Supply Chain Challenges Impacting Electric Vehicle Adoption

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Mobility
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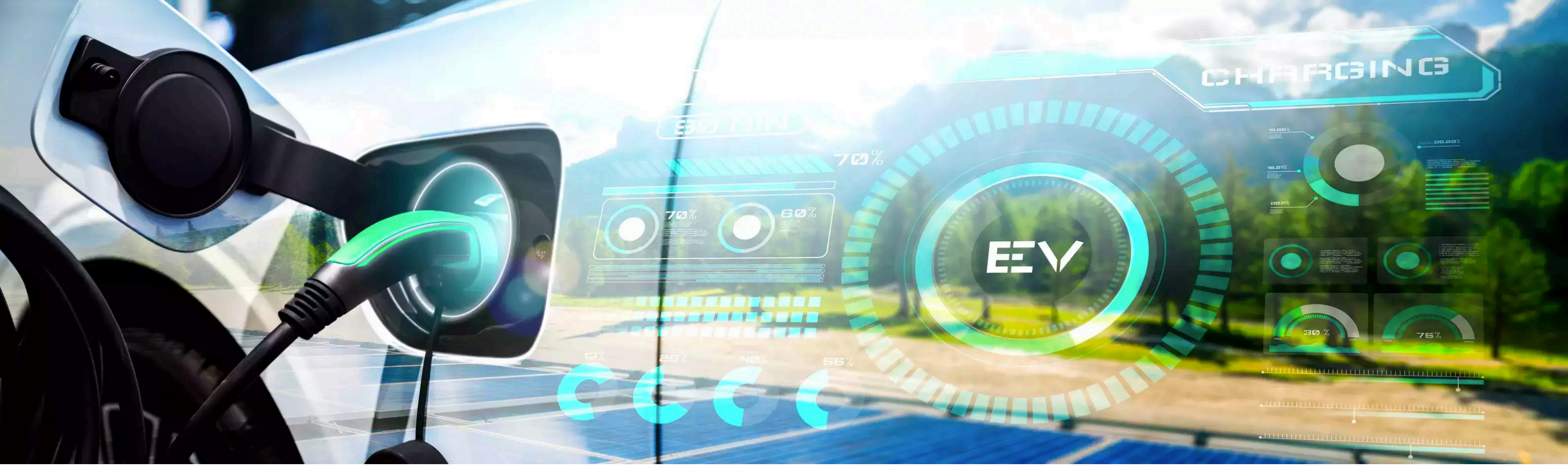
Vehicle electrification is gathering steam. But supply chain disruptions and the soaring cost of raw materials, exacerbated by geopolitical conflicts, threaten to put the brakes on electric vehicle (EV) sales just as demand is taking off. This convergence of factors has presented automakers with a significant opportunity to reshape their EV businesses and modernize business models. All this tests supply chains, increasing expectations for battery lifecycle management and the technology and policy incentives that power the industry.

The battery pack is the most expensive part of an EV, contributing to up to 40% of the cost of a new EV. In the near term, meeting increased EV production commitments and demand means more mining. The U.S. reliance on importing materials critical to EV battery production has become an economic and national security vulnerability. Fortunately, the U.S. has the resources to build an EV supply chain strategy from the mine up. While efforts to jumpstart critical mineral production for the metals that can be found stateside are currently underway, it takes time. Further, for metals not common in scale in the U.S., like cobalt, first-life extension and recycling become more important.

While recycling EV batteries minimizes the amount of mining needed to meet growing demand both the technology and volumes of end-of-life EV batteries are in the early stages. That's why end to end EV battery lifecycle management, extending first life through responsible servicing has emerged as a linchpin to deliver on the sustainability goals of electrification.

Coupled with government policy support, EV battery first life extension is paving the way for meaningful progress in protecting the planet while accelerating the uptake of EVs in a challenging environment.



State of EV Adoption

EV Sales Surge Among Consumers

Americans are buying EVs at a record pace, despite rising prices and long waits for delivery. Many consumers, alarmed by double-digit increases in gas prices, have been looking to EVs to help stabilize their budgets. While gas prices have been on the decline as of late, they remain well above historical levels.

According to Cox Automotive, EV sales in the U.S. jumped 66.4% to 196,788 units in the second quarter 2022 compared to the same period a year ago – a record high – while overall new car sales slumped (20.4%).[1] In the second quarter of 2022, there were 33 EV models for sale in the U.S., an increase from the 19 available the same period last year.

Electrified Vehicle Sales Growth

	Q2 2022	Q2 2021	Y-O-Y
EVs	196,788	118,235	66.4%
HEVs/PHEVs	245,204	272,935	-10.2%
Fuel Cell	796	1,074	-25.9%
Total Electrified	442,788	392,244	12.9%
Total Market	3,522,210	4,422,544	-20.4%
% Electrified	12.6%	8.9%	41.7%

Source: Cox Automotive

[1] Cox Automotive Data Point, "EV Sales Hit New Record in Q2 2022," July 13, 2022.

Manufacturers' New Model Commitments Spike Adoption

The introduction of new electric models – including the highly anticipated pickup truck segment – is also fueling consumer interest. Today's EVs have moved beyond the luxury segment with more offerings from established legacy brands – and lower price tags. In short, EVs and those who want to buy them, are on the path to becoming mainstream.

Automaker	EV Model Commitments in U.S. & Europe	Current Offerings by Body Type
BMW Group	Nine all-electric models by 2025 (includes two Mini models)	SUV/Crossover – 2 Sedan/Coupe – 3 (additional 1 upcoming in 2023)
Ford	Two new dedicated all-electric manufacturing platforms by 2025 European line-up all-electric by 2030	SUV/Crossover – 1 (additional 1 upcoming in 2024) Pickup Truck – 1 Van – 1
General Motors	30 new all-electric vehicles globally by 2025 Heavy-duty all-electric trucks by 2035	SUV/Crossover – 4 (additional 2 upcoming in 2023) Pickup Truck – 2
Honda	30 all-electric vehicles globally by 2030 Honda/GM partnership for lower-cost, higher volume EVs for sale starting in 2027	SUV/Crossover – 2 (upcoming in 2024) Sedan/Coupe – 1 (sold in Europe and Japan)
Hyundai	23 all-electric models by 2025	SUV/Crossover – 5 Sedan/Coupe – 1 (upcoming in 2023)
Jaguar/Land Rover	Jaguar all-electric by 2025 Six all-electric Land Rovers by 2026 Land Rover all-electric by 2030	SUV/Crossover – 1
Mazda	Three all-electric models by 2025	SUV/Crossover – 1
Mercedes-Benz	130 electrified models by 2030 – including EVs, plug-in hybrids, traditional hybrids All-electric from 2025 onward	SUV/Crossover – 1 Sedan/Coupe – 2
Nissan	At least 15 all-electric vehicles globally by 2030	SUV/Crossover – 2
Stellantis	40 all-electric models in the U.S. & Europe by 2025	SUV/Crossover – 1 Sedan/Coupe – 3 (additional 1 upcoming in 2024) Pickup Truck – 1 (upcoming in 2024) Van – 4
Toyota	15 all-electric vehicles globally by 2025 Lexus all electric by 2035	SUV/Crossover – 2
Volvo	All Volvos from 2019 onward have electric motors 50% all-electric/50% hybrid global sales by 2025	SUV/Crossover – 2
VW Group	70 new models of electric vehicles between 2020-2026 25 all-electric vehicles in North America by 2030	SUV/Crossover – 7 (additional 1 upcoming in 2023) Sports Car – 1 (additional 1 upcoming in 2025) Van – 1 (upcoming in 2023)

