COMPETITION, CLIMATE, AND RESILIENCE:
Securing the EV Supply Chain in America

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Wilson Center

SUPPLY CHAIN INITIATIVE

Executive Summary:

This report focuses on the challenges and opportunities facing the United States as it embarks on the ambitious transition from gas powered to electric vehicles while geopolitical competition is intensifying between the US and China.

The paper reflects the dialogue sustained by a high-level group of stakeholders, including industry experts, policymakers, and independent analysts convened by the Wilson Center.

The EV supply chain highlights the complexities of modern manufacturing in the energy transition: the need for both efficient legislation and regulation, adequate financial incentive structure, and fast-moving innovation. The industry requires an approach that embraces the complete lifecycle of the product, from extracting critical minerals through to end-of-life recycling and repurposing.

The United States must make the EV supply chain more resilient by strengthening the critical minerals supply chain, enhancing battery design and recycling, and expanding the charging network.

Our report argues that to do this, a number of important steps must be taken by government and industry:

Critical Minerals

- Streamline regulatory and permitting practices
- Work with allies to develop resources and processing
- Accept the geopolitical and climate implications of the critical minerals industry
- Invest in human capital
- Develop and negotiate global governance structures
- Build critical minerals stockpiles
- Develop new technologies for extraction and processing

Battery Design

- Develop modularity in EV batteries
- Invest in human capital development, specifically for R&D and battery maintenance
- Utilize technology and AI, specifically mathematical modeling and digital twins in the battery design process

Battery Recycling

- Utilize anticipatory thinking to develop adequate infrastructure and facilities, and at the same time, public education and workforce development training
- Fully develop the distinct ecosystems that comprise battery recycling, including dismantling, recycling, and transportation of recycled materials, while also incorporating the auto industry
- Develop and implement a nationwide regulatory system for the transportation of battery materials for recycling as well as for the value chain with auditing protocols

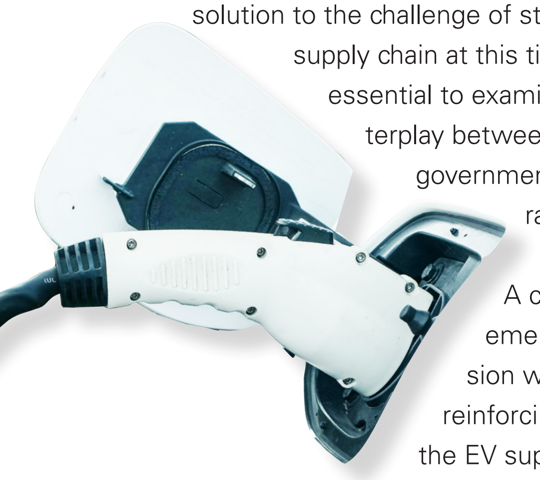
- Ensure appropriate training and workforce development for those dismantling batteries and transporting components
- Determine whether the private sector (and more specifically, individual companies) will lead recycling or if the federal government should lead and coordinate the effort
- Foster regional collaboration within North America for battery recycling to better compete in the face of increasing geopolitical competition

Charging Network

- Develop and implement a common North American standard for chargers and the charging network
- Scale up and build out the charging network, particularly outside of cities, via partnerships between OEMs and car dealerships to install charging stations in their lots and incorporate new, innovative points of charging into architectural guidelines, so that charging points are built into new construction
- Sustain the long-term health of the charging network, specifically the maintenance, repair, and upgrading of current EV charging stations
- Focus on the human capital element, both the labor pool required for building out the charging network and conducting upkeep
- Implement policies that encourage managed charging so as to not overload the electricity system while also taking advantage of peak production of renewable energy

Introduction

Since the passage of the Inflation Reduction Act (IRA) it has become clear that, while the IRA addressed some of the issues facing the electric vehicle (EV) supply chain, there are many remaining challenges that need to be resolved if the American public is to adopt EVs rapidly and en masse. In 2023, the Wilson Center convened a group of industry experts, former policymakers, and independent analysts to discuss the EV supply chain and to identify challenges and potential solutions. In doing so, the working group considered the entire extent of the supply chain, from mining battery metals to the building out of the charging network and battery recycling. The group observed that challenges in the transition to EVs stem from a complex combination of factors, including but not limited to the geopolitical context, developing international norms, government policy, major corporate decisions, the impact of climate change, and political incentives. Given this complexity, as well as the intricacy of the supply chain itself, it would be naïve to assume that there is a simple solution to the challenge of strengthening the EV supply chain at this time. Instead, it is essential to examine the dynamic interplay between the global context, government actions, and corporate decision-making.



A central theme that emerged in the discussion was the importance of reinforcing the resilience of the EV supply chain. In many ways, the EV supply chain highlights the complexities of modern manufacturing in the energy transition: the need for both efficient legislation and regulation and adequate financial incentive structure, fast-moving innovation, and an approach that embraces the complete lifecycle of the product, from extracting critical minerals through to end-of-life recycling and repurposing.

The resilience of the supply chain is not the only factor that must be incorporated into our analysis. Other elements, such as sustainability and geopolitical competition, as well as competitiveness and consumer preferences, must be considered. Furthermore, to bring about the transition to electric vehicles in the United States, while protecting US jobs and building independence from Chinese value chains, much more attention must be paid to the changing dynamics of the market, the complexity of supply chains, the tension between geopolitics and energy transition and the urgent need for closer industry-government cooperation.

> **The complexity of the EV supply chain highlights the need for international cooperation in the policy, raw materials extraction and processing, and manufacturing sectors.**

In addition, the supply chain highlights the need for international cooperation and coordination in the policy, raw materials extraction and processing, and manufacturing sectors. China has established a dominant position in almost every aspect of the EV supply chain, from the extraction and processing of battery metals, through to battery technology and design, and the building out of charging infrastructure. Reducing dependence on China has been embraced by both the government and the private sector in the United States, but Chinese vehicles are making inroads into markets around the world due to their sophistication and competitive pricing.

