for a BEV battery is displayed below (figure 5).

[21] This calculation is imperfect but helps provide production estimates for countries where BEV production data are not readily available. This estimation does not consider vehicle inventories. This gap could lead to an overestimation of production in a given year; but over a longer period, it likely corrects itself. Not often used to estimate automotive production (where aggregate data tend to be readily available), similar calculations are used in many other fields.

[22] CAAM, "Production of New Energy Vehicles in December 2022," accessed August 18, 2023.

[23] Lithium-ion batteries are the only batteries currently used in BEVs, but other battery formulations will likely be used in future vehicles. Coffin and Horowitz, "The Supply Chain for Electric Vehicle Batteries," December 2018, 3.

[24] The average BEV is priced at $61,488. Assuming that 80 percent of that price is the production cost ($49,190) and the BEV has a 60-kWh battery (the global average), the battery likely costs a bit more than $9,000, or 18.6 percent of the cost of the vehicle. Ewing, "Electric Vehicles Could Match Gasoline Cars on Price This Year," February 10, 2023; USDOE, Vehicle Technology Office, "Electric Vehicle Battery Pack Costs in 2022," January 9, 2023; Venditti, "Visualized," October 15, 2023.

Figure 5 Traditional BEV battery supply chain

Source: Author created.
Note: Some manufacturers, in the steps above, use "cell to pack" and omit the modules step. Future vehicles may use "cell to chassis", which omits separate modules or packs, and integrates the cells directly into the chassis of a vehicle.

The starting point of the battery supply chain is typically a combination of new and recycled minerals that are refined and used in the production of battery cells. Battery cells have four major parts: an anode, a cathode, the electrolyte, and a separator, all packaged in a can or pouch. Several of the minerals that are important in the production of a lithium-ion battery are often referred to as "critical minerals." (See box A for additional information on battery critical minerals.) Lithium-ion battery cells are typically then attached via terminals to form a battery module; multiple modules form a battery pack, which is then used to power a BEV.[25]

[25] For more information on the various intermediate components in a BEV battery and their uses, see Coffin and Horowitz, "The Supply Chain for Electric Vehicle Batteries," December 2018, 5–9.

Box A Lithium-Ion Battery Critical Materials

The cathode is the most expensive part of the lithium-ion battery cell and contains different critical minerals, depending on its formulation. Most critical materials (e.g., lithium, nickel, and cobalt) are used in cathode production.[a] The four most-used cathode formulations in BEVs are nickel-cobalt-aluminum (NCA), nickel-manganese-cobalt (NMC), lithium-iron-phosphate (LFP), and nickel-cobalt-manganese-aluminum (NCMA).[b] Anodes historically have been made of graphite but are increasingly made of a graphite-silicon composite.[c]

The United States is not a major producer, processor, or refiner of most of these critical materials (table A). It has significant lithium resources that are being developed but will primarily rely on imported minerals to produce battery materials as battery material production comes online.[d] The United States may increase its critical mineral processing ability but most processing will likely occur in other countries.[e] China is a major processor of nearly every critical mineral and does some mining, as well.[f]

Table A Critical materials in lithium-ion batteries

NMC = nickel-manganese-cobalt; NMCA = nickel-manganese-cobalt-aluminum; NCA = nickel-cobalt-aluminum.

Mineral	Battery use	Major sources for mining	Major sources for processing
Lithium	Cathode, electrolyte	Australia, Chile, China, Argentina	China and United States
Nickel	NMC, NMCA, and NCA cathodes	Indonesia, Philippines, Russia	Australia, China, Japan, South Korea
Cobalt	NMC, NMCA, and NCA cathodes	Democratic Republic of the Congo, Cuba, Russia, Australia	China
Graphite	Anode	China, Brazil, India, United States (artificial graphite)	China, Japan, South Korea, United States, Western Europe

Sources: Scott and Ireland, "Lithium-ion Battery Materials," June 2020, 8; LaRocca, "Lithium in Lithium-Ion Batteries for Electric Vehicles," July 2020; Tsuji, "Graphite in Lithium-Ion Batteries," May 2022.

[a] Scott and Ireland, "Lithium-Ion Battery Materials," June 2020, 8.
[b] Although manganese is important in lithium-ion batteries, it is not included in the U.S. Department of Energy's critical materials for energy list and not expected to be in short supply through 2035. USDOE, "What Are Critical Materials and Critical Minerals?," accessed February 26, 2024.
[c] Tsuji, "Graphite in Lithium-Ion Batteries," May 2022, 2; Silva, "Graphite's Hold on Battery Anodes to Be Challenged by Silicon," June 16, 2023.
[d] Tracy, "Critical Minerals in Electric Vehicle Batteries," August 29, 2022, ES.
[e] Scott and Ireland, "Lithium-Ion Battery Materials," June 2020, 9–10.
[f] Dempsey, et al., "Rival Battery Technologies Race to Dominate Electric Car Market," August 14, 2023.

BEV Battery Trends

BEV production capacity is measured in units. EV battery production capacity is measured in GWh of aggregate storage capacity to provide a measure that is comparable across all EV battery plants. EV battery production capacity is typically described using gigawatt hours or GWh (1 GWh is equal to 1 million kWh). Most EVs sold in the United States have battery packs with capacities ranging from 60 to 100 kWh.

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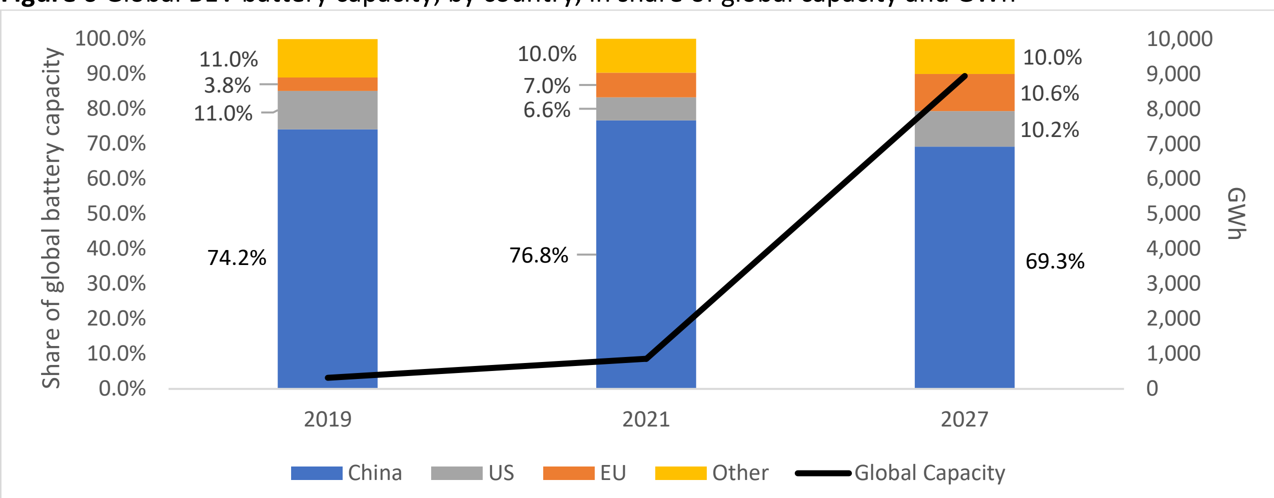
BEV battery demand has skyrocketed in recent years, with BEV sales and battery sizes increasing. Global demand for BEV batteries in 2021 totaled 340 gigawatt-hours (GWh), which was more than double the demand in 2020.[26] Demand in 2022 increased by 62 percent, to 550 GWh.[27] BEV battery demand is projected to reach as high as 1,000 GWh by 2025 and nearly 2,500 GWh by 2030.[28] The rapid rise in BEV battery demand has encouraged greater geographic distribution of battery production and usage of a greater variety of battery chemistries. Trade has increased to meet demand in locations that lack sufficient domestic production, and investment to meet future demand has also increased.