Source: *Wonder Research, official OEM websites and press releases*

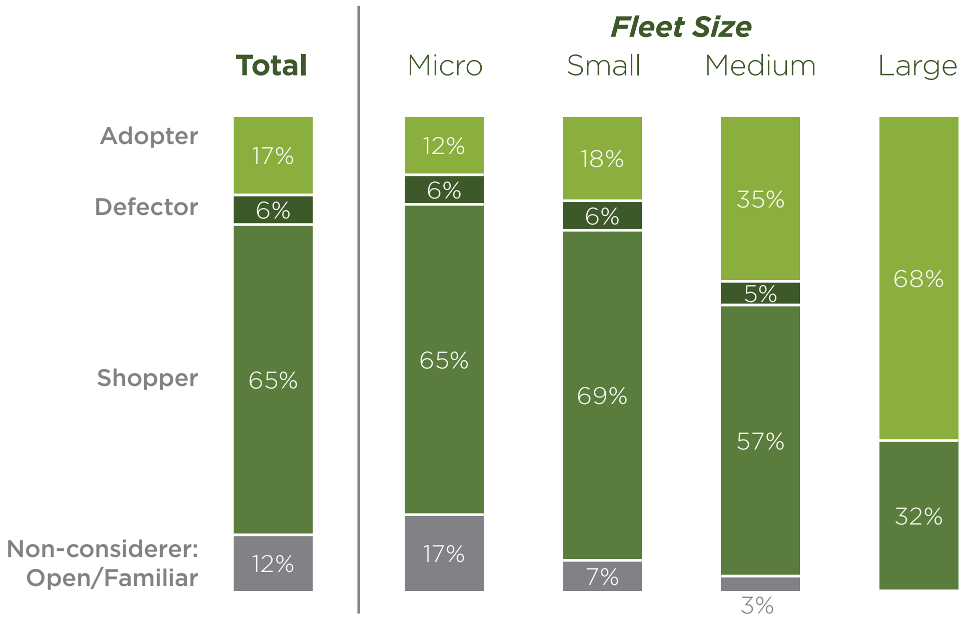
Startups like Rivian, Lucid, Fisker and others are also staking their claim in the era of electrification. In fact, Rivian's R1T pickup, named the 2022 Motor Trend Truck of the Year, is now on sale. And, Lucid is now delivering the touring model of the Air sedan, named the 2022 Motor Trend Car of the Year.

These growing EV model commitments have also increased demand for the components that power these vehicles and highlighted the need for a more efficient, reliable supply chain model.

Fleet Electrification Continues

In addition to consumer adoption, the fleet industry is taking note. To achieve sustainability goals, drive efficiency and reduce total cost of ownership, fleet operators are highly motivated to replace their gas-powered fleets with EVs.

EVs are already appearing in fleets, with a current adoption rate of 17% of new fleet vehicle purchases and an additional 65% of fleet operators identifying as EV shoppers. With fleets representing 11.4% of the car parc in the U.S. alone, this demand is further straining a supply chain already stretched thin.



Source: *Escalent 2021 Fleet Electrification Impact of Infrastructure Report*

Commercial EVs & Trucks

Despite making up only about 10% of vehicles on the road, heavy-duty vehicles are responsible for 28% of greenhouse gas emissions, 45% of nitrogen oxides, and 57% of fine particulate pollution from vehicles in the U.S.[2] Accelerating the manufacture and adoption of clean trucks is crucial for meaningful reductions in climate-warming and toxic air pollution.

Van & Step Van Delivery Vehicles

All major delivery companies are starting to replace their gas-powered fleets with electric or low-emission vehicles, a switch that companies say will boost their bottom lines, while also fighting climate change and urban pollution.

Compared to the 18-wheelers that carry packages between states, last-mile delivery vehicles – typically vans and smaller trucks – are much easier to electrify as range is typically not a major challenge. Furthermore, they can be charged at fleet depots, a driver's home or at public charging stations. And the total cost of ownership of electric versions of these vehicles is approaching parity with diesel- and gasoline-powered vehicles once incentives are factored in.

The North American Council on Freight Efficiency (NACFE) estimates that a gas-powered delivery van driving an average of 100 miles per day will spend just over $10,000 a year in fuel versus just under $2,000 for an electric one – sizeable savings multiplied across a fleet of EV delivery vehicles.

Amazon operates thousands of electric delivery vans and has ordered 100,000 from EV-maker Rivian. UPS has ordered 10,000 electric vans from EV company Arrival. One-fifth of DHL's delivery fleet is electric with Lightning eMotors electric cargo vans. By 2030, FedEx is aiming to have all new vehicle purchases be electric and to electrify its entire pickup and delivery fleet by 2040. The United States Post Office recently revised its EV fleet purchases from 10% to 40% of new vehicles.

> "An EV uses a fraction of the energy that an internal combustion engine (ICE) uses to keep the cab cool or warm for driver shelter. In one hour, a diesel burns about a half a gallon (approx. US$2.80). Also remember that a combustion engine has nearly 10,000 parts on average, whereas an EV only has approximately 700. All in all, EV maintenance costs are about 60%-70% less than ICE maintenance costs."
>
> *- Terry Rivers*
> *VP Maintenance & Provost of FleeTec Academy*

Box Trucks

Box trucks have a cargo box that is inaccessible from the cab, and they are longer than vans/step van delivery vehicles. Box trucks are often used as moving vans by companies such as U-Haul and Ryder. There are approximately 400,000 of them in the United States and Canada.

According to NACFE, this entire segment is electrifiable. That's because box trucks tend to travel less than 100 miles per day, making them ideal for electric powertrains. Although these trucks are more likely to face weight limitations as they often carry quite heavy cargo, the reality is that often the freight compartment fills up before reaching the legal gross vehicle weight.

Electric box trucks are already on the roads today. For example, Frito-Lay has six 220EV Peterbilt electric box trucks and Day & Ross, a transportation and logistics company, is using electric box trucks in Canada.

Big Rigs

Heavy-duty tractor-trailers are also moving toward electrification. But this segment is a bit more challenging to electrify because of the longer ranges and heavier loads. However, a recent RMI study found that 49% of these heavy-duty trucks operating in New York and California are regularly driving short-enough routes that they could be replaced with electric trucks that are now for sale or will be by year-end.

Anheuser-Busch is already using heavy-duty electric trucks to deliver throughout California and has ordered another 20 from BYD. Biaggi Brothers is delivering wine from Napa Valley in heavy-duty electric trucks.

The greatest concern to scaling the number of commercial EVs at a site is the lead times for the charging infrastructure as well as the incremental cost to install charging solutions for your fleet. If the number of commercial EV chargers at a site requires significant infrastructure updates, fleet owners will need to work with utilities and municipalities to coordinate the work. Concerted efforts will have to be made to redesign parking lots and depots to support electrification.

[2] *Union of Concerned Scientists,* "Congress Considers First-Ever Purchase Incentives for Commercial EVs", August 2, 2022.

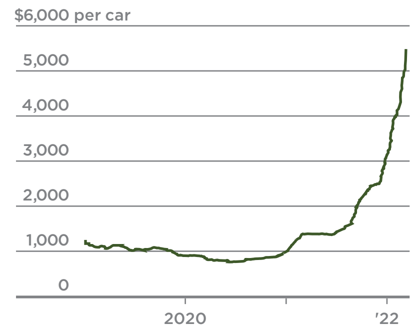
The Importance of Price Parity in Driving Adoption

The average price paid for a new EV is on the decline as lower-priced models enter the market and offset the many luxury EVs already available. Still, the average price for a new EV – more than $64,000 according to Kelley Blue Book estimates – is well above the auto industry average of $47,148 and more aligned with luxury prices than mainstream prices.[3] So, while EVs can offset higher prices over time in terms of lower operating costs, the upfront investment remains cost-prohibitive for many American households.

At some point, EVs should become less expensive to buy than gas-powered, internal combustion engine (ICE) vehicles. But rising raw material prices could delay the timeline on cost parity between EV and ICE vehicles. Although EVs, on average, are still more expensive to buy than ICE vehicles, unstable gas prices create significant fluctuations in the cost to operate ICE vehicles. So, gas price anxiety could serve as a counterbalance, spurring greater interest in EVs after years of growing demand for gas-guzzling sport utility vehicles and pickup trucks.

Inflation

Proxy for the cost of metal components in an EV battery pack.



Note: Includes lithium, cobalt, nickel, and other metals.

Sources: *Bloomberg, Barron's calculations*

What's Driving EV Inflation

The electric segment also has been hit by the tide of inflation affecting the overall auto industry since the spring of 2021.

Most EV batteries utilize four principal minerals: lithium makes up 10% of the battery, cobalt 18%, manganese 25% and nickel accounts for 45%, according to Nature, a scientific journal.

Rising minerals prices threaten to slow and even temporarily reverse the long-term trend of falling costs of batteries, the most expensive part of EVs. In the short term, the cost of building EVs is going up as the demand for key materials increases and the supply remains challenged.