The Importance of the EV Revolution and its Impact on US Security and Prosperity

Much is riding on the future of the global EV market. In addition to the obvious impact on carbon emissions and climate mitigation, there are significant implications for US employment and international competitiveness.

Climate and Emissions:

As the energy transition advances globally, reducing emissions from transportation is a critically important element, without which progress will be almost impossible. Since 1990, the United States has made considerable progress in reducing the overall carbon intensity (CI) of its economy, seeing overall emissions decline by an average of 0.9% per year since 2005, at the same time as GDP has increased from $13.04 trillion to $25.46 trillion, and population has grown from 295.5 million to over 333 million people. Energy and emissions consumption per capita and per dollar of GDP have therefore declined significantly.

However, some sectors of the economy have seen greater changes than others. Whereas both industry and electricity generation have dramatically reduced their overall emissions since 1990 (by 16.8% and 16.2% respectively), greenhouse gas emissions (GHG) from transportation have actually grown by 20.3% since that year. In 2022 in the United States, transportation activities accounted for the largest portion of (GHG) (28.9%). Even when electricity generation emissions are redistributed to the different consuming sectors, transportation remains tied with industry as the main emitter. When it comes to emissions from fossil fuel consumption, the transportation sector dominates, producing over 500 million tons (MMT) of CO^2 equivalent more than industry.

These figures point to the urgency of reducing emissions from transportation and therefore of transitioning away from the internal combustion engine (ICE) to EVs, especially when the carbon intensity of electricity generation is declining so rapidly in the US.

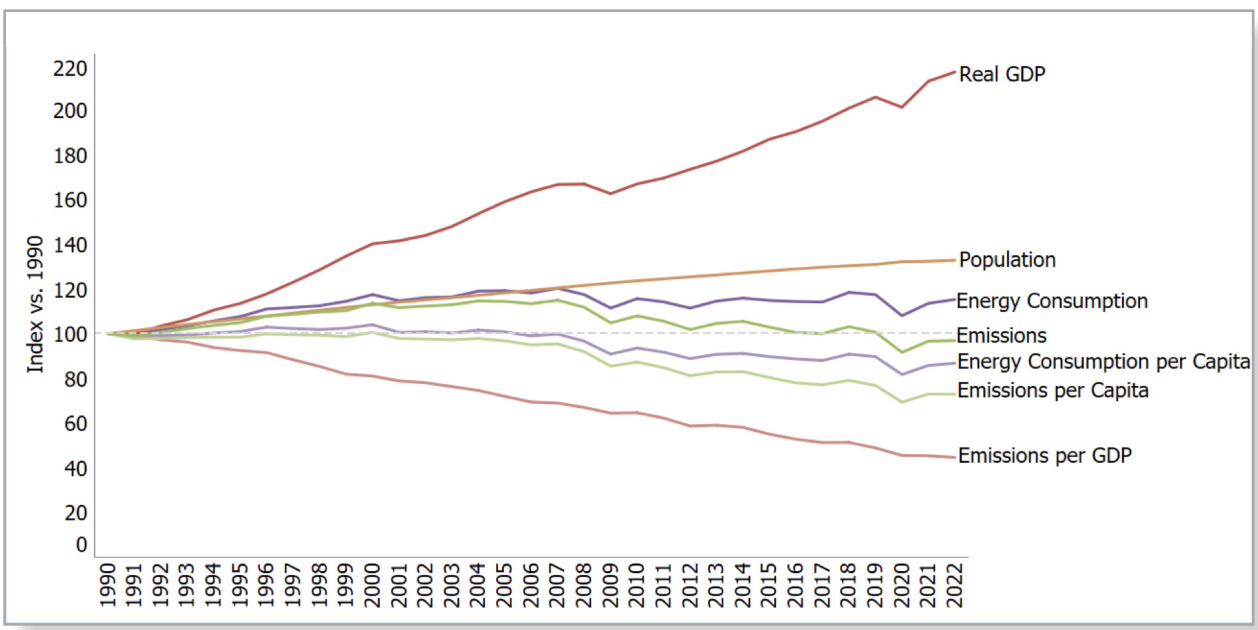


Figure 1. U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product (GDP) 1990-2022 [1]

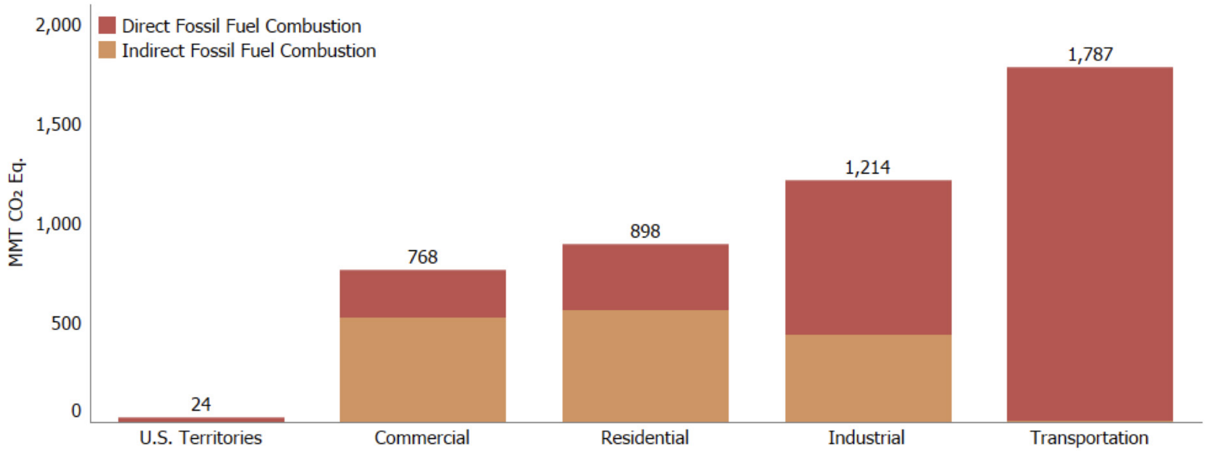


Figure 2: 2022 U.S. End-Use Sector Emissions of CO2 from Fossil Fuel Combustion [2]

Employment Effects:

The technological complexity of electric vehicles necessitates input from and the involvement of various disciplines. From scientific research and design and development (involving chemical, electrical, industrial, materials, and mechanical engineers, software developers, and industrial designers) to manufacturing (involving electrical and electronic equipment assemblers, industrial production managers, and engine and other machine assemblers), EV maintenance, and sales and support, the EV industry has the potential to play a significant role in terms of jobs and economic competitiveness in the US.