Production Capacity

The majority of BEV battery production capacity is in China, and China's share of global battery production has been relatively stable for multiple years. China's share, however, is expected to decline in future years as global capacity rapidly increases (figure 6). From 2019 to 2021, China's share of global production capacity increased from 74 percent to nearly 77 percent and the U.S. share shrank from 11 percent to 6.6 percent.[29] By 2027, however, production capacity increases outside China are predicted to outpace those within China, leading to a decline in the Chinese share to 69 percent (though a significant share of production outside China would be by Chinese companies).[30]

Figure 6 Global BEV battery capacity, by country, in share of global capacity and GWh



Sources: BloombergNEF, Battery Manufacturing, May 30, 2019; IEA, "Global Supply Chains of EV Batteries," July 2022, 33; Bhutada, "Visualizing China's Dominance in Battery Manufacturing (2022–2027P)," January 19, 2023.
Note: The 2027 estimate does not include announcements made after January 2023. Therefore, the impact of the Inflation Reduction Act (IRA) on U.S. BEV battery production capacity expansion may not be fully shown in the 2027 estimate, which is based on mostly pre-IRA data.

[26] For example, the Ford F-150 Lightning offers a 98-kilowatt hour (kWh) battery and a 131-kWh battery with a range of 240 miles and 320 miles, respectively.
[27] IEA, "Global Supply Chains of EV Batteries – Analysis," July 2022, 11; IEA, "Global EV Outlook 2023 – Analysis," April 2023, 11.
[28] FCAB, "National Blueprint for Lithium Batteries," June 7, 2021, 12.
[29] BloombergNEF, Battery Manufacturing, May 2019; IEA, "Global Supply Chains of EV Batteries – Analysis," July 2022, 33; Bhutada, "Visualizing China's Dominance in Battery Manufacturing (2022–2027P)," January 19, 2023.
[30] Bhutada, "Visualizing China's Dominance in Battery Manufacturing (2022–2027P)," January 19, 2023.

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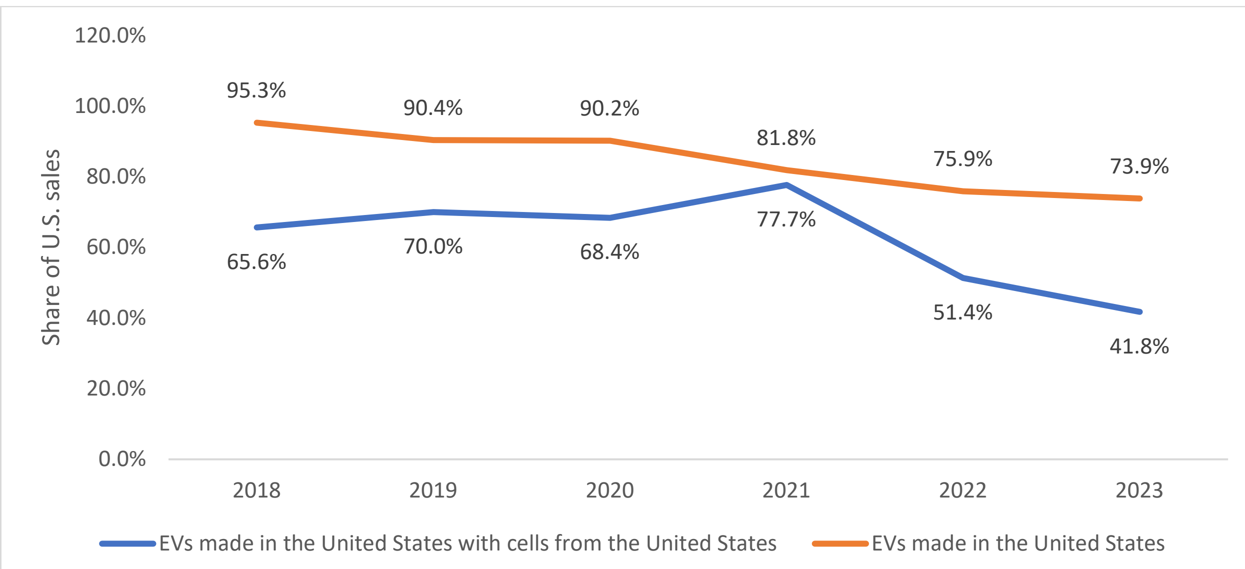
In 2023, the majority of BEVs sold in the United States used cells produced outside the United States (58 percent of BEVs sold in the United States used non-U.S. cells, figure 7). Two factors that drove this use of non-U.S. cells were the lack of BEV production in the United States (resulting in imported BEVs, as discussed above) and the lack of U.S. battery production capacity. Both factors increased reliance on imported battery cells. Production capacity for BEV batteries in the United States in 2022 and 2023 was not sufficient to meet demand. For U.S. BEV production, this significantly increased the share using batteries containing cells imported from Asia or Europe. For example, Tesla began importing lithium-iron-phosphate (LFP) cells from China for its Model 3 and Model Y in 2022, and VW imported cells from Europe for its ID.4 production in the United States.[31]

This capacity shortage may be only temporary. Projected U.S. production capacity in 2027 would be enough to produce 9 million 100-kilowatt-hour (kWh) batteries, or 15 million BEVs with 60-kWh batteries (the average size of a BEV battery in 2022).[32] Full capacity utilization in 2027 may not be possible for new BEV battery plants, but the new BEV battery plants will likely be able to reach full capacity utilization after a few years of production.[33]

Figure 7 Estimated share of BEVs sold in the United States that were produced in the United States and share of BEVs sold in the United States that used cells manufactured in the United States, 2018–23



Source: Wards Intelligence, "U.S. Vehicle Sales by Model, 2018–2022," February 9, 2023; Wards Intelligence, "U.S. Car and Light Truck Sales by Model by Month 2023," January 30, 2024; Wards Intelligence, "% Powertrain Installations," various years; and various sources for vehicle production, battery assembly, and cell production locations.
Note: For each BEV sold in the United States, authors determined the location of vehicle production, battery assembly, and cell production, as well as cell manufacturer. Next, the authors used vehicle sales data from Wards Intelligence to compute the share of BEVs sold in the United States that were produced in the United States and the share of BEVs sold in the United States that used cells manufactured in the United States.

[31] Kim, "LG Energy to Double," July 22, 2022.

[32] IEA, "Global EV Outlook 2023 – Analysis," April 2023, 26.

[33] Fleischmann, Herring, and Linder, "Unlocking Growth in Battery Cell Manufacturing for Electric Vehicles," October 25, 2021.

The diversification of BEV battery production has been driven by increased U.S., Canadian, and EU BEV production and production incentives. Because of the size and weight of BEV batteries, BEV battery packs tend to be assembled near the BEV production location. Cells are easier to transport but also tend to be produced as close to the BEV production location as possible. For example, for BEVs sold in the United States, all battery packs were assembled on the same continent (and usually the same country) as the vehicle.[34] Also, more than 70 percent of BEVs sold in the United States from 2018 to 2023 used cells produced on the same continent as the vehicle was assembled.[35]