- Despite retreating from April highs, the price of lithium has jumped more than 600% since the start of the year, according to Benchmark Market Intelligence. The increase comes as the process for extracting lithium, and a relative lack of investment, has yet to catch up with the rising demand.
- Limited availability of cobalt has also inflated cobalt prices in recent months. Supply chain hiccups and fears over access have tightened supply. The price for cobalt is 71.8% higher in late May 2022 compared to 2021.
- It has been an extraordinarily volatile year for the nickel market. Prices nearly tripled in three days alone in March 2022 over fears of supply shortages as the invasion of Ukraine by nickel powerhouse Russia intensified, and Western nations tightened sanctions. While the price has somewhat rebounded as of late, it remains 57.2% higher year over year.[4]

Raw material costs for EVs more than doubled during the coronavirus pandemic, according to a recent report by AlixPartners. Average raw material costs for an EV totaled $8,255 per vehicle as of May 2022, up 144% from $3,381 per vehicle in March 2020.

And the cost increases aren't limited to EVs: Raw material costs for traditional vehicles have also more than doubled during that time period to $3,662 per vehicle, up 106% from an average of $1,779 per vehicle in March 2020. As a result, automakers are raising prices across the board.

[3] "New-Vehicle Prices Flirt with Record High in May, according to Kelley Blue Book, as Luxury Share Remains Strong", June 9, 2022.
[4] *S&P Global Commodity Insights,* "High battery metals costs add to electric vehicle sales slowdown", June 7, 2022.

The Role of Federal Incentives

As part of the Inflation Reduction Act of 2022, the EV federal tax credit created in 2009 during the Obama administration, will renew in January 2023 and will last a decade to the end of 2032. This legislation continues to encourage automakers to embrace electrification and consumers to purchase electric by offsetting the cost of pricey EVs.

The new federal tax credit can be applied upfront at the point of sale if purchased from a dealer, rather than needing to file for it on personal income taxes the following April.

The previous tax credit had a cap of 200,000 cars per manufacturer, a limit that Tesla and GM surpassed years ago, and Toyota just exceeded this quarter. Other auto manufacturers were also on track to surpass that number this year. Now, all manufacturers have access to unlimited credits as long as they fulfill the other requirements of the bill.

New requirements include that the cars must be assembled in North America and that materials and critical minerals in the battery must come from the U.S. or a country with a free trade agreement with the U.S. These requirements are intended to spur domestic manufacturing and a more diverse supply chain for EV materials. The government will release these guidelines by the end of the year, but the mineral and material guidelines don't go into effect until 2024.

To qualify for the federal tax credit, vehicles must have an MSRP of under $55,000 for cars and $80,000 for SUVs and trucks. Plus, buyers of new EVs would need to have an adjusted gross income (AGI) of less than $150,000 for individuals, $225,000 AGI for heads of households, and $300,000 AGI for joint filers.

For the first time, the federal tax credit will now be available on used EVs, with a credit of up to $4,000 on cars priced $25,000 or less, and subject to several other requirements. For used EVs, the income caps are $75,000 adjusted gross income (AGI) for individuals, $112,500 AGI for heads of households, and $150,000 AGI for joint filers.

There is also a provision that allows usage of the previous credit on a car delivered after the bill is enacted if there is a valid purchase order signed in 2022.

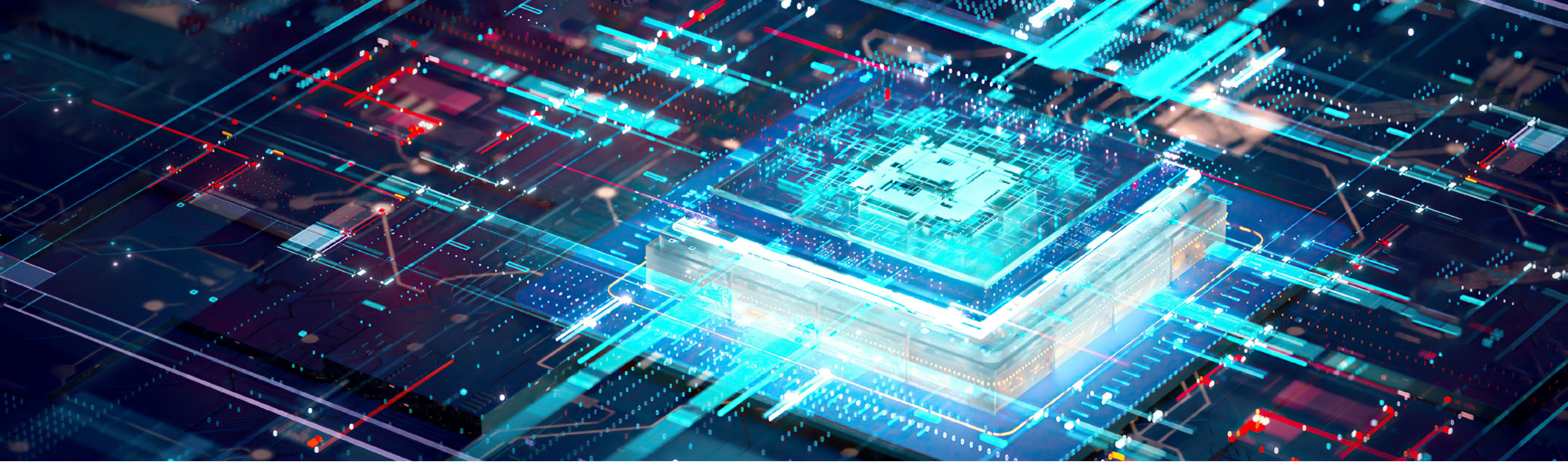
Certain states offer additional EV purchase incentives. Connecticut and Delaware lead with the highest tax rebates, while Maryland, California and Massachusetts follow closely behind.

The Critical Role EV Batteries Play

Batteries have emerged as a critical factor in the EV transition. Constraints in the supplies of crucial raw materials for batteries are hampering the rollout of EVs, even as demand vastly exceeds manufacturers' current production capacities.

In the past, the single largest barrier to EV adoption was battery cost. However, advancements in battery technology increased energy density, and cost savings from supply-chain efficiencies helped lower costs. But the recent surge in battery raw materials costs threatens to reverse falling battery expenses, possibly delaying price parity with ICE vehicles.

The lack of battery supply, coupled with vehicle price inequity compared to ICE vehicles, present serious challenges to EV sales targets and climate goals. But The National Alliance for Advanced Transportation Batteries (NAATBatt) International, a trade association of companies and research institutions, looks to stabilize the metal supply and supply chain through manufacturing advances, including improved recycling methods. The organization recently held its fifth annual workshop on lithium battery recycling and lifecycle management.



Supply Chain Constraints Threatening EV Growth

Consumers looking to buy an EV face a major obstacle: finding one to buy. While some EV models may be easier to find than others, the pandemic, material shortages, and international conflicts have created a perfect storm of bottlenecks. The stuttering supply chain has some automakers warning of long waits to buy their most popular models.

Global Computer Chip Shortage

Global auto supply chains have been snarled by a semiconductor chip shortage. When car sales dropped dramatically in early 2020 during the COVID-19 lockdown, many auto manufacturers slashed orders for chips. So, the semiconductor industry shifted production lines to meet demand for other applications, like laptops, TVs and video games.

When new vehicle demand recovered faster than anticipated in the second half of 2020, chipmakers were inundated with orders, and they still haven't caught up. Thus, auto manufacturers were unable to make enough cars because they didn't have enough microchips.

While the COVID-19 pandemic was the catalyst, structural factors are also part of the picture. The auto industry is changing, with a major shift toward automation and EVs. Microchips play a big role in today's vehicles, controlling everything from windows to the navigation screen to even passenger seat sensors. These require more chips, causing further strain on an already stretched industry.

A limited supply of chips left automakers with a choice – build fewer cars or build them with fewer options. Automakers cut back and made fewer cars. They decided to put their chips into making bigger, more expensive vehicles to get more bang for their buck. This also means that automakers have been making fewer compact cars and sedans – the more affordable vehicles. The result is that new vehicle prices have soared. The average cost of a new traditional car is hovering at the highest level on record, topping $47,000. New cars, even gas-powered ones, are out of reach for many buyers.

The average EV has about 2,000 chips, roughly double the average number of chips in a non-electric car.[5] And the chip shortage has not yet been resolved. Semiconductor capacity takes time to build, which impacts supply, production, and inventories.