The Edison Electric Institute estimates that by 2030, the US will have 22 million electric vehicles on the road.[3] Particularly optimistic estimates foresee the creation of 650,000 additional jobs, those both directly and indirectly related to the EV industry, including supporting infrastructure such as charging stations.[4] More conservative estimates, such as those from the Economic Policy Institute (EPI), estimate the creation of around 150,000 jobs in the auto industry by 2030 - if the share of battery electric vehicles reaches 50% of domestic auto sales by that same year.[5]

Job growth in recent years has been impressive. According to the Department of Energy, the electric hybrid, plug-in hybrid, and EV industries combined employed 198,000 individuals in 2016 and 242,700 in 2019.[6] In 2020, over 130,000 people were employed in just the EV industry in the US - a year in which sales for EVs grew by 40% compared to the year prior.[7, 8] The majority of EV jobs are located in California, Michigan, and Texas, but recent investments in light, medium, and heavy-duty factories in Tennessee, Colorado, Indiana, Georgia, Ohio, Michigan, and Massachusetts may change the current picture. According to DOE's 2020 US Energy and Employment Report, electric vehicle-related jobs increased by 26.2% in 2022, adding a total of 21,961 jobs to the industry.[9] Relatedly, hybrid electric vehicle jobs grew by nearly 20% (23,577 new jobs), plug-in hybrid vehicle jobs grew by 30% (14,790 new jobs), and hydrogen fuel cell jobs increased by just over 40% (4,160 new jobs) in 2022, according to the DOE.[10]

It is not just the number of jobs that has attracted attention. The skill sets required in the auto industry are rapidly changing as EV manufacturing demands more software engineers, automation experts and, of course, battery technicians and design experts. The Bureau of Labor Statistics is predicting a major shortage of software engineers (1.2 million) in the next few years.[11] This means that universities and community colleges are having to adapt their curricula and hire new instructors. Auto companies are recruiting from countries with strong engineering higher education systems. As a recent article on NPR's website noted, "the race is on. Not simply to reach the electric future, but to find the right minds to get there."[12]

US Competitiveness and Strategic Competition with China:

There is little doubt that the US automobile industry has come to be seen as not only a major driver of employment and overall prosperity, but also as a central part of the American identity. In this sense, US auto manufacturing is the iconic industry for the nation. Taking the industry into its new era will not only transform the industry itself but it also has the potential to transform the economy and in turn, competitiveness.

A large part of that equation is to be found in the technological and research and design dimensions of the EV industry. As companies compete to improve the driving experience for motorists while also producing more safe and efficient cars with a longer range, we are seeing impressive technological advances to not only reduce weight, but also lower the total amount of key minerals used in battery chemistry. There is also a greater focus on "smart" vehicles that interact with their environment, whether that be urban or rural, through V2X systems.[13] Though this has less to do with the move to electric vehicles and more to do with overall innovation in the auto sector, it is clear that the new generation of EVs is going to be much more deeply integrated into 5G technologies that connect cars to data flows from their surroundings.

This is where we begin to see the broader implications for the US economy. We are going to need the massive build-out of charging infrastructure here in the US, and in the rest of North America as motorists demand more and faster charging stations to give them greater freedom to drive long distances. This charging infrastructure will involve massive investments in transmission, renewable energy generation, and in training and retraining technicians and specialists for installation, maintenance, and customer service.

The race to improve battery performance is currently focused on three competing systems: lithium-ion, lithium-sodium, and solid-state batter-

ies. We should expect progress in all three approaches, and there is a lot is at stake. While China currently dominates the global EV battery industry, with more investment now taking place, the US could leapfrog Chinese manufacturers and produce cutting-edge technologies. In turn, it will boost the competitiveness of US manufacturers, open overseas markets and provide broader opportunities for global engagement.

Where the US does not retain its lead in the EV sector it cedes ground to competitors, and EPI estimates that the failure to take meaningful policy-driven action could result in the loss of over 75,000 jobs, driven by overseas production.[14] Bloomberg estimates the number of EV sold in the US to be around 10 million by the year 2040, but the failure to capture this market will push production overseas, with some estimating imports at around $100 billion, just for EV batteries.[15]

Globally, the EV transition is advancing rapidly, which can be seen in the shifting structure of car sales. Global sales of internal combustion engines (ICE) vehicles peaked in 2017 and, by 2026, sales of combustion vehicles are estimated to be 39% lower.[16] China has led the way, with explosive growth in EV sales in recent years (2022 saw 74% growth in EV sales), driven by generous consumer subsidies and a strong economy. Although 2023 saw the end of those subsidies and broader economic malaise, EV sales still increased by 21%