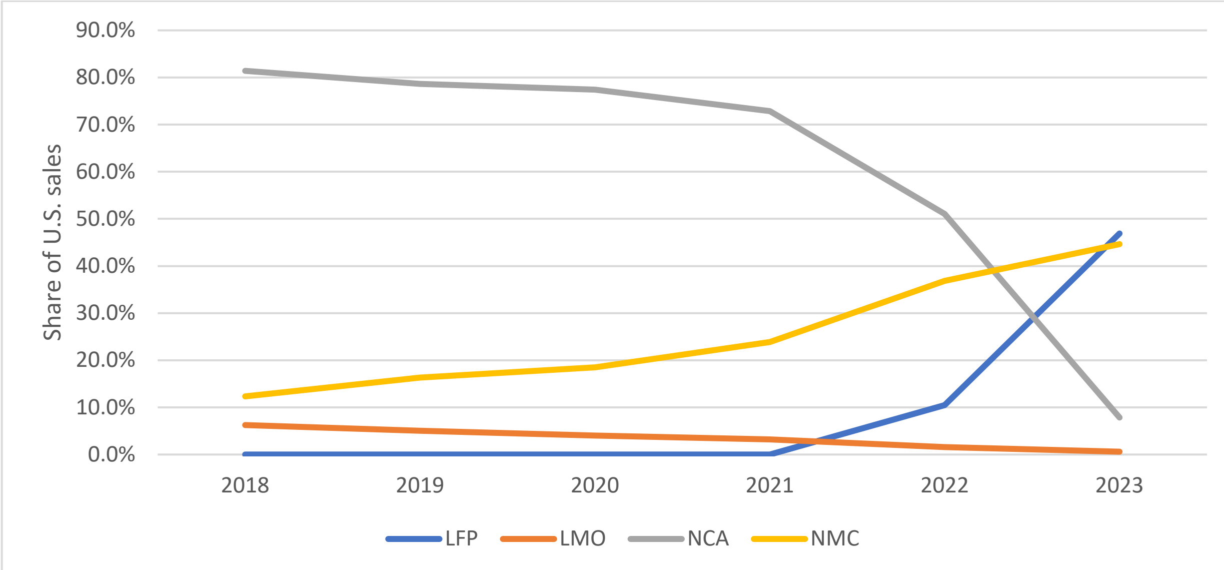
Battery Chemistry

Globally, nickel-manganese-cobalt (NMC) formulations made up 60 percent of BEV batteries in 2022, followed by lithium-iron-phosphate (LFP) formulations (30 percent) and nickel-cobalt-aluminum (NCA) formulations (8 percent).[36] Batteries with LFP cathodes had a 30 percent market share in 2022, which was its highest ever.[37] Roughly 95 percent of LFP batteries were in BEVs produced in China.[38] LFP batteries are generally less energy dense and thus heavier than NMC or NCA batteries, but LFP batteries tend to be significantly cheaper and do not contain nickel or cobalt.[39] Batteries with LFP cathodes also lose more power in the cold than other batteries and are less effective for towing.[40] But LFP batteries are also safer, have a longer life cycle, and charge faster.[41]

From 2018 to 2023, most U.S. BEV sales were of Tesla BEVs (64 percent), and more than two-thirds of those had NCA batteries (44 percent of U.S. BEV sales). Through 2022, almost all other BEVs sold in the United States had NMC batteries (figure 8). Until 2022, no U.S. BEVs had LFP batteries. In 2022, Tesla announced that its base Model 3 and Model Y would have LFP batteries.[42] That same year, Rivian announced it was developing LFP battery packs.[43] Ford also announced that it would begin using LFP batteries in 2023.[44]

[34] Wards Intelligence, "U.S. Vehicle Sales by Model, 2018–2022," February 9, 2023; "% Powertrain Installations on U.S. Cars and Lt. Trucks, '22 Model Year: Wards Intelligence," accessed September 18, 2023. See note after figure 7 for more detail.
[35] Wards Intelligence, "U.S. Vehicle Sales by Model, 2018–2022," February 9, 2023; "% Powertrain Installations on U.S. Cars and Lt. Trucks, '22 Model Year: Wards Intelligence," accessed September 18, 2023. See note after figure 7 for more detail.
[36] IEA, "Global EV Outlook 2023 – Analysis," April 2023, 11.
[37] IEA, "Global EV Outlook 2023 – Analysis," April 2023, 11.
[38] IEA, "Global EV Outlook 2023 – Analysis," April 2023, 11.
[39] Dreibelbis, "Carmakers Are Switching to Cheaper EV Batteries," February 21, 2023; Lienert, "Lithium Iron Phosphate Narrows the Gap," June 22, 2023.
[40] Dreibelbis, "Carmakers Are Switching to Cheaper EV Batteries," February 21, 2023.
[41] Dreibelbis, "Carmakers Are Switching to Cheaper EV Batteries," February 21, 2023; RELiON, "How Are LiFePO4 Batteries Safer than Other Lithium Batteries?," accessed March 14, 2024.
[42] Dreibelbis, "Carmakers Are Switching to Cheaper EV Batteries," February 21, 2023.
[43] Rivian, "Q4 2021 Shareholder Letter," March 10, 2022; Kolodny, "Rivian Will Follow Tesla," March 10, 2022.
[44] Ford, "Ford Taps Michigan for New LFP Battery Plant," February 13, 2023.

Figure 8 U.S. BEV sales, by battery chemistry, in share of U.S. BEV sales, 2018–23
LFP= lithium-iron-phosphate; LMO= lithium-manganese oxide; NCA = nickel-cobalt-aluminum; NMC = nickel-manganese-cobalt



Source: Wards Intelligence, "U.S. Vehicle Sales by Model, 2018–2022," February 9, 2023; Wards Intelligence, "U.S. Car and Light Truck Sales by Model by Month 2023," January 30, 2024; Wards Intelligence, "% Powertrain Installations," various years.
Note: For each BEV sold in the United States, authors determined the location of vehicle production, battery assembly, and the cell production, as well as cell manufacturer and cathode type.

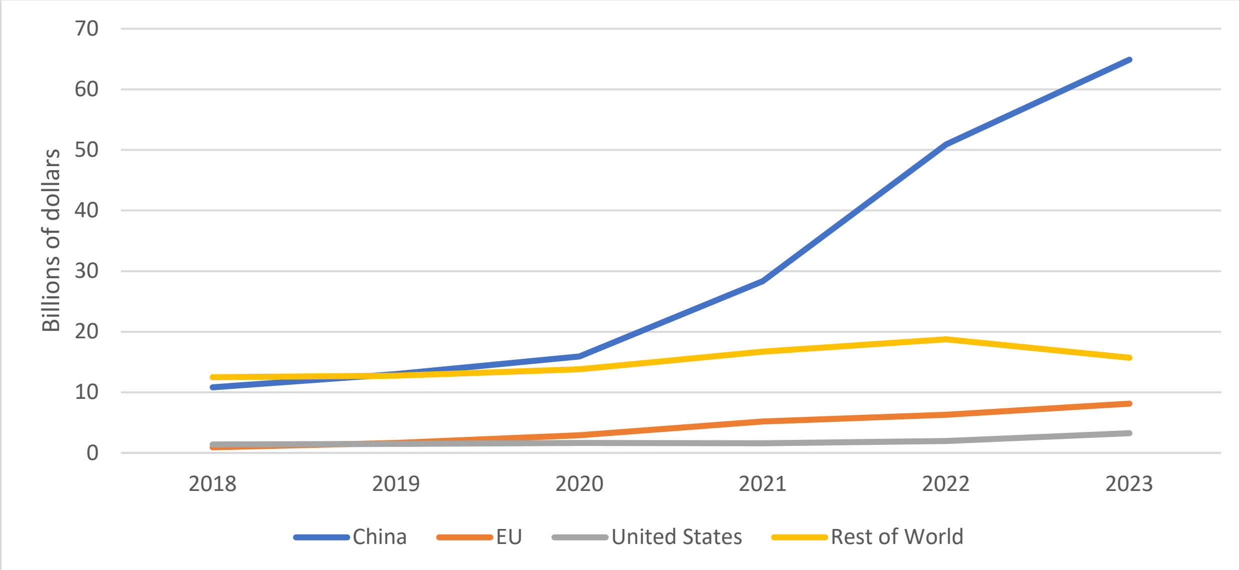
Trade

Increased demand for BEV batteries has led to significant increases in trade of BEV batteries and their components. The United States is a leading importer of BEV batteries but not a significant exporter. Imports of BEV battery components in the United States have also increased significantly to supply domestic BEV battery production.[45]

Global exports of lithium-ion batteries passed $100 billion for the first time in 2022, with Chinese and EU exports making up just under 80 percent by value, if intra-EU trade—which totaled more than $23 billion—is included. Excluding intra-EU trade, global exports topped $90 billion in 2023, with Chinese exports making up more than 70 percent (figure 9). U.S. lithium-ion battery exports totaled $3.25 billion in 2023, ranking fifth.[46]

[45] USITC/Census, DataWeb (accessed February 25, 2024). HTS subheadings 2504.10.00, 2827.39.90, 2833.29.51, 7501.20.00, 7607.20.50, and 8105.20.60. HTS statistical reporting numbers 2530.90.8050, 2805.19.9000, 2820.10.0000, 2825.20.00, 2826.19.0000, 2842.90.9000, 3801.10.5000, 3801.20.0000, 3824.90.3900, 3824.99.9297, 3919.10.2055, 7616.99.5190, 8111.00.4910, and 8507.90.8000.
[46] S&P Global, Global Trade Atlas, accessed June 28, 2023. In addition to China and the EU, the other exporters with more exports than the United States are South Korea, Hong Kong, and Japan.