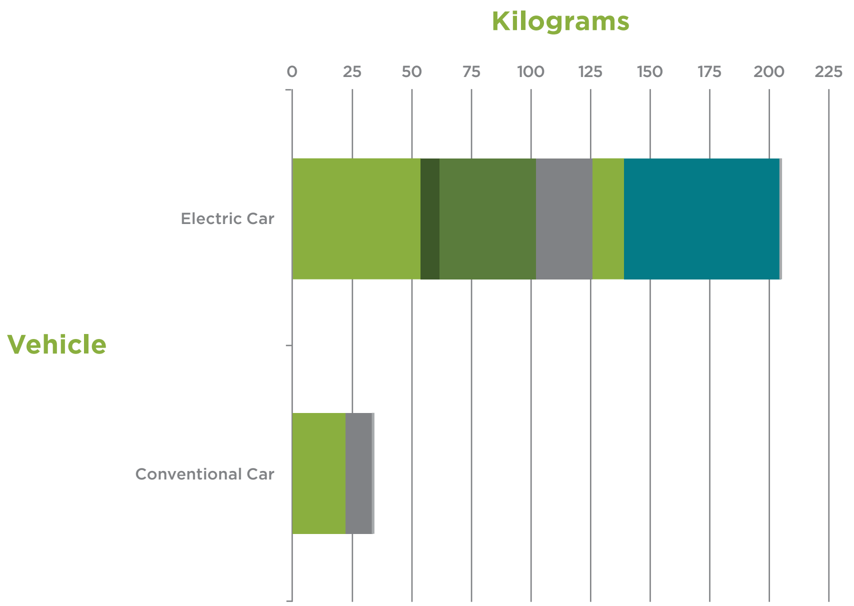
[5] *News briefing,* U.S. Commerce Secretary Gina Raimondo, November 29, 2021.

Minerals Shortage

Most batteries used to power EVs are lithium-ion batteries. According to a 2018 report from the U.S. International Trade Commission, lithium-ion batteries make up more than 70% of the rechargeable battery market.

The minerals needed for EV batteries can differ based on the chemistry of the cathodes, but lithium, cobalt, nickel, graphite, and manganese are considered to be the key materials. EVs use around six times more minerals than conventional vehicles.

Minerals Used in Electric Cars Compared to Conventional Cars



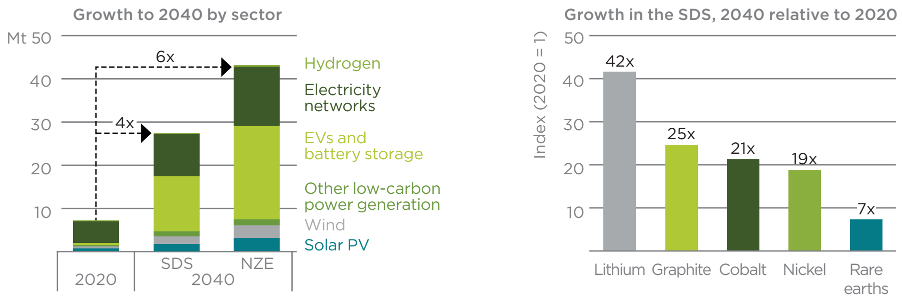
Source: *IEA*

Note: Steel and aluminum not included. The values for vehicles are for the entire vehicle including batteries, motors and glider.

While these minerals are abundant in the earth's crust, the supply depends on mine production capacity. The exceptional rise in demand for EV batteries is now outstripping supply, with new mines not being built fast enough to keep pace.

Mineral Demand for Clean Energy Technologies by Scenario

SDS = Sustainable Development Scenario, **NZE** = Net-zero by 2050 Scenario



Demand for critical minerals is set to soar over the next two decades as the world pursues net-zero goals; overall requirements rise by as much as 6 times, but individual minerals, led by lithium, rise even faster

Source: *IEA*

Ukraine Conflict

The war in Ukraine hasn't just caused gas prices to soar. Russia's invasion of Ukraine has disrupted vehicle production in Europe, which sends exports to the United States.

Impact on Raw Materials

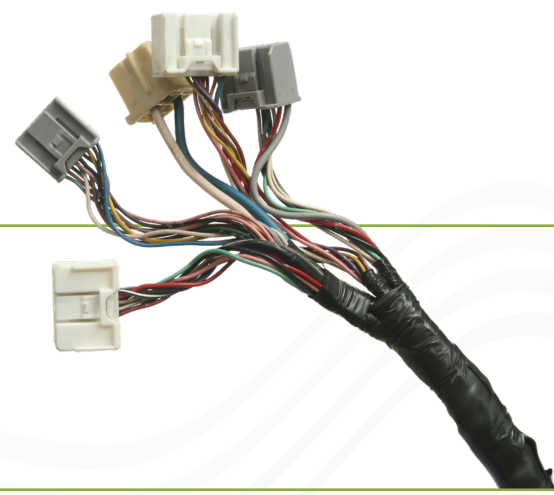
War and sanctions have crimped the supplies of raw materials from Russia that carmakers need. Those include palladium, used for antipollution equipment in cars, and nickel, essential for EV batteries. In fact, the price of EV battery metals has jumped by 50% since Russia invaded Ukraine on February 24, 2022.[6] And Ukraine is a major source of neon, a gas used for high-performance lasers that, in turn, are required to produce those scarce semiconductors chips.

Russia represents nearly 40% of the world's total palladium mine production and supplies 20% of global battery-grade nickel.

Source: *Barrons*

Impact on Wire Harnesses

The Ukraine invasion has also hampered wire harness supplies for European carmakers. According to an analysis of 2020 Comtrade data by consultancy AlixPartners, wire harnesses were Ukraine's most critical automotive component exported to the European Union, accounting for nearly 7% of all imports of this product.



A wire harness is a vital set of parts that neatly bundles up to 3.1 miles of cables in the average car. Unique to each car model, vehicles cannot be built without them.

Source: *Sumitomo Electric Wiring Systems*

Automakers have had to increase capacity at other locations – requiring factory space, machinery and tools, workers, and financing – as well as switching to alternate sources of wiring systems in other countries that produce them, like Tunisia.

The war in Ukraine has also highlighted the risks of doing business with authoritarian countries – not just Russia, but also China. The conflict has increased the pressure that automakers now face to manufacture closer to home and reduce the risk that turmoil in a faraway place will throw their operations into chaos.

[6] *Barrons,* "Tesla Stock Drops as Analyst Takes Worst-Case View of EV Economics", May 12, 2022.

Building a Robust EV Supply Chain in the U.S.

The U.S. currently has a vulnerable EV supply chain heavily reliant on imports for semiconductor chips, raw materials and EV batteries. The country is in a sprint to produce its own EV components in order to increase economic competitiveness, energy independence, and to shore up national security.

The key components of the federal EV strategy, as laid out in the 2021 Bipartisan Infrastructure Law, is to:

- Increase domestic manufacturing of EV batteries and components
- Advance environmentally responsible domestic sourcing and recycling of critical minerals

Boosting Domestic Semiconductor Chip Manufacturing

The U.S. is seeking to regain leadership in the semiconductor chip industry it created. In recent decades, the U.S. government invested less and less in its homegrown chip industry, while other governments including Japan, Taiwan, South Korea, and, more recently, the European Union and China, invested more.

That's why today's state-of-the-art semiconductor chipmaking and packaging is currently centered in East Asia. This geographical concentration of the industry has contributed to global shortages.

Congress recently approved the CHIPS Act, which awards $52 billion in government subsidies for domestic semiconductor chip manufacturing. The CHIPS Act funding comes with stipulations to ensure that U.S. subsidies are spent on building factories in the U.S and not toward expanding production of chips in China.

Meanwhile, semiconductor chipmakers are making strides to expand U.S. production:

- In January 2022, Intel Corporation announced plans to build what could be the largest semiconductor facility in the world, located in New Albany, Ohio.
- In late 2021, Ford and Global Foundries announced a partnership for semiconductor manufacturing and technology development within the U.S. This agreement could result in new chip designs specifically for Ford as well as an increase in the domestic production and supply of chips for the overall automotive industry.
- Wolfspeed opened a new, $1 billion semiconductor chip facility in upstate New York on April 25, 2022.

These efforts are designed to boost domestic semiconductor chip capacity and reduce America's reliance on Asian manufacturing hubs.

Building a Domestic Battery Supply Chain

Most of the batteries that U.S. EV manufacturers rely on come from outside of the country, with China being a major supplier. This is largely because the U.S. is still lacking a cradle-to-grave battery supply chain.