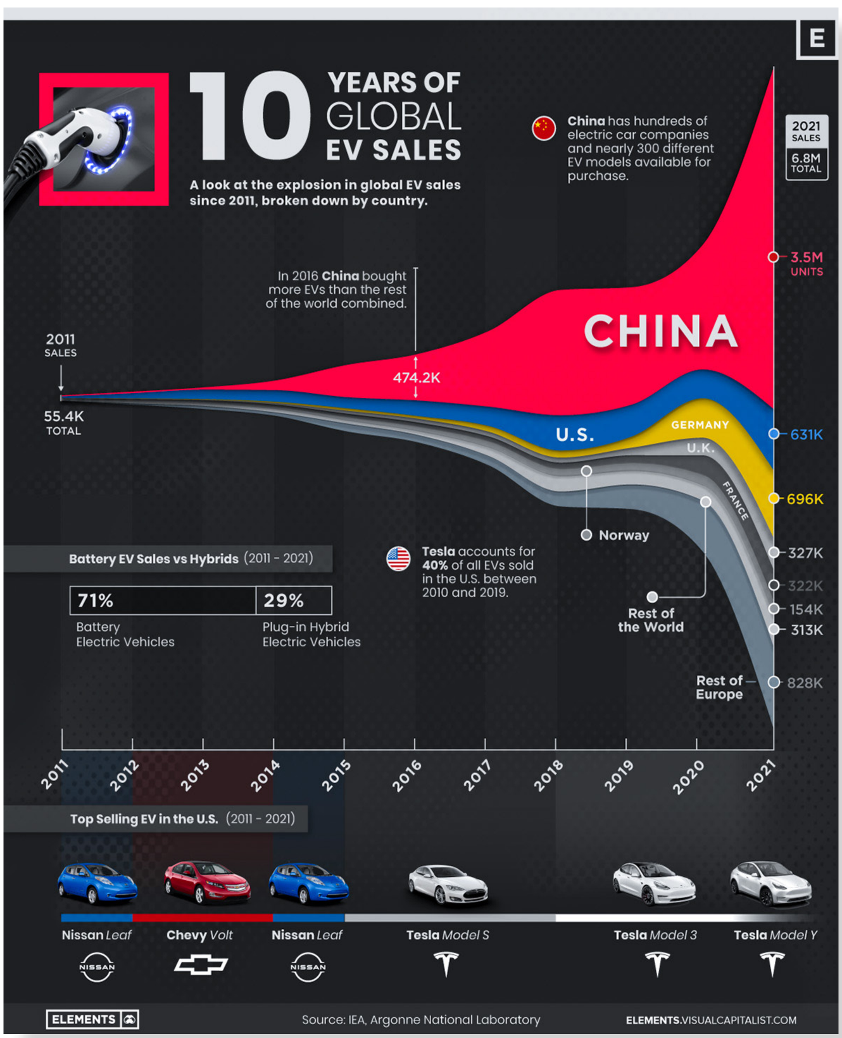


Figure 3: 10 Years of Global EV Sales[18]

in 2023.[17] Growth in EV sales has been slower to develop in Europe and the US, but in 2023 with the Chinese deceleration, those two regions surpassed China, growing by 37% and 47% respectively.

The deceleration in China is significant for three reasons. First, it shows the importance of the subsidy regime in jump-starting consumer interest in EVs. Second, it has led to a price war among EV manufacturers to try to maintain market share. Third, it puts extra pressure on Chinese manufacturers to focus more on exports. In fact, announced increases in EV manufacturing capacity far exceed projected domestic demand, with China expected to export millions of EVs in the coming years.

Despite increasingly assertive policies in Europe and the US towards Chinese EV imports, China's firms are both exporting and investing overseas. BYD, China's leading EV manufacturer, replaced Tesla as the world's largest seller of EVs in the world in the final quarter of 2023, and has been investing aggressively in Uzbekistan, Thailand, Brazil, Hungary, and Mexico.[19] As the company finds the domestic market more saturated, it is clearly looking to overseas markets and is intent on gaining access to global major economic blocs. In the past two years, this China-US struggle for EV markets has become even more acute. China has become a major player in the EV industry, not only within its own borders, but increasingly on international markets. In addition to exporting excess capacity of ICE vehicle production, China has increasingly been flooding global EV markets with low-cost, and often highly advanced car models that are unknown here in the US.[20, 21] Not only is this putting extra pressure on North American and European manufacturers today, it is also establishing brand recognition for Chinese producers that will pay dividends in the long term.

The ambitions of Chinese firms have been identified by major US manufacturers as an existential threat to their business. The Alliance for American Manufacturing has stated that the "introduction of cheap Chinese autos – which are so inexpensive because they are backed with the power and funding of the Chinese government – to the American market could end up being an extinction-level event for the U.S. auto sector."[22] In 2024 we have seen intensifying competition among Chinese auto makers, with the result that they are looking to break into the US market using brand names with which US customers are already comfortable.

As a recent article put it, "in the China market, the world's largest, dozens of domestic EV brands are fighting it out in a price war while foreign automakers have steadily lost market share. The intense competition has driven China's biggest EV makers...to accelerate exporting of EVs that can capture higher prices and profits in less competitive overseas markets."[23]

"in the China market, the world's largest, dozens of domestic EV brands are fighting it out in a price war . . ."

In recent months, a new argument has been added to the narrative on US-China EV competition. In February 2024, President Biden identified Chinese EVs as a security threat to the United States and the Commerce Department has been instructed to begin an investigation into the national security implications of the technology that is embedded in Chinese EVs.[24] According to the *New York Times*, the administration has identified a threat from "Chinese-made versions of common automotive software, which administration officials said could track where Americans drove and charged their vehicles, or even what music or podcasts they listened to on the road."[25] This argument is likely to take on added poignancy in an election year and in the light of widespread consensus in the US on the need to take aggressive action to counter Chinese geopolitical ambitions.

For the US EV industry to grow as projected, the US must take tangible and sustainable steps to bolster its leadership in EV production, such as incentivizing onshore investment, increasing domestic production of drivetrain components, increasing advanced manufacturing capacity, and pursuing and promoting trade agreements with enforceable measures.[26] There must also be a targeted focus on workforce development, job quality, and industry employment. Failure to do so will result in stagnation and in extreme scenarios, a decline in employment in this sector, which will have resounding consequences for the auto industry and US GDP overall - as the US auto sector has historically contributed around 5.5% of the country's GDP.[27]

The challenge for the US is multi-faceted:

1. Speed up the transition from ICE vehicles to EVs to reduce emissions from the auto-sector.
2. Secure the supply chain for batteries to provide the materials needed for mass production of EVs and build out opportunities for US employment and investment.
3. Ensure that current Chinese domination of the EV battery supply chain does not compromise national and economic security.