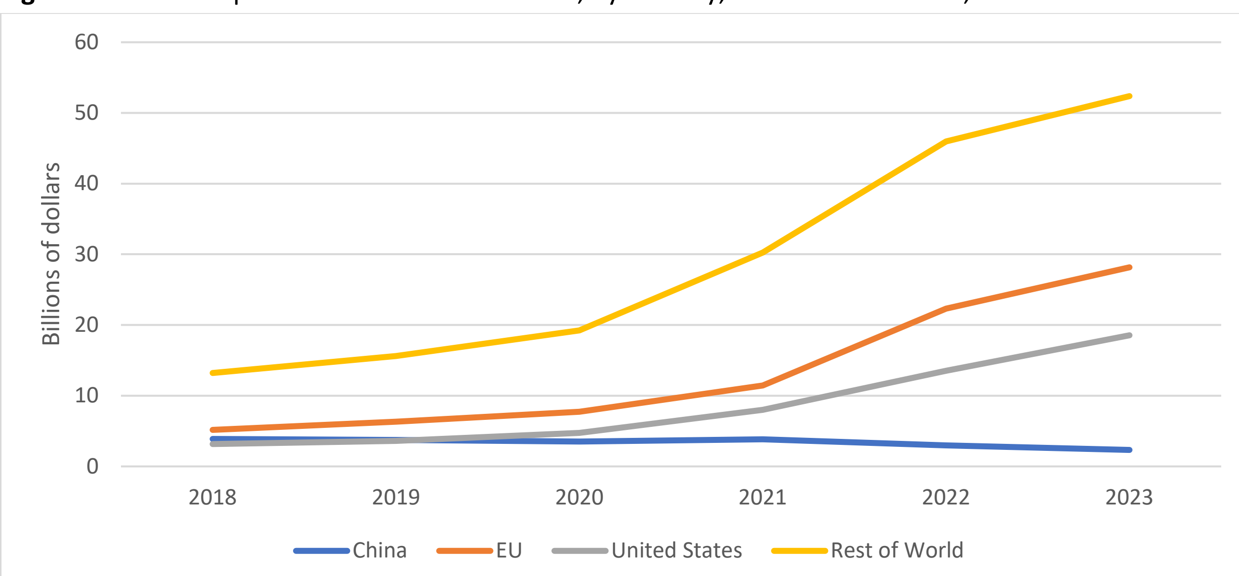
Figure 9 Global exports of lithium-ion batteries, by country, in billions of dollars, 2018–23



Source: S&P Global, Global Trade Atlas, accessed February 25, 2024. HS subheading 8507.60.
Note: EU exports include only exports to outside the EU.

From 2018 to 2023, the EU was the largest importer of lithium-ion batteries (figure 10). This was due to a shortage in EU battery production capacity relative to BEV production, leading to imports of battery cells from China and South Korea. During that same time, U.S. lithium-ion battery imports increased from $3.2 billion to $18.5 billion (486 percent). At the same time, global imports of lithium-ion batteries in other markets increased by $39 billion (296 percent).

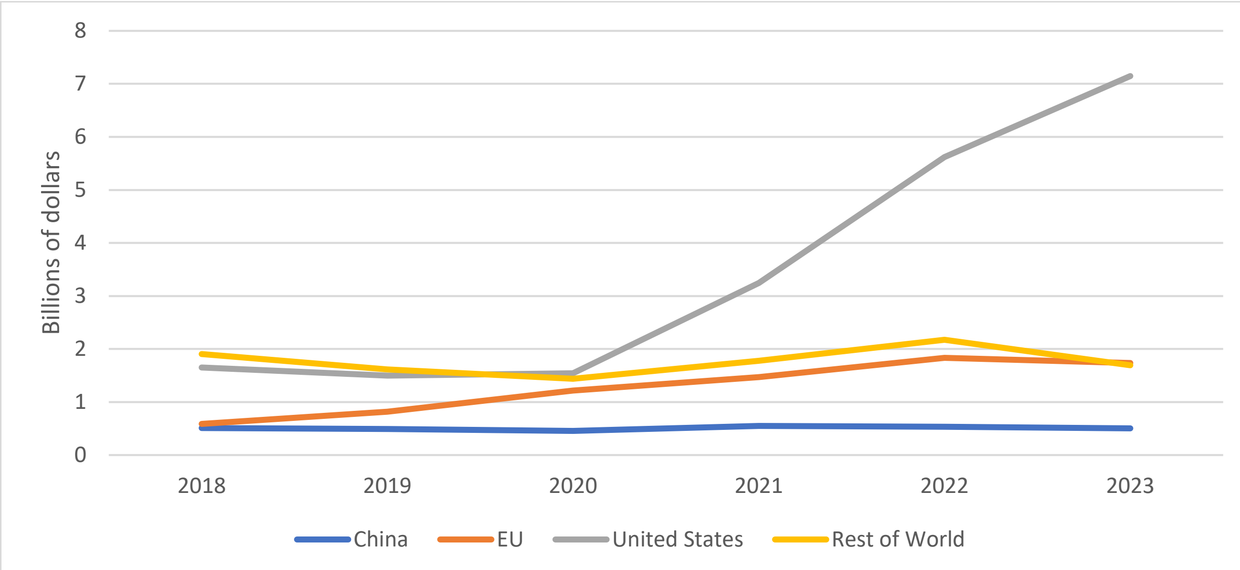
Figure 10 Global imports of lithium-ion batteries, by country, in billions of dollars, 2018–23



Source: S&P Global, Global Trade Atlas, accessed February 25, 2024. HS subheading 8507.60.
Note: EU imports include only imports from outside the EU.

The United States is the largest importer of lithium-ion battery parts, and its imports grew rapidly from 2018 to 2023 (figure 11). This rapid increase is due to increased demand for battery cells, as discussed earlier in this paper. Major sources of U.S. imports include China, South Korea, and Japan.

Figure 11 Global imports of lithium-ion battery parts, by country, in billions of dollars, 2018–23



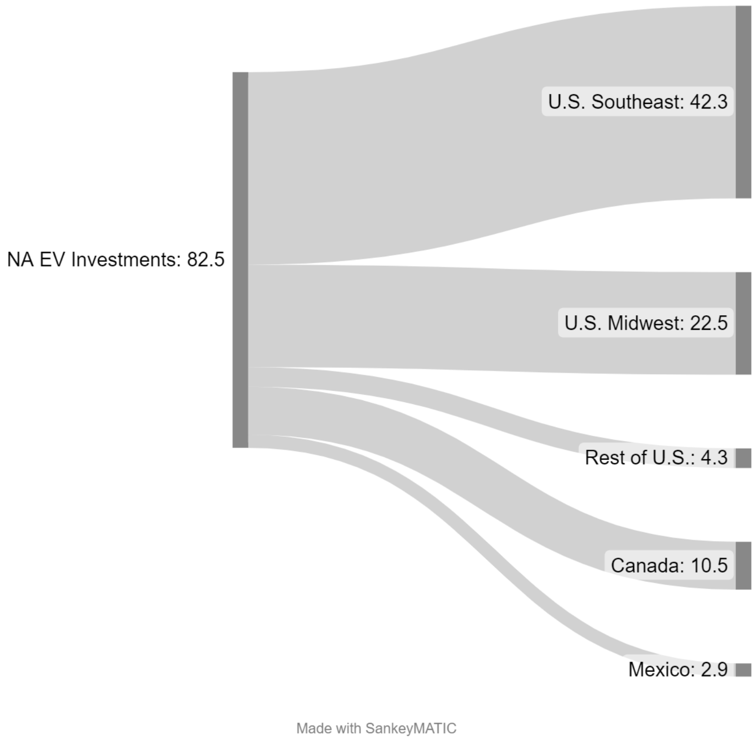
Source: S&P Global, Global Trade Atlas, accessed February 25, 2024. HS subheading 8507.90.
Note: EU imports include only imports from outside the EU.