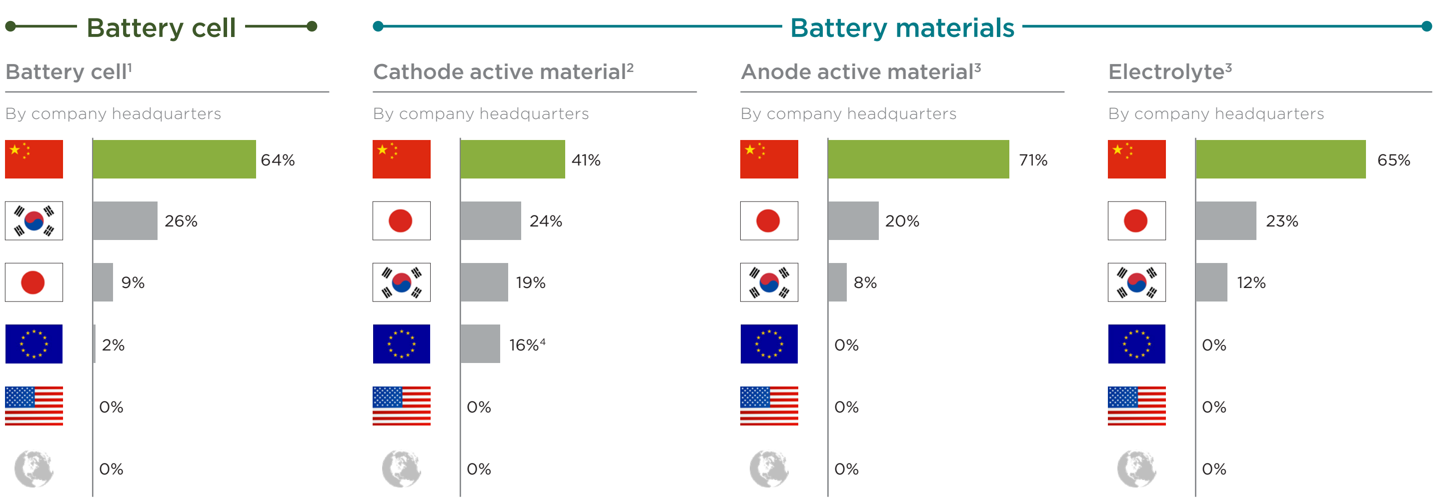
The Top 10 EV Battery Manufacturers

Rank	Company	2021 Market Share	Country
#1	CATL	32.5%	China
#2	LG Energy Solution	21.5%	Korea
#3	Panasonic	14.7%	Japan
#4	BYD	6.9%	China
#5	Samsung SDI	5.4%	Korea
#6	SK Innovation	5.1%	Korea
#7	CALB	2.7%	China
#8	AESC	2.0%	Japan
#9	Guoxuan	2.0%	China
#10	PEVE	1.3%	Japan

Source: *Elements "Ranked: The Top 10 EV Battery Manufacturers"*, September 25, 2021.

China dominates the EV supply chain. Although rich deposits of battery-grade minerals are located in places like Australia, South America and the Democratic Republic of the Congo, China built the refineries that are needed to process these metals. Today, China controls nearly three-quarters of the market for the raw materials that go into these batteries.

Suppliers of key battery sub-components by country/region



1) Based on CY 2019 production; 2) Based on CY 2021 production, NMC and NCA technology only; 3) Based on CY 2021 production; 4) Reflects recent JV between BASF (51%) and Hunan Shanshan (49%) for CAM.

Source: B3, Benchmark Minerals Intelligence, Roland Berger

With battery components so heavily controlled by Chinese companies, the U.S. EV supply is vulnerable to disruption and price instability. Ensuring a domestic battery supply chain is necessary in order meet growing EV demand and achieve national climate goals.

In 2020, global EV lithium-ion cell manufacturing capacity was 747 gigawatt-hour (GWh). The U.S. accounted for roughly 8% of that capacity, or approximately 59 GWh. The U.S. capacity to manufacture batteries for EVs is expected to grow to 224 GWh by 2025.[7] But some analysts estimate that the U.S. alone may need 20-40 gigafactories over the next 15 years, with a combined terawatt (1000 GWh) of new battery capacity to meet projected demand.[8]

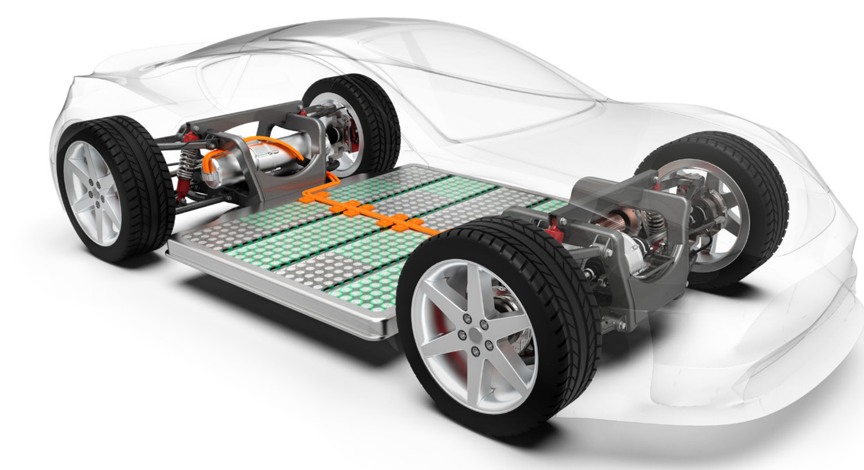
Gigafactories are plants that produce electric batteries at huge scale, primarily for use in EVs but also for a range of other renewable energy storage applications.

Source: *JustAuto*

Currently, the United States has no centralized place-based strategy for its battery industry. Several states, particularly those along what's known as "auto alley," have policies and strategies in place to encourage battery manufacturing and industries along the battery supply chain.

- For example, Michigan, Ohio, Kentucky and Tennessee are using economic development corporations to coordinate with private stakeholders and generate incentive packages to encourage new battery manufacturing plants in their states.
- Another approach is "innovation clusters" of complementary industries anchored around a research center or university. Kentucky, for example, has set up the Kentucky-Argonne Battery Manufacturing Research and Development Center in Lexington with both federal and state funding, to build a local battery supply chain hub. Similarly, Michigan provided support from the Michigan Strategic Fund attract EV battery R&D investments.[9]

Automakers and battery companies are spending unprecedented sums of money to build out North America's EV battery supply chain. In just the past year, automakers and their battery suppliers have committed $13.5 billion to create EV battery plants in North America. (This figure does not include projects where manufacturers have not clarified how much of their investments are earmarked for new battery plants and how much will go toward the vehicle production lines that will need the batteries. So the actual figure is higher.)[10] This includes investments being made by BlueOval SK, a joint venture between Ford Motor Company and SK Innovation to develop a 3,600-acre campus in Tennessee and lithium-ion battery plants in Kentucky.[11]



[7] *Senate Energy Committee Hearing,* "Full Committee Hearing to Examine the Scope and Scale of Critical Mineral Demand and Recycling of Critical Minerals", April 7, 2022.

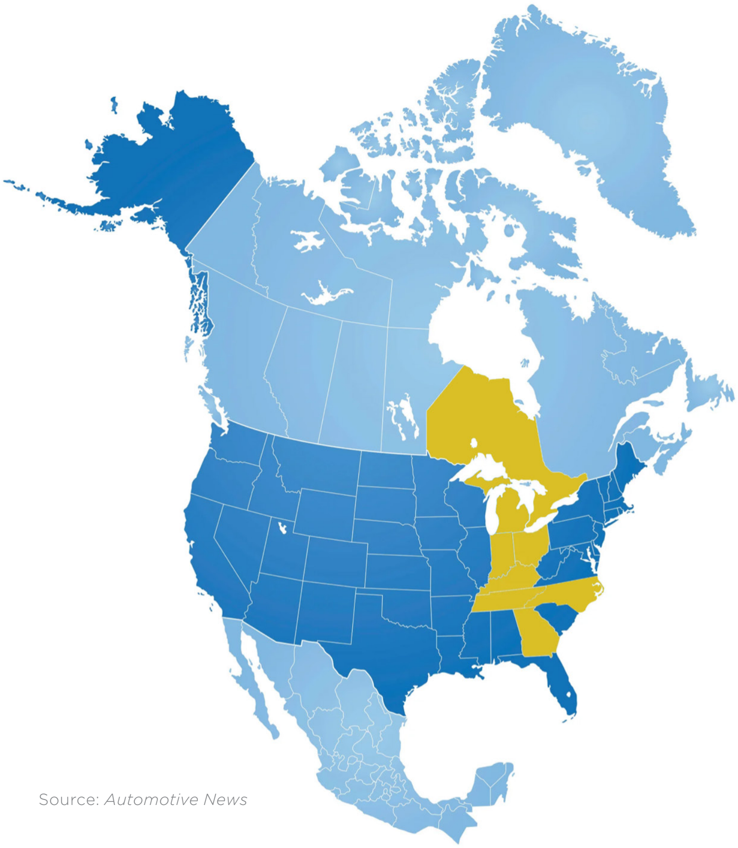
[8] *IEEE Spectrum,* "The Top Ten EV Battery Makers," August 26, 2021.