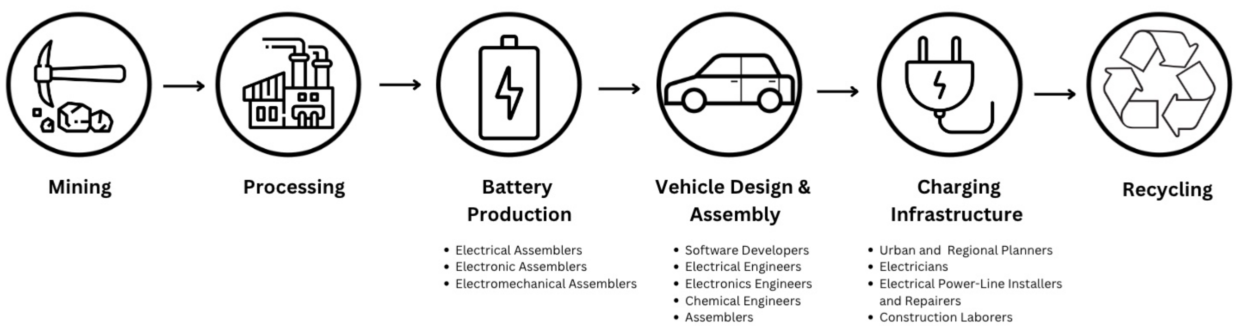


Figure 4: The Extended EV Supply Chain

The EV Supply Chain

The electric vehicle supply chain consists of many complex stages and processes, but for the sake of simplicity can be categorized into four primary processes: upstream, midstream, downstream, and end-of-life.

The upstream portion of the EV supply chain is the foundation for the EV battery and involves the extraction of raw materials. Lithium, nickel, cobalt, graphite, and manganese are all important materials for battery production, but the first three – lithium, cobalt, and nickel – are the most critical minerals for lithium-ion batteries. Lithium is primarily extracted from brine or hard rock. Explorations to extract lithium from geothermal brine are underway but have not yet yielded conclusive results. It's important to note the energy-intensive nature of both the upstream and midstream portions of the EV supply chain.

Upon extraction, the raw minerals are transported to facilities for processing and refining. Once the raw materials have been processed, they are used to produce cathode and anode active battery materials, which are then installed into battery cells. Heavy industrial processes involving heat and/or chemical treatment are essential to process and refine the raw materials into the high-grade sources required for battery chemical precursors. Though the development of new technologies is underway, processing is still very much regionally concentrated, and monopolies are more common than not. For example, five companies process three-quarters of global lithium carbonate and hydroxide production.[28] As explored in the *Mosaic Approach*, extraction and refining/processing facilities are often geographically distributed, meaning that additional resources, financial and energy-wise, are required in the transport of raw materials to their intermediate destination for processing.[29] It's estimated that battery minerals travel approximately 50,000 miles from their site of extraction to production.[30] In recent years, it has become increasingly common for processing facilities to be onsite at extraction facilities, though it is not the norm.

In the downstream portion of the EV supply chain, the precursor chemicals are used to produce battery cells, a process of two stages: electrode manufacturing and cell fabrication. Though cell manufacturing is proprietary, the process is relatively uniform across companies. Because cell manufacturing is highly energy intensive, the use of low-carbon energy is essential to keep emissions low. In simplistic terms, cell manufacturing entails three main steps: the production of electrodes, the rolling and subsequent drying out of the electrodes, and then the stacking of the electrodes with separators in between to produce the battery cell. The battery cells are then assembled into modules (stacks of battery cells protected by a metal frame) and the integration of modules, battery management system, electronics, and sensors produces the battery pack which is encompassed by protective materials to shield the battery from elements that could cause damage to the battery (such as water and salt).

Specifications of battery modules depend on various factors, including cell type and vehicle range. A module can hold less than ten, but in some cases, hundreds of battery cells. After this assembly process, battery manufacturers sell the battery packs to automakers who then install and integrate the battery pack into the vehicle, connecting it with the electric motor. Battery pack manufacturing can be done by cell manufacturers, but in some cases, like Ford and Stellantis, the automaker produces and then installs their own battery packs.

The fourth and final stage of the EV supply chain is end of life, sometimes referred to as re-use and recycling – which are two distinct processes. Refurbishing EV batteries can yield additional value – though this repurposing is often for "less demanding second-life applications…such as stationary energy storage and lower-power electromobility applications."[31] According to estimates by BMW, the minerals in an EV are worth approximately 1,000 to 2,000 euros per vehicle.[32] As of 2023, approximately 80 companies worldwide are involved in the EV battery recycling industry and this number is expected to increase more than tenfold by 2030. Experts estimate the global market for EV battery recycling to grow by $7 billion from 2022 to 2028.[33] The re-use process entails "disassembly of the pack, testing module/cells, and repackaging" for new applications.[34] Though reuse can generate additional revenue, the process is logistically intensive and is subject to significant economic and regulatory challenges.

As of 2023, approximately 80 companies worldwide are involved in the EV battery recycling industry and this number is expected to increase more than tenfold by 2030.

Technology for lithium-ion batteries is rapidly developing, but at this point, there are only three primary options for recycling: pyrometallurgy, hydrometallurgy, and direct recycling – all of which prioritize the reclaiming of expensive battery materials, specifically nickel, cobalt, copper, and aluminum. The battery is removed from the EV and undergoes pre-treatment which entails the removal and opening of the battery cells from the battery pack. Differences in battery pack designs mean that the process is manufacturer-specific and must be done by hand, which is time-consuming and costly.

The pyrometallurgical process entails melting the battery materials into an alloy composed of iron, copper, nickel, and cobalt. This process is energy-intensive, releases toxic chemicals, and results in the burning of still-viable materials. The hydrometallurgical process, on the other hand, utilizes an aqueous solution to separate materials from the compound. Currently, battery recycling is dominated by independent recyclers, but as EV uptake increases, more parties are entering the recycling market, including "OEMs, battery manufacturers, miners, and processors."[35] It's important to note that recycling processes are directly tied to specific cathode chemistry, meaning that recycled cathodes can only be installed in the same battery type.