Investment and Incentives

North American investment in new or retrofitted BEV assembly plants, BEV battery plants, and the BEV supply chain quadrupled from 2020 to 2021, with most of the investment going into the United States. In 2021 and 2022, BEV and BEV battery investments made up most U.S. automotive investments.[47] Ford, GM, and Hyundai announced BEV and BEV battery–related investments totaling more than $10 billion each during this period.[48] North American BEV and BEV battery investments were concentrated in the Southeastern and Midwestern United States, making up $64.7 billion (79 percent) during 2018–22 (figure 12).[49] These two regions produced 62 percent of North American light vehicles during this period. Canada received multiple investments related to cathode production, making up most of their BEV and BEV–battery related investment.[50] Investment in the rest of United States primarily came from start-up companies.[51]

[47] CAR, “Automotive Communities Partnership,” February 2023.
[48] CAR, “Automotive Communities Partnership,” February 2023.
[49] CAR, “Automotive Communities Partnership,” February 2023.
[50] Wards Intelligence, “North America Vehicle Production by State and Plant, 2018–2022,” March 21, 2023.
[51] CAR, “Automotive Communities Partnership,” February 2023.

Figure 12 North American BEV and BEV battery investments, by region, in billions of dollars, 2018–22



Source: CAR, "Automotive Communities Partnership," February 2023.
Note: The U.S. Southeast is composed of AL, FL, GA, KY, MS, NC, SC, TN, and WV. The U.S. Midwest is composed of IL, IN, KS, MI, MO, and OH.

The United States has significant battery production incentives that will drive even more investment. The United States passed the Inflation Reduction Act (IRA) in August 2022.[52] The IRA includes incentives for new and used BEV purchases and leases, as well as the production of BEV batteries and their inputs (table 2). Along with increased U.S. BEV demand, the IRA is one of the key drivers of BEV and BEV battery supply chain investment in North America.[53] Mexican and Canadian production of BEVs, BEV components, and critical minerals all contribute to qualification under the $7,500 consumer incentive.[54] The IRA includes a $35 per kWh incentive for U.S. battery cell production and $10 per kWh incentive for U.S. module production.[55]

According to BloombergNEF, the average BEV battery cost $151 per kWh to produce in 2022, making the IRA's production incentive almost 30 percent of the cost to produce a battery that year.[56] The average BEV battery cost in 2023 declined to $139 per kWh, increasing the value of the IRA's production incentive for batteries and modules to more than 32 percent of the cost to produce a battery.[57] If costs

[52] Inflation Reduction Act of 2022, Pub. L. No. 117-169, https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf.
[53] Environmental Defense Fund, *U.S. Electric Vehicle Manufacturing Investments and Jobs*, August 2023.
[54] Inflation Reduction Act of 2022, Pub. L. No. 117-169 § 13401 (codified at 26 U.S.C. 30D)
[55] Inflation Reduction Act of 2022, Pub. L. No. 117-169 § 13502 (codified at 26 U.S.C. 45X)
[56] BloombergNEF, "Lithium-Ion Battery Pack Prices Rise for First Time to an Average of $151/KWh," December 6, 2022.
[57] BloombergNEF, "Lithium-Ion Battery Pack Prices Hit Record Low of $139/KWh," November 26, 2023.

continue to decline, the incentive's share of battery costs in the United States will increase further. Many state and local governments have additional incentives.[58] In response to U.S. incentives, the EU and Canada also rolled out battery production incentives.[59]

Table 2 IRA incentives for "clean vehicles" (BEV/PHEV/FCEVs) and their supply chain (most phase out in 2032)
BEV = battery-electric vehicle; PHEV = Plug-in hybrid electric vehicle; FCEV =fuel cell electric vehicle

Type of incentive	Value	Requirements
Consumer purchase of new clean vehicle	Up to $7,500	• Final assembly of clean vehicle occurs in North America. • Clean vehicle manufacturer's suggested retail price is below cap ($55,000 for cars and $80,000 for pickup trucks, sport utility vehicles, and vans). • $3,750 if clean vehicle meets critical mineral requirements. • $3,750 if clean vehicle meets component requirements. • No inputs from "foreign entit[ies] of concern" (see below for proposed definition) • Buyer meets annual income requirements (less than $150,000 for individuals, $225,000 for head of household, or $300,000 for couples filing jointly).
Purchase of used clean vehicle	Up to $4,000 or 30% of sales price	• Buyer meets income requirements (less than $75,000 for individuals, $112,500 for heads of households, $150,000 for couples). • Clean vehicle has not previously been included in qualifying used clean vehicle purchase. • Price <$25,000.
Lease of new clean vehicle	Up to $7,500	• Clean vehicle price below cap. • No assembly location, critical mineral, or component requirements.
Clean vehicle battery production	$45 per kWh	• Production in United States. • $35 per kWh for cell production. • $10 per kWh for module production. • $45 per kWh if for module production that does not use cells.
Battery cell components	10 percent of costs	• Production in United States. • Includes electrode active materials (cathode electrode materials, anode electrode materials, and materials that contribute to the electrochemical process). • *Proposed:* Does not include battery management systems, cell containments, gas release valves, and other battery parts.

[58] See for example, Colorado Energy Office, "Electric Vehicle Tax Credits," accessed November 20, 2023; California Air Resources Board, "Incentive Search | DriveClean," accessed November 20, 2023; Pennsylvania Department of Environmental Protection, "Alternative Fuel Vehicle Rebates for Consumers," accessed November 20, 2023.
[59] Inagaki, Chazan, and Fleming, "A Global Subsidy War?," July 13, 2023; Dentons, "Canadian batteries and EVs," February 14, 2024.

Type of incentive	Value	Requirements
		• A taxpayer may only claim one credit under this rule, even if material qualifies as both an electrode active material and a critical mineral.
Critical minerals	10 percent of production costs	• Production in United States. • Includes aluminum, antimony, arsenic, barite, beryllium, bismuth, cerium, cesium, chromium, cobalt, dysprosium, erbium, europium, fluorspar, gadolinium, gallium, germanium, graphite, hafnium, holmium, indium, iridium, lanthanum, lithium, lutetium, magnesium, manganese, neodymium, nickel, niobium, palladium, platinum, praseodymium, rhodium, rubidium, ruthenium, samarium, scandium, tantalum, tellurium, terbium, thulium, tin, titanium, tungsten, vanadium, ytterbium, yttrium, zinc, and zirconium.

Sources: Pub. L. No. 117-169, §§ 13401, 13403, and 13502, 136 Stat. 1818, 1954–62, 1964–66 and 1971 (2022) (codified at 26 U.S.C. 30D, 45X); *see also* IRS, Proposed Rule for Section 45X Advanced Manufacturing Production Credit, 88 Fed. Reg. 86844, December 15, 2023.