[9] *Center for Strategic & International Studies,* "The United States' Industrial Strategy for the Battery Supply Chain", December 14, 2021.

[10] *Automotive News,* "$13.5B committed to North American EV battery plants only scratches the surface," March 28, 2022.

[11] *CNBC.com,* "Ford and SK Innovation to spend $11 billion, create 11,000 jobs on new U.S. EV and battery plants", September 27, 2021.

North American EV Battery Plant Commitments



Source: *Automotive News*

There are 13 new battery cell gigafactories coming online in the U.S. by 2025, according to the Department of Energy. Of the 13 plants that are planned, 8 are joint ventures between automakers and battery manufacturers. Many of these new plants will be located in the Southeast or Midwest.

New Battery Plants Announced by Vehicle Manufacturers as of October 25, 2021

Manufacturer	Location	Expected Opening
Ford	NE of Memphis, TN	2025
Ford & SK Innovation	Central KY	2025
Ford & SK Innovation	Central KY	2026
General Motors & LG Chem	Lordstown, OH	2022
General Motors & LG Energy Solution	Spring Hill, TN	2023
General Motors & LG Energy Solution	TBD	TBD
General Motors & LG Energy Solution	TBD	TBD
SK Innovation	NE of Atlanta, GA	2022
SK Innovation	NE of Atlanta, GA	2023
Stellantis & LG Energy Solution	TBD	2024
Stellantis & Samsung SDI	TBD	2025
Toyota	SE of Greensboro, NC	2025
Volkswagen	Chattanooga, TN	TBD

Source: *Automotive News*

On May 2, 2022, the Biden administration announced that it will provide $3.1 billion in funding to support efforts to make EV batteries and components in the U.S. The funding, part of the Bipartisan Infrastructure Law enacted last year, will aid plans by U.S. companies to build new factories and retrofit existing ones to make EV batteries and related parts.

Across the pond, the European Union has allocated 2.9 billion euros ($3.1 billion) specifically to support EV battery plants, with individual member states providing additional money. As of March 2022, Benchmark Mineral Intelligence reports that the European Union is on track for 27 EV gigafactories by 2030, up from seven at year-end 2022.

Post BREXIT, Great Britain has allocated up to 1 billion pounds ($1.2 billion) to support Britain's EV battery supply chain. It currently has one small 1.9 gigawatt-hour (GWh) Nissan plant in Sunderland, northeast England, and two larger ones planned as of May 2022.

Domestic Sourcing of Critical Metals

Lithium-ion batteries are expected to remain the most widely used technology for EVs for the foreseeable future. Responsible and sustainable domestic sourcing of the critical materials used to make those batteries – lithium, cobalt, nickel and graphite – will help avoid or mitigate supply chain disruptions and accelerate battery production in America to meet demand and support the adoption of EVs.

President Joe Biden has invoked the Defense Production Act in a bid to boost domestic production and processing of key battery raw materials to reduce the country's dependence on foreign supplies. This executive action aims to increase the country's output of these minerals and require companies to prioritize federal rather than foreign contracts. In terms of actual financial incentives, mining companies will be able to access $750 million from a federal fund.

The U.S. has enough reserves of lithium, and other metals to build millions of its own EVs, however, it takes years to develop new mines and processing facilities. Although the U.S. pioneered many of the methods of mining and extraction globally, it sold or surrendered many of those facilities in previous decades. Until Congress can align on stronger infrastructure spending to help build the supply chain to the next level, such presidential executive actions are baby steps to gain U.S. mineral and metal preeminence back.

Buying Direct from Mines

The price volatility of critical minerals is passed downstream to battery production capacity and ultimately, automakers' bottom line. So they recognize the need to vertically integrate their businesses into battery materials as well. Right now, that means directly sourcing raw materials from mines, instead of going through suppliers. This harkens a return to the historical automotive business, which was deeply integrated, and away from the modern auto industry, which was pushed by investors to buy raw materials via suppliers.

With the domestic mining push in its nascent stage, U.S. automakers are building long-term mining relationships in North America and finding stable trading partners like Australia in order to secure a steady supply of battery metals. According to the Initiative for Responsible Mining Assurance, automakers are pushing mines for more transparency and audits of their practices.

The Role of Technology

Right now, the U.S. doesn't have enough domestically supplied materials, so materials substitution and recycling will be key to the transition to EVs.

Battery Chemistry Reformulations

Battery chemistries are constantly evolving, as automakers come up with new models with different characteristics. New ingredient formulas—in addition to new designs—are deprioritizing the need for certain raw materials.

The Problem with Cobalt

According to The Cobalt Institute, EVs are the top driver of cobalt demand, responsible for 34% of the global total in 2021. EVs use a variety of lithium-ion battery chemistries, with cobalt-containing cathodes currently having the largest share. This is due to their energy density and performance – cobalt is particularly important for stability and safety. And cobalt is relatively expensive; the U.S. Department of Energy says cobalt accounts for 25% of the cost of an EV battery.

To make matters worse, mining cobalt is linked to child labor, environmental damage and loss of habitat to local wildlife. Some 74% of mined supply comes from the Democratic Republic of Congo while 72% of the total production is refined in China. Both regions have been accused of environmental and human rights abuses.

So many EV makers are moving toward low-cobalt and cobalt-free batteries, lowering production costs. SPARKZ, a California-based start-up is spearheading the first high-energy-density cobalt-free, lithium-ion battery made in America. Some automakers have also developed batteries using more nickel or aluminum to reduce reliance on harder-to-source, pricier metals.

Emergence of LFP Batteries

One type of lithium-ion battery chemistry without cobalt that has gained traction with some automakers is Lithium Ferrous (Iron) Phosphate (LiFePo4 or LFP). Chinese EV-makers have favored LFP for a while, and now some American and European brands have announced that they will use LFP in lower-priced models. The LFP battery operates similarly to other lithium-ion batteries, however, phosphate is used instead of cobalt oxide.

The biggest advantage of LFP is its low cost; the iron and phosphorus that make up its composition are mined at enormous scales across the globe and are widely used in many industries. Other advantages of LFP batteries are a longer lifespan and being safer than other battery chemistries.

But a key sticking point for wide-scale LFP adoption has been energy density, which impacts driving range. LFP batteries offer only 65% to 70% of the density that chemistries containing nickel, cobalt, and manganese provide.[12] This means that to achieve the same driving range, the physical size of an EV battery would need to be bigger – a concern in vehicles where space is at a premium. The bigger size would also make the LP battery heavier, which can reduce efficiency in an EV and possibly cause more wear on tires. Other LFP disadvantages include a slightly higher self-discharge rate and according to some reports, a potential loss of range in very cold conditions. Analysts speculate that LFP batteries will be more geared toward entry-level vehicles, instead of premium models.

Self-discharge is when a battery loses the energy stored in it by itself – even when not demanding any energy. It happens in every type of battery system that stores energy, but the speed of self-discharge can cause concern.

Source: *Panasonic Batteries*

Lithium prices have surged this year, causing a big bump in battery pack prices. So the LFP price advantage has been blunted somewhat. But all EV batteries use lithium, so the price rise affects all chemistries.

While battery experts believe lithium-ion batteries will continue to dominate the battery sector in the next decade, a number of rapidly emerging new battery technologies could potentially challenge the proposed future dominance of lithium-ion batteries. U.S. start-ups Factorial Energy, QuantumScape and Solid Power have placed big bets on solid-state technology. Solid-state batteries don’t have a liquid electrolyte and, thus, will be lighter, store more energy and charge faster. They are also a lot less likely to ignite and, therefore, need less cooling equipment.

Improvements in the energy density of EV batteries, such as the amount of energy batteries can store per kilogram, as well as their cycle life, how many times a battery can be charged and discharged, will also affect the demand for minerals. Should density and cycle life increase meaningfully, then the demand for new batteries and the minerals they require will fall.