Government and Corporate Progress in the EV Supply Chain

To compete with China and establish a truly resilient EV supply chain outside of China, the US government has established a clear set of incentives for the production of EVs manufactured in North America and a small number of free trade agreement (FTA) partners. These incentives, in the form of tax credits, represent a large part of the fiscal package included in the 2022 Inflation Reduction Act (IRA) and they have resulted in a dramatic rise in investment in the EV manufacturing sector across the United States. The IRA, by its inclusion of FTA countries in the definition of an eligible supply chain, has also spurred the nearshoring and friend-shoring phenomenon.

Presidential Determination for Critical Materials in Large-Capacity Batteries

In March 2022, President Biden signed a determination authorizing the use of Defense Production Act (DPA) Title III authorities to strengthen the supply chain for large capacity batteries. The determination specifically mentioned (but was not restricted to) lithium, nickel, cobalt, graphite, and manganese. The explicit connection to national security made in the determination is significant and is seen by industry and policy makers alike as an indication of the priority being given to this issue now in Washington. Although the funds being appropriated to support the DPA in this regard only total around $500 million, the impact may be significant in terms of:

- feasibility studies for mining and processing projects;
- by-product and co-product production at existing facilities; and,
- modernization of mining, beneficiation, and value-added processing with a focus on productivity, sustainability, and safety.

Although only a proverbial "drop in the bucket" of the total financing needed for critical minerals development in the US, this "seed capital" will further incentivize private investment and will encourage innovation and development of both green and brown field projects.

The 2022 Inflation Reduction Act (IRA)

The Inflation Reduction Act represented a major step forward in the nation's efforts to promote clean energy technologies in the automotive industry and it "....is perhaps the most significant legislation to accelerate transportation electrification in U.S. history."[36] Perhaps the most widely recognized provision of this legislation is the extension of the EV tax credit of $7,500 to 2032 (for consumers who earn less than $150,000 individually or $300,000 as a family). This tax credit is broken down into two main credit components: $3,750 credit for batteries constructed with materials mined in the US and/or countries with which the US has a free trade agreement, or materials recycled within North America. The second $3,750 credit is for vehicles with batteries manufactured or assembled in North America. The percentage of the value of components for both types of credit will begin increasing in 2024. Of note, to be eligible for the tax credit, no portion of the material can be extracted and/or processed by countries of concern (such as Russia or China). This stipulation will come into effect in 2024 for batteries and in 2025 for critical minerals. Provisions for the new manufacturer's suggested retail price (MSRP) and income caps began in 2023. The IRA also added another $500M to the DPA funds available for critical mineral projects.

Table 1: IRA Support for EVs

• *Light-duty EV tax credit* (Section 30D):
○ Extends through 2023 the tax credit of $7,500 for light-duty EVs (for consumers who earn less than $150,000 individually or $300,000 as a family).
• $3,750 credit for batteries constructed with materials mined in the US and/or countries with which the US has a free trade agreement or materials recycled within North America. The percentage of the value of critical minerals mined or processed in these countries is to increase over time, from 40% in 2023 up to 80% by 2032. Starting in 2025, to be eligible for the tax credit, critical minerals cannot be mined or processed in foreign entities of concern.
• $3,750 credit is for vehicles with batteries manufactured or assembled in North America. The percentage of the value of battery components manufactured and/or assembled in North America is to increase over time, from 50% in 2023 to 100% in 2029.
○ Eliminates the 200,000 vehicles sold per year cap for manufacturers.
○ Final assembly of the EVs must be in North America.
○ There will be MSRP limits and income caps starting in 2023.
• *Used EV tax credit* (Section 25E):
○ Used EVs that weigh less than 14,000 lbs., cost less than $25,000, and are less than 2 years old are eligible for either a $4,000 credit or 30% of the sales price of the vehicle – whichever is less.
• *Commercial EVs tax credit* (Section 45W):
○ Commercial EVs that weigh 14,000lbs or more are eligible for a tax credit of up to 30% of the sales price for heavy duty trucks, up to $40,000.
○ Commercial EVs weighing less than 14,000 lbs. are eligible for a tax credit capped at $7,500.

Furthermore, in May of 2023, the United States signed a bilateral battery minerals agreement with Japan, allowing cars using Japanese-sourced minerals to qualify for IRA tax credits in the US. Ensuing negotiations with the European Union have proven more difficult and have been a cause of tension between Congress and the Biden administration. However, the talks taking place at the Minerals Security Partnership (MSP) level may help to pave the way for an ultimate agreement.

The results of the various actions by the US government in terms of investment in the sector have been impressive. Across the country, more than 90 projects have been announced in the EV supply chain, with new investments totaling over $83 billion.

In May 2024, the Biden administration announced tariffs on $18 billion worth of imported Chinese goods, specifically electric vehicles, advanced batteries, solar cells, steel, aluminum, and critical minerals.[37] While President Trump initially implemented tariffs of 25% during his term as president, the Biden administration has quadrupled EV tariffs to 100%, while also doubling tariffs on semiconductors to 50%.[38] There are also new tariffs on certain critical minerals coming from China. These tariffs are slated to gradually go into effect over the next three years, meaning that inflationary impact should be minimal in the short term, but the Chinese response has yet to be seen. During his announcement of the new tariffs, President Biden argued that they are an attempt to combat the Chinese government subsidies which give Chinese companies an unfair advantage in the global market and reaffirmed his commitment to ensuring that EVs be made in the United States and by union workers.[39] Though US Trade Representative Katherine Tai recommended significant tariff exclusions, she did affirm that the implementation of the tariffs was also direct result of Chinese theft of US intellectual property.[40]