The most complex areas of these incentives are the IRA's critical mineral and battery component requirements. The critical mineral requirement is a minimum share of critical minerals used in the production of batteries that are extracted or processed in the United States or a country that has a free trade agreement with the United States. The minimum percentage starts at 40 percent in 2023, increasing 10 percent per year until reaching 80 percent in 2027.[60] The component requirement starts at 50 percent in 2023 and increases by 10 percent per year until reaching 100 percent in 2029.[61]

The Internal Revenue Service of the U.S. Department of the Treasury published the final rule on May 6, 2024.[62] In the rule, battery components "include, but are not limited to, a cathode electrode, anode electrode, solid metal electrode, separator, liquid electrolyte, solid state electrolyte, battery cell, and battery module."[63] The final rule also allowed vehicle manufacturers to exclude "impracticable-to-trace" battery materials from its critical mineral calculations through January 2027. Graphite contained in anode materials and applicable critical minerals contained in electrolyte salts, electrode binders, and electrolyte additives are all considered impracticable-to-trace under these rules.[64]

[60] Pub. L. No. 117-169, § 13401(e)(1)(B)(i)–(v); "Section 30D New Clean Vehicle Credit," April 17, 2023, 30; Inagaki, Chazan, and Fleming, "A Global Subsidy War?," July 13, 2023.

[61] Pub. L. No. 117-169, § 13401(e)(2)(B)(i)–(vi); "Section 30D New Clean Vehicle Credit," April 17, 2023, 30.

[62] "Clean Vehicle Credits Under Sections 25E and 30D; Transfer of Credits; Critical Minerals and Battery Components; Foreign Entities of Concern," 89 Fed. Reg. 37706, May 6, 2024.

[63] Clean Vehicle Credits Under Sections 25E and 30D; Transfer of Credits; Critical Minerals and Battery Components; Foreign Entities of Concern," 89 Fed. Reg. 37706, proposed § 1.30D–3(c)(5), May 6, 2024.

[64] Clean Vehicle Credits Under Sections 25E and 30D; Transfer of Credits; Critical Minerals and Battery Components; Foreign Entities of Concern," 89 Fed. Reg. 37706 § 1.30D-2(b), May 6, 2024.

Further complicating the critical mineral and battery component requirements is the exclusion of "foreign entities of concern (FEOCs)." Vehicles in which any of the applicable critical minerals were extracted, processed, or recycled by an FEOC are not eligible for IRA incentives, and neither are vehicles where an FEOC manufactured or assembled any of the components contained in the battery. FEOCs are companies owned by, controlled by, or subject to the jurisdiction or direction of a government of a foreign country that is a covered nation (currently China, Russia, North Korea, and Iran). In December 2023, the U.S. Department of Energy (USDOE) issued a proposed rule that defined an FEOC and clarifies that an entity is "owned by, controlled by, or subject to the direction of" if:

> (i) 25% or more of the entity's board seats, voting rights, or equity interest are cumulatively held by that other entity, whether directly or indirectly via one or more intermediate entities; or
>
> (ii) With respect to the critical minerals, battery components, or battery materials of a given battery, the entity has entered into a licensing arrangement or other contract with another entity (a contractor) that entitles that other entity to exercise effective control over the extraction, processing, recycling, manufacturing, or assembly (collectively, "production") of the critical minerals, battery components, or battery materials that would be attributed to the entity.[65]

The IRA set aside an additional loan subsidy for the USDOE's Advanced Technology Vehicles Manufacturing Loan Program to provide loans for battery and battery component production.[66] Ford recently received $9.2 billion under this program. Because the USDOE structured the minimum loan offering to $50 million, MEMA (an automotive supplier association) raised some concern that many component producers would not be able to access the program because capital investments for parts suppliers to manufacture components, systems, or technologies for BEVs range from $10 million to $80 million.[67]

As of February 17, 2024, vehicle manufacturers and battery suppliers responded to these incentives with plans for more than $85 billion in new investments in BEVs, BEV batteries, and upstream input production. Most of the investments have been in battery production (38 projects totaling $60.2 billion), which has the highest incentives, but investment in BEV production (16 projects totaling $12.5 billion) and upstream input production (17 projects totaling $12.8 billion) has also increased.[68]

The EU has a variety of policies that provide a similar level of subsidies to the United States. For example, the *Financial Times* estimated that the average subsidy for a BEV in the EU was €6,000

[65] USDOE, 88 Fed. Reg. 84082, Section IV, December 4, 2023.

[66] The additional loan subsidy totaled $3 billion. The loan subsidy is not the amount of loan available. Rather, it is "the estimated present value of the cash flows from the Government (excluding administrative expenses) less the estimated present value of the cash flows to the Government resulting from a direct loan or loan guarantee, discounted to the time when the loan is disbursed.…Only the unreimbursed costs of making or guaranteeing new loans (the subsidy cost, on a present value basis, and administrative expenses, on a cash basis) are included in the budget." OMB Circular A-11 Section 185.2(b). The IRA increased ATVM's available subsidy by $3 billion. The money available to be loaned out by the program is significantly larger. USDOE, "Inflation Reduction Act of 2022," accessed August 18, 2023.

[67] MEMA, Letter to Secretary of Energy, July 25, 2023.

[68] Turner, "U.S. and Canada Electric Vehicle Supply Chain Map," February 17, 2024.

($6,680) per car and its clean tech manufacturing subsidies were forecast to be €35 billion ($38.1 billion compared to U.S. subsidies of $37 billion).[69] In December 2019, the European Commission announced €3.2 billion to support development of an EU battery supply chain.[70] Germany provided half a billion euros in incentives for a Northvolt plant in 2023.[71] Meanwhile, France provided more than €2 billion in subsidies for two battery makers to open plants there.[72]

Some vehicle manufacturers are pursuing strategies that will increase vertical integration—and potentially technology transfer—through joint ventures, while others are depending on suppliers in the belief that BEV batteries will become a commodity.[73] Several vehicle manufacturers have entered joint ventures or licensing agreements with battery manufacturers to ensure an adequate supply of BEV batteries. For example, GM has a joint venture with LG Chem, a South Korean chemical company, called Ultium. The joint venture will reportedly have battery plants in Ohio, Tennessee, and Michigan, with a combined capacity of 135 GWh.[74] GM also announced a partnership with South Korean battery and electronic materials manufacturer Samsung SDI to spend $3 billion for a battery cell plant in Indiana, with more than 30 GWh of capacity.[75]

Ford is another company that appears to be following a vertical integration strategy. Ford has a joint venture with a South Korean company, SK Innovation, called BlueOval SK, to produce batteries in Kentucky and Tennessee. According to Ford, those plants would have a combined capacity of 129 GWh.[76] Ford also has a licensing agreement with Contemporary Amperex Technology Co., Ltd. (CATL), a Chinese battery manufacturer and technology company, and plans to produce LFP batteries in a new battery plant in Michigan.[77]

Other examples include Stellantis and Honda, which have similar arrangements with battery manufacturers. Volkswagen has gone a step further. VW created its own BEV battery company, Power Co., which will produce batteries in Canada beginning in 2027.[78]

Several other vehicle manufacturers have pursued a commodification strategy, wherein they designed a battery architecture that could use a variety of batteries or battery cells produced by a variety of battery makers.[79] For instance, Mercedes decided to acquire batteries on the open market instead of making significant up-front investments and locking themselves into deals with specific producers.[80] BMW invested in cell design and awarded contracts to CATL and EVE Energy, both headquartered in China, to

[69] Inagaki, Chazan, and Fleming, "A Global Subsidy War?," July 13, 2023.
[70] European Commission, "State Aid," December 9, 2019.
[71] Reuters, "Northvolt to Build Multi-Billion-Euro Battery Plant in Germany," May 12, 2023.
[72] White, "French Car Battery Start-up Verkor Secures €2bn for First Plant," September 14, 2023; White, "Taiwanese Car-Battery Maker Bets on Northern France with €5.2bn Plant," May 12, 2023.
[73] Dempsey, Davies, and Campbell, "The Search for Winners in the New Battery Era," August 21, 2023.
[74] General Motors, "GM Reveals New Ultium Batteries," March 4, 2020; Ultium Cells, "GM and LG Energy Solution Investing $2.6 Billion," January 25, 2022.
[75] Hall, "GM, Samsung EV Battery Cell Plant to be Built in Indiana," June 13, 2023.
[76] Ford, "Ford Commits to Manufacturing Batteries," May 20, 2021.
[77] Ford, "Ford Taps Michigan for New LFP Battery Plant," February 13, 2023.
[78] Volkswagen, "Volkswagen Steps Up Activities," March 13, 2023.
[79] Dempsey, Davies, and Campbell, "The Search for Winners in the New Battery Era," August 21, 2023.
[80] Automotive News Europe, "Daimler Declines to Invest in Battery Cell Production," February 24, 2016.