Last year, the Department of Energy allocated $200 million to seven national labs where scientists are charged with cutting battery costs, increasing range, and getting charge times down to 15 minutes or less.

[12] *IEA*, “Global Supply Chains of EV Batteries”, July 2022.

Extension of First Life for Batteries

Extending the first life of an EV battery reduces the need for critical materials; it's an alternative to a new battery. First life extension opportunities include battery repair, refurbishment and remanufacturing.

Remanufactured batteries are comprised of repaired components instead of sourcing, manufacturing and installing new batteries. The failed battery from the vehicle is removed and fixed for use in the next vehicle.

Just like the remanufacture of an ICE transmission is 50% of the cost of replacement, first life extension of EV batteries is the most economical and environmentally friendly option. A remanufactured/refurbished/repaired battery reduces the cost of replacement by up to 50% compared to a new battery.

The Basics of EV Battery Structure

In general, EV batteries are composed of cells. A cluster of cells makes up a module, and a cluster of modules make up a pack. Ultimately the pack is installed in an EV.

An EV module has cells welded or otherwise physically attached to each other. Multiple battery cells are assembled into a module, wrapped in steel plates, and have their poles welded together to produce the correct voltage. Normally, around 12 cells go into a conventional battery module for EVs.

Source: *Samsung SDI*

At this juncture, not all EV batteries meet the technical requirements to extend the first life. Depending on failure type, some batteries are more desirable to fix due to the complexity and cost of the replacement parts. Typically, battery cells cannot be economically replaced when welds prevent the individual removal of the cells.

Plus, the failure rate of the modules dictates the yield when recapturing material and drastically effects the economics of the repair. But designing batteries for serviceability improves the yield, reduces the cost and raw material consumption, and allows for a more complete lifecycle.

Everything will eventually meet its end of life, including EV batteries' recapture of critical materials. Deferring this day as long as possible preserves the materials both in the ground and in the battery by allowing the technological advancements of recycling to improve, increasing the material yield and lowering the costs of the recycling process.

Reducing the cost to service batteries while the vehicle and battery are still under the manufacturer's warranty also reduces the cost of EVs. Additionally, providing a low-price battery for aftermarket extends the useful life of EVs and makes them more desirable in the older years when resold.

The role of first-life EV battery extension is moving to the forefront to combat current raw material shortages and rising commodity prices. Widespread first-life extension reduces the need for new mining and extraction as battery demand continues to grow unabated. Moreover, first-life extension of EV batteries is in everyone's best interests as battery recycling systems evolve and mature. After all, climate change waits for no one and there is only one planet to live on right now.

The Role of Recycling

The lithium-ion batteries that power EVs can be recycled, but this is not yet a universally established practice. But countries that can reclaim valuable minerals and metals from spent batteries can lessen their reliance on foreign sources and potentially cut materials costs. The U.S. 2021 Bipartisan Infrastructure Law provides an additional $60 million to support the reuse and recycling of used EV batteries. However, the U.S. currently has no federal recycling mandate or recycled content requirements for lithium-ion batteries.

California created the Lithium-Ion Car Battery Recycling Advisory in 2018 to draft recommendations with the goal of ensuring that virtually all lithium-ion EV batteries in the state are reused or recycled in a safe and cost-effective way. The group submitted its final policy recommendations to the state legislature in May 2022.[13] These recommendations, if adopted, may provide a useful roadmap for the rest of the country on how to manage and recycle EV batteries. At the federal level, a bill that would set up a similar task force to develop regulatory pathways for battery recycling has so far failed to advance in Congress.

Countries in Europe and East Asia have already set ambitious targets for battery life-cycle sustainability. U.S. auto industry players are already partnering with companies abroad that provide technical solutions for compliance requirements in Europe and elsewhere abroad. Any U.S. precedent for battery recycling will need to align with global standards so American automakers and battery manufacturers avoid penalties when exporting vehicles abroad. Representatives from more than 15 countries, including Japan and China, are expected to meet in September 2022 to discuss International Organization for Standardization (ISO) standards for EV battery material, which could end up impacting recycling standards.

Lithium-ion batteries are used in EVs, for energy storage on the electric grid, and in consumer electronics. China produced nearly 60% of the world's EVs last year so it's not surprising that the country is also the global leader in recycling lithium-ion batteries, far outpacing all other nations.[14] As of late 2021, China had more than three times as much existing and planned lithium-ion battery recycling capacity as the U.S.[15]

[13] *California Environmental Protection Agency,* Lithium-Ion Car Battery Recycling Final Report, March 16, 2022.
[14] *CleanTechnica,* "Top 3 Countries in the Global EV Revolution in 2021 – Part 2", May 6, 2022.
[15] *ACS Energy Lett.* 2022, 7, 2, 712–719, January 19, 2022.

China leads the world in lithium-ion battery recycling

Existing and planned lithium-ion battery recycling capacity in late 2021 in tons per year

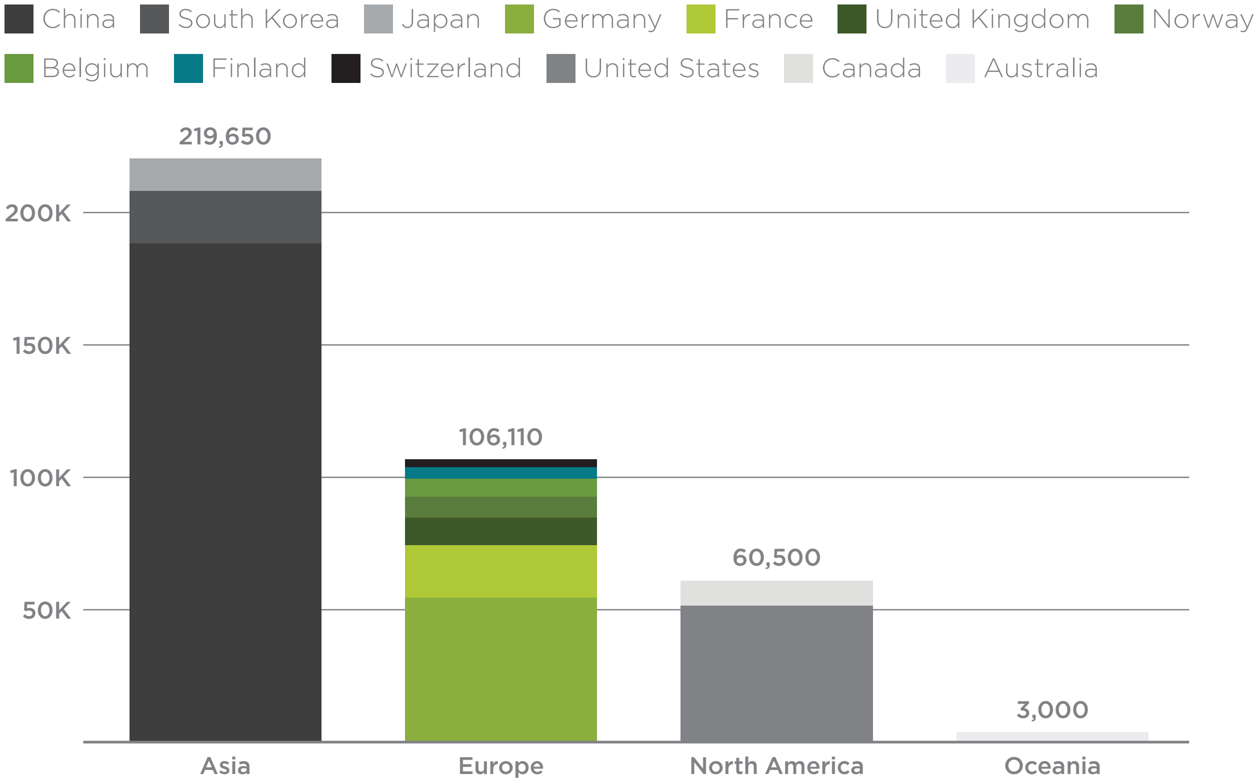


Chart: Canary Media • Source: Z.J. Baum, et al. (2022) Lithium-Ion Battery Recycling—Overview of Techniques and Trends. ACS Energy Letters