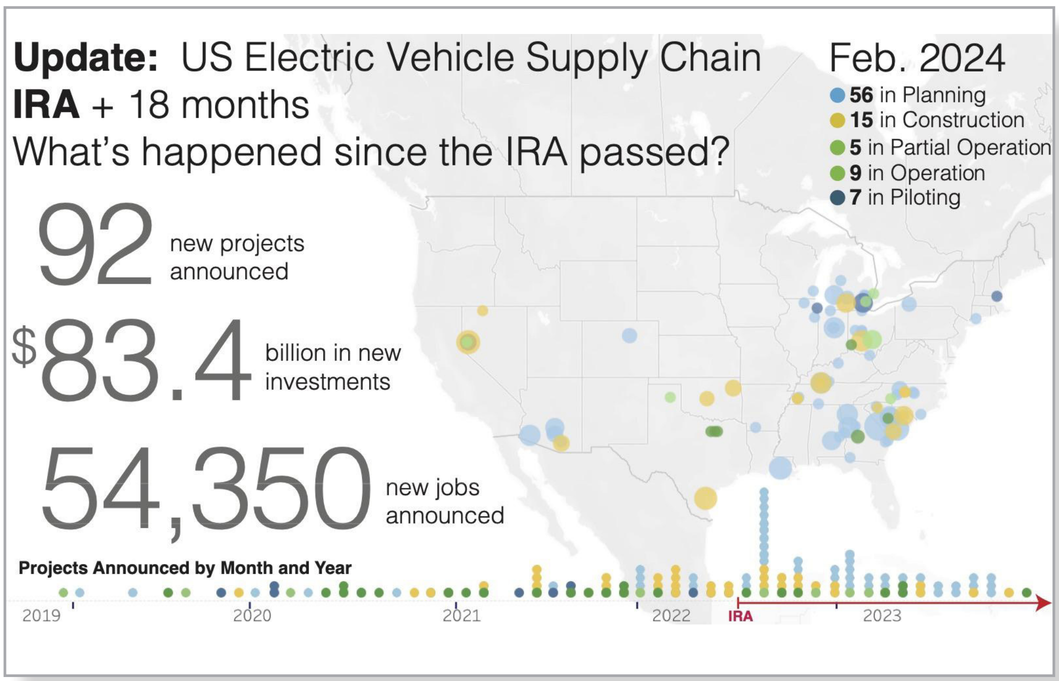


Figure 5: EV Supply Chain Investing since Passage of the IRA[41]

Vertical Integration

In China, the government has essentially acted as a central planning authority for the EV supply chain, ensuring that industry has the inputs it needs, at the right price and in plentiful supply. China's more unified approach to the EV supply chain means that auto and battery companies there have fewer concerns over the availability of the minerals needed for electric vehicles. Even so, Chinese firms, such as Great Wall Motors, are investing in battery technology firms and BYD has expanded from being a battery firm to auto assembly.

For non-Chinese auto manufacturers, the challenge is much greater and therefore they have been more aggressive. GM and Ford have invested heavily in battery manufacturing, in partnership with battery firms, and European companies such as BMW and Mercedes Benz have partnered with Chinese battery firms.[42] Some OEMs are even looking at investing in the mining and processing of critical minerals, as markets become tighter and the threat of disruptions in the supply chain more real.

Extracting and Processing Battery Metals

In 2021, the Wilson Center published *The Mosaic Approach: A multidimensional Strategy for Strengthening America's Critical Minerals Supply Chain*.[43] The report, based on extensive dialogue with stakeholders, experts, and government representatives, established that the US faces severe challenges to the resilience of its critical minerals supply chain and is highly vulnerable to potential actions by the Chinese government to restrict US access to those minerals. It included a number of recommendations for the US government and private sector to pursue domestically and internationally to try to make the supply chain more resilient.

Table 2: Policy Recommendations from *The Mosaic Approach*

Short-term actions	Long-term actions
Streamlining regulatory & permitting processes	Human capital investment
Working with allies to develop resources & processing	Developing & negotiating global governance structures
Accepting the geopolitical & climate implications of the critical minerals industry	Building critical minerals stockpiles
Improving the image & reality of the mining industry	Developing new technologies

In the two years since that report was published, the United States has made limited progress in strengthening the supply chain for some of these minerals. The expansion of the US Geological Survey (USGS) critical minerals list from 35 minerals in 2018 to 50 in 2022 marked an important step. The USGS has also been partnering with state governments to map critical minerals deposits in the US more accurately. The USGS Mineral Resources Program's Earth Mapping Resources Initiative (Earth MRI) was partly funded through the Bipartisan Infrastructure Law and provides $320 million over 5 years through the USGS to advance scientific innovation and map critical minerals. The Earth MRI is designed to "modernize our understanding of the Nation's fundamental geologic framework and improve knowledge of domestic mineral resources both in the ground and in mine waste, a key step in securing a reliable and sustainable supply" of critical minerals.[44]

The permitting of new mining and processing projects remains a serious problem for the United States. As Senate Energy Committee Chair Senator Joe Manchin has noted, "In the United States, it often takes between five and ten years — sometimes longer — to get critical energy infrastructure projects approved, putting us years behind allies like Canada, Australia, and more recently the EU,