produce batteries in Europe and China based on BMW's design.[81] Nissan sold its battery business in 2018 because it believed that batteries would become commoditized.[82]

Battery Components and Other Upstream Inputs

China is the largest producer of most battery components (e.g., 93 percent of anodes and 82 percent of cathodes in 2023), but investments in battery components outside China have increased significantly as a result of increased BEV battery production outside China and related incentives.[83] Similar to many automotive parts suppliers, battery component producers will often locate their production in proximity to battery manufacturers. For many years, most lithium-ion battery production was in China, South Korea, or Japan, leading battery component producers to invest in those countries.

As battery production outside East Asia increased, battery component investments outside that region followed. During the time between battery component investment announcements and battery component production, U.S. imports of battery components will continue to increase. The composition of the imports may include more upstream inputs (e.g., critical minerals) as U.S. production of downstream components (cathodes, cells, battery packs, etc.) increases.

U.S. imports of battery inputs increased significantly both on a value basis and as a share of automotive parts imports from 2018 to 2023 (figure 13). China, Japan, and South Korea were the top sources for U.S. battery input imports. Low U.S. processing and refining capacity limited U.S. demand for imported raw materials, and low U.S. component production led to relatively low U.S. battery material imports.[84] As component production increases, demand for battery materials will likely rise.[85]

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[81] BMW Group, "More Performance, CO2-Reduced Production, Significantly Lower Costs," September 9, 2022.

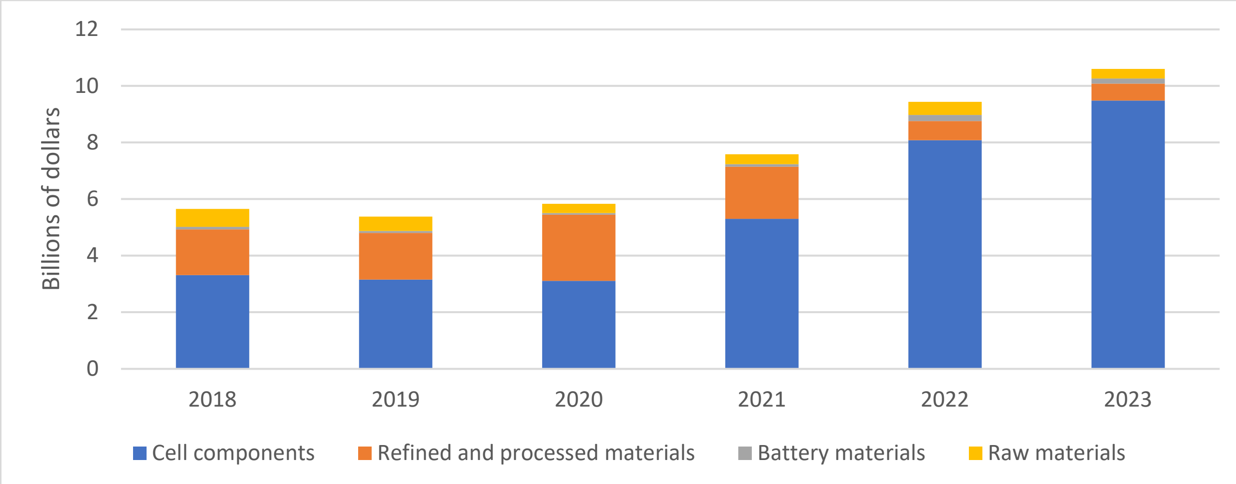
[82] Dempsey, Davies, and Campbell, "The Search for Winners in the New Battery Era," August 21, 2023.

[83] Dempsey et al., "Rival Battery Technologies Race to Dominate Electric Car Market," August 14, 2023.

[84] S&P Global, Inflation Reduction Act: Impact on North America Metals and Minerals Market, August 15, 2023.

[85] S&P Global, Inflation Reduction Act: Impact on North America Metals and Minerals Market, August 15, 2023.

Figure 13 U.S. imports of battery inputs, by supply chain stage, in billions of dollars and share of U.S. automotive parts imports



Source: USITC/Census, DataWeb (accessed February 25, 2024). HTS subheadings 2504.10.00, 2827.39.90, 2833.29.51, 7501.20.00, 7607.20.50, and 8105.20.60. HTS statistical reporting numbers 2530.90.8050, 2805.19.9000, 2820.10.0000, 2825.20.00, 2826.19.0000, 2842.90.9000, 3801.10.5000, 3801.20.0000, 3824.90.3900, 3824.99.9297, 3919.10.2055, 7616.99.5190, 8111.00.4910, and 8507.90.8000.

U.S. imports of cells and cell components made up the largest share of U.S. battery input imports from 2018 to 2023. Imports of cathodes and cells made up 74 percent of U.S. imports of cells and cell components in 2023.[86] Such cell imports support U.S. battery pack assembly, and cathode imports support U.S. cell production. These imports increased from $1.4 billion in 2018 to more than $7 billion in 2023, an increase of more than 340 percent. Data constraints prevent differentiation because both cathodes and battery cells are imported in a statistical reporting number (8507.90.8000) that is for battery parts of lithium-ion batteries. The top sources of these imports are South Korea, China, and Japan. All three countries produce both cathodes and battery cells.[87] The IRA's FEOC requirements, which bar from eligibility vehicles using Chinese components may lead to decreased demand for imports from China, which made up 56 percent of U.S. battery input imports in 2023.[88]

Meeting U.S. goals (and IRA requirements) will require significant investments in battery component production and other upstream input production.[89] A public-private alliance focused on domestic supply chains for lithium-based batteries published a report in 2023 that claimed U.S. content composed less than 30 percent of the value of a cell consumed in the United States.[90] Additionally, this report put forth

[86] USITC/Census, DataWeb (accessed May 23, 2023). Note: HTS subheading 7607.20.50 and statistical reporting numbers 3919.10.2055, 3824.99.9297, 7616.99.5190 and 8507.90.8000.

[87] USITC/Census, DataWeb (accessed May 23, 2023). Note: HTS statistical reporting numbers, 3824.99.9297, 3919.10.2055 7607.20.50, 7616.99.5190, and 8507.90.8000.