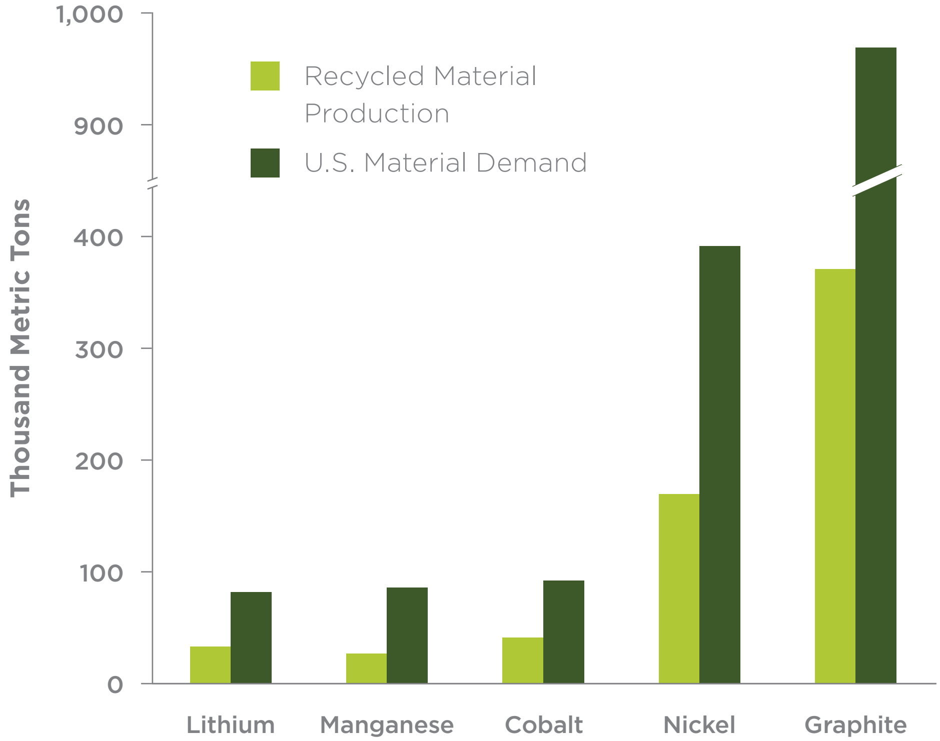
EV battery recycling capacity has lagged battery production, in part, because it takes years of operating an EV before its battery pack needs disposal and EVs are still a relatively new mass-market trend. The amount of spent EV batteries reaching the end of their first life is expected to surge after 2030, at a time when mineral demand is set to still be growing rapidly.

Recycling would not completely eliminate the need for continued investment in new supplies. But recycled quantities of copper, lithium, nickel and cobalt from spent batteries could reduce combined primary supply requirements for these minerals around 10% by 2040, according to some estimates.[16] Other analysts predict that under a best-case scenario – which assumes a 95% collection and recovery of the relevant metals, as well as a shift toward low-cobalt and no-cobalt chemistries – the U.S. could meet up to 30% to 40% of the anticipated material demand for lithium, nickel, manganese, cobalt and graphite in passenger EVs with recycled battery materials by 2035.[17]

[16] *IEA (2021),* The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris

[17] Ambrose, Hanjiro and Jimmy O'Dea. 2021. *Electric Vehicle Batteries: Addressing Questions about Critical Materials and Recycling.* Cambridge, MA: Union of Concerned Scientists.

Meeting U.S. Passenger EV Battery Demand with Recycled Materials, 2035



Source: *BNEF 2019; Dunn, Et Al.*

Note: Material supply and demand is based on the weighted average of U.S. passenger EV sales and cathode market shares. The analysis is based on an on-road passenger EV population of roughly 1 million in 2019, increasing to 43 million in 2035, and assumes 95% of metals from retired batteries are recovered.

Direct Lithium Extraction & Enhanced Metals Recovery

Emerging technologies, such as direct lithium extraction or enhanced metal recovery from waste streams or low-grade ores, could augment future supply volumes.

Direct lithium extraction extracts lithium from underground brine. It could be a game-changing extraction method, potentially delivering 10 times the current U.S. lithium demand from California's Salton Sea known geothermal area alone. The Salton Sea sits on the seismically active San Andreas Fault. Lithium-rich geothermal brines represent a vast, untapped resource that can potentially be developed into a sustainable, robust domestic supply.

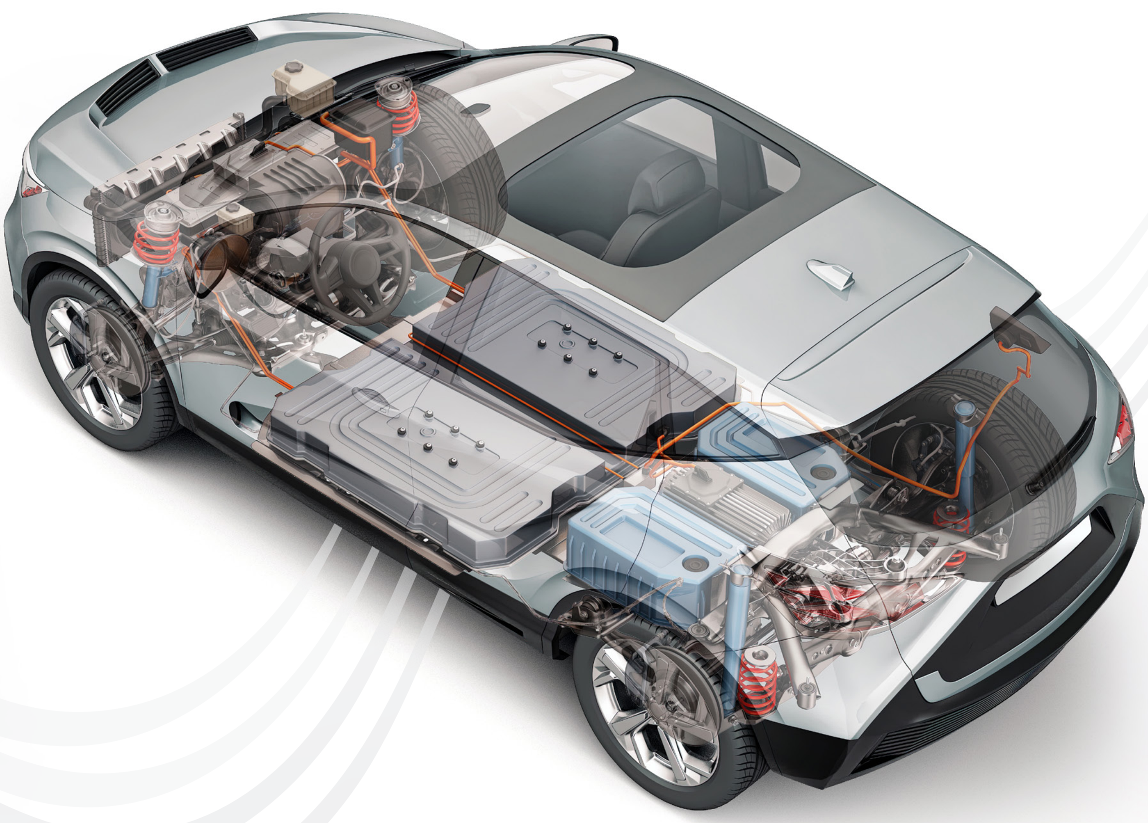
Enhanced metals recovery from mining and processing waste (mining residues, slag, sludges and tailings) provides a clear opportunity to increase supply. Better treatment of waste streams can also reduce the risk of hazardous materials entering the environment. Worldwide governments are increasingly taking notice of the opportunities to improve metal recovery from waste streams.

Innovative Solutions Will Overcome Supply Chain Challenges and Propel Our Electric Future

The pandemic and political instability have wreaked havoc on car companies' complex global supply chains. Going forward, automakers look to exert greater control over their inputs – from the semiconductor chips that EVs run on to the metals that go into EV batteries to EV battery composition, manufacturing and recycling.

A meaningful portion of demand for EV battery materials could be met by recycling, transitioning to low-cobalt cathode formulations, and high levels of material recovery. Widespread battery recycling can create a more stable domestic source of materials for battery production, reduce the demand for raw materials, and minimize the risks of supply chain disruptions. Recycled EV batteries can also provide the U.S. with an added measure of energy independence.

Climate scientists agree that vehicle electrification is one of the best ways to reduce planet-warming greenhouse gas emissions. The switch to EVs is also making the U.S. more energy independent from a turbulent global oil market. The multiple fuel sources used to generate electricity results in a more secure energy source for the electrified the transportation sector. All of this adds to the nation's energy security, cleaner air and water, and a better quality of life for all.



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