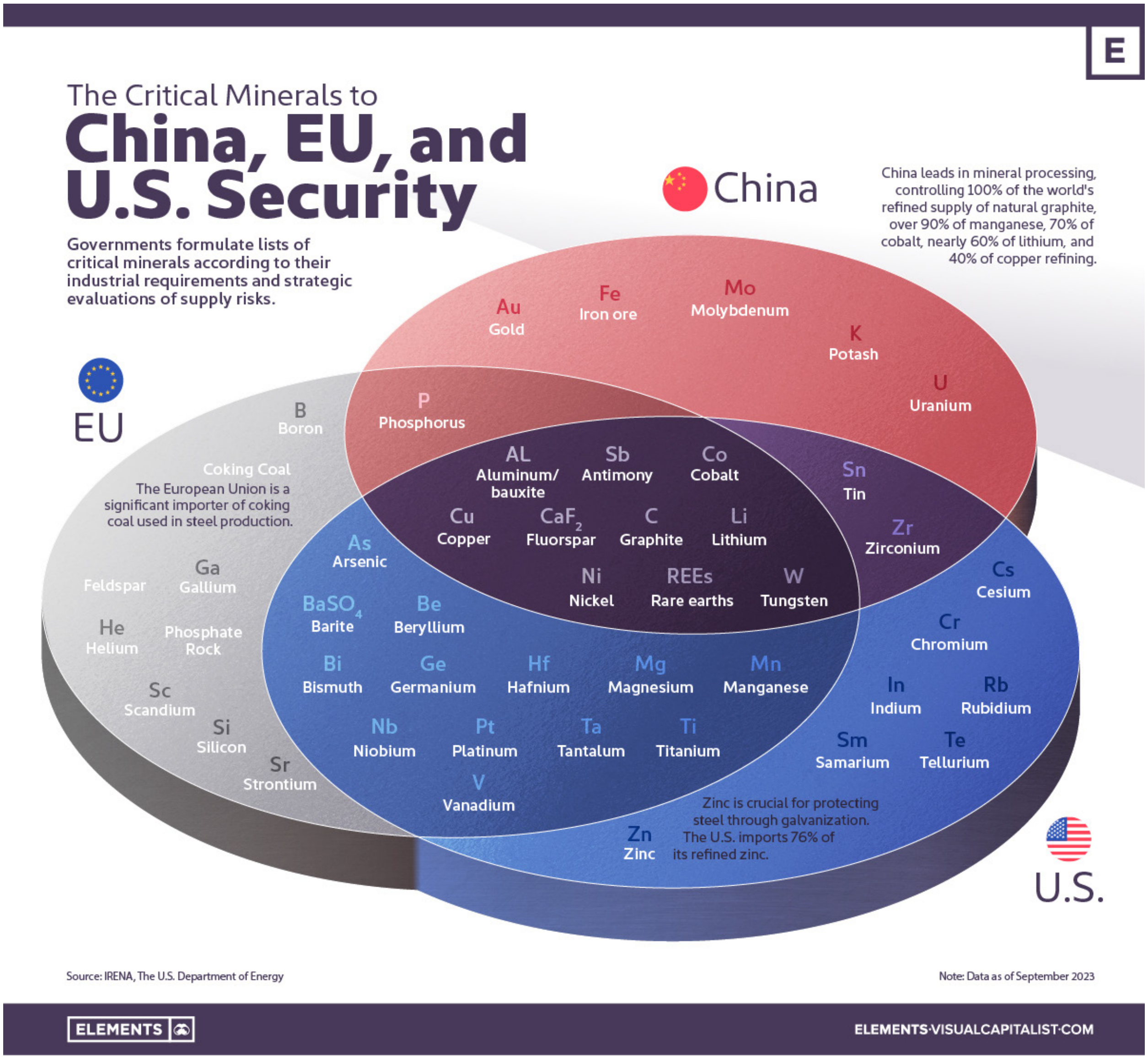


Figure 6: Critical Minerals Designations According to China, the EU, and US Governments[45]

who each have policies designed to complete permitting in three years or less. It is clear that without comprehensive permitting reform we will never ensure lasting American energy security and independence and will delay progress on environmental goals."[46]

However, little progress has been made on streamlining the regulatory and permitting process in the US. Since the passage of the IRA, there have been several attempts to secure permitting reform, but none have been successful thus far. At the COP28 Climate Summit in December 2023, former Presidential Special Envoy for Climate, John Kerry, noted that permitting reform is critically important to the United States' climate goals, and said that reforming the current system was an "emergency."[47]

Indeed, the shortfall in battery metals remains severe. In the case of cobalt, it is estimated that in total there will be a deficit of 40% by 2030; for lithium that number is 30%; for nickel, 15%; and, for copper, 10%.[48] At the same time we see a heavy geographic concentration of battery metals extraction. In the case of lithium, Chile boasts the world's largest reserves, followed by Australia, and then China.[49] Cobalt is most often sourced as a byproduct of copper and/or nickel mining. The DRC is home to the world's largest cobalt reserves, followed by Australia, and then Cuba.[50] Indonesia has the world's largest nickel reserves, followed by Australia and then Brazil.[51] Whereas other battery materials remain difficult to procure, manganese resources are more widely geographically distributed and as such, are available at low costs.[52] Graphite, essential for anode material, can be found naturally but also can be synthetically produced.

What's more, control over those metals and others remains highly concentrated in China. As the Wilson Center has highlighted in a series of maps,[53] while China is relatively resource poor when it comes to critical minerals reserves (with the clear exception of REEs), it has built up its processing and refining capacity to dominate global supply chains. China dominates lithium processing (followed by Chile, and then Argentina). China dominates cobalt processing with its nearest competitor, Finland, processing less than 15% of what China processes. China also fully dominates nickel refining. When combined with Chinese investment overseas in both mining and processing, China's lead seems almost unassailable.

However, this does not mean that there has not been progress. At the international level, the US worked with allies and partners in 2022 to create the (MSP)[54] which has established principles for responsible critical minerals supply chains and is examining 15 potential projects in extraction and processing of critical minerals around the world.[55] This kind of international collaboration will be essential in increasing the supply of minerals, and in reducing the vulnerabilities of member countries to the current dominance of China in the sector.

In addition to the pending issues of permitting reform and increased international cooperation, the processing and refining of critical minerals must be bolstered in the US and friendly nations. According to 2023 data from the IEA, while China was responsible for only 3% of the extraction of nickel and cobalt, it processed 31% and 74% respectively within China's borders.[56] For REEs it was even more dramatic, with China producing 68% of the world's rare earths, and processing 90%. The US clearly needs to invest more in the production of critical minerals at home and abroad, but a more readily achievable goal would be to re-shore, near-shore, and ally-shore processing and refining capacity, freeing an essential part of the US battery metals supply chain from Chinese control.

Another pending question is what to do with seabed mineral extraction, specifically deep sea mining for battery metals, in particular the polymetallic nodules found in abundance in the Clarion-Clipperton Zone (CCZ) in the