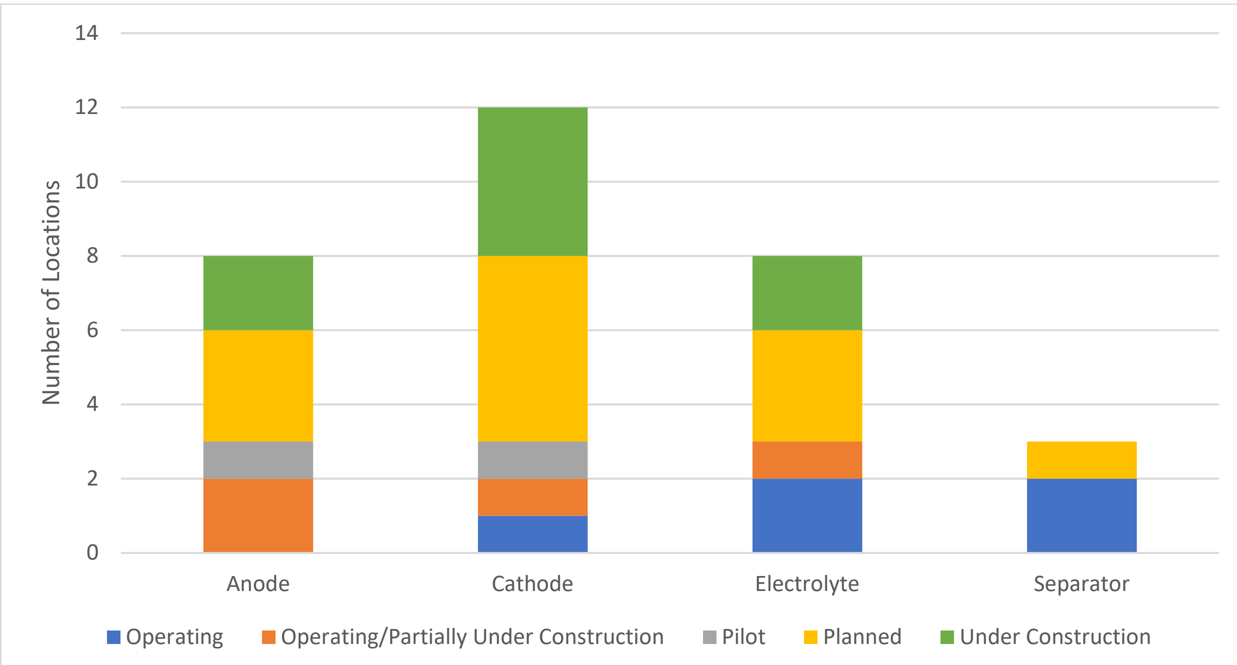
[88] USITC/Census, DataWeb (accessed May 23, 2023); Home, "US Looks to Shut China out of Its Battery Supply Chain," December 6, 2023; Nakano and Robinson, "U.S.-China EV Race Heats Up with Forthcoming Guidance on 'Foreign Entity of Concern' Rules," November 2, 2023.

[89] Ragozzino, "U.S. DOE and Trade Groups Outline Steps," February 22, 2023; Li-Bridge, *Building a Robust and Resilient U.S. Lithium Battery Supply Chain*, February 2023, 4; Minott and Nguyen, "IRA EV Tax Credits," accessed April 29, 2024.

[90] Ragozzino, "U.S. DOE and Trade Groups Outline Steps," February 22, 2023; Li-Bridge, *Building a Robust and Resilient U.S. Lithium Battery Supply Chain*, February 2023, 4.

that a realistic goal should be 50 percent self-sufficiency in battery components by 2030, which is significantly less than the requirements set forth in the IRA (a BEV will need 100 percent North American components in 2029 for a vehicle to qualify).[91] Five battery component plants were operating in 2023, four more were operating while partially under construction, and eight more were under construction; plans have been announced for an additional dozen (figure 14), with investments totaling more than $16 billion.[92]

Figure 14 Battery component plants in North America, by number of locations



Sources: Authors' analysis based on information from Charged-the-Book EV Dashboard and company websites (accessed August 2023).

Battery Recycling

The United States can make up for some of its lack of domestic mining, refining, and processing capacity by recycling scrap from battery production and end-of-life batteries. Globally, most battery recycling capacity is in China.[93] In the United States, incentives in the Infrastructure Investment and Jobs Act[94] and the IRA, along with increasingly available production scrap and end-of-life batteries, are leading to increased investments in battery recycling.[95]

[91] Li-Bridge, *Building a Robust and Resilient U.S. Lithium Battery Supply Chain*, February 2023, 7.

[92] Authors' research based on information from Charged-the-Book EV Dashboard and company websites (accessed August 2023).

[93] Carey et al., "Dead EV Batteries Turn to Gold with U.S. Incentives," July 21, 2023.

[94] Pub. L. No. 117-58, § 40208, 135 Stat. 429, 971 (2021) (codified in 42 U.S.C. § 17231).

[95] Carey et al., "Dead EV Batteries Turn to Gold with U.S. Incentives," July 21, 2023; USDOE, "Bipartisan Infrastructure Law," November 1, 2022.

Batteries made using recycled material would qualify for incentives under the IRA and receive duty-free treatment under the United States-Mexico-Canada Agreement (USMCA).[96] The IRA's critical minerals requirement explicitly allows recycled minerals to qualify.[97] The USMCA does not address recycled materials directly, but the rules of origin for battery cells prevent the use only of spent cells.[98] Because the battery recycling process transforms spent batteries into recycled materials before those materials are used to make components for a new cell, they would qualify for duty-free treatment under the USMCA.[99]

U.S. companies are already using IRA incentives to expand their battery recycling operations. For instance, Redwood Materials, the most prominent U.S. battery recycling company, has announced three locations (Nevada, Kansas, and South Carolina) where it will process spent batteries to make cathodes and anodes.[100] The company has set goals of 100 GWh of cathode production capacity by 2025 and 500 GWh/year of materials for both cathodes and anodes by 2030, which would be enough cathode and anode material for 5 million BEVs per year (i.e., approximately half of U.S. vehicle production in 2023).[101]

Several other battery recycling companies either have recycling plants in the United States or have plans to build them. For example, Ascend Elements has a small battery recycling plant in Georgia and received $500 million in grants from the USDOE to open a significantly larger plant in Kentucky.[102] The Kentucky plant would produce precursor cathode active material (pCAM), with a capacity to supply enough pCAM for 750,000 BEVs per year.[103] Meanwhile, Li-Cycle (a Canadian company) has a battery recycling plant in New York state, that converts spent batteries into "black mass," which can be used in production of new batteries.[104]

Conclusion

Global BEV demand has increased rapidly, and the global BEV battery supply chain is quickly expanding to meet this demand. The United States is projected to account for a greater share of the global BEV battery supply chain. This share will increase because of growth in U.S. production of BEV batteries and expansion of U.S. production of cell components and other upstream inputs. These increases are driven at least in part by U.S. government incentives, particularly those in the IRA. Assuming future U.S. BEV

[96] Pub. L. No. 116-113 (codified in 19 U.S.C. § 4501 SEC. 202); Pub. L. No. 117-169, § 13401(e)(1)(A)(ii) (codified in 26 U.S.C. § 30D); U.S. International Trade Commission, *USMCA Automotive Rules of Origin*, June 2023, 99.
[97] Pub. L. No. 117-169, § 13401(e)(1)(A)(ii) (codified in 26 U.S.C. § 30D).
[98] U.S. International Trade Commission, *USMCA Automotive Rules of Origin*, June 2023, 99.
[99] U.S. International Trade Commission, *USMCA Automotive Rules of Origin*, June 2023, 99.
[100] Redwood Materials, "Panasonic to Source High-Nickel Cathode from Redwood," November 15, 2022; "Redwood Chooses Charleston, South Carolina Region for New Battery Materials Campus," December 14, 2022.
[101] Redwood Materials, "Panasonic to Source High-Nickel Cathode from Redwood," November 15, 2022.
[102] Carey et al., "Dead EV Batteries Turn to Gold with US Incentives," July 21, 2023; Ascend Elements, "Ascend Elements to Supply Sustainable Cathode Precursor," June 7, 2023.
[103] Ascend Elements, "Ascend Elements to Supply Sustainable Cathode Precursor," June 7, 2023.
[104] "Black mass" is a term for crushed and shredded end of life batteries. This mass contains mixtures of valuable metals that can be used in producing a new battery. Carey et al., "Dead EV Batteries Turn to Gold with U.S. Incentives," July 21, 2023; Li-Cycle, "Li-Cycle Announces Commercial Lithium-Ion Battery Recycling Plant," December 2, 2020; Alfred H Knight Research, "Black Mass and the 'Battery Revolution,'" July 8, 2023.

battery production capacity reaches the levels predicted by combining company announcements of future capacity, there will likely provide adequate capacity for U.S.-assembled BEVs. That production, however, will likely continue to rely, at least in part, on imported cell components and other upstream inputs. Much of these cell components and upstream inputs will likely continue to come from China, preventing many EVs from meeting IRA requirements.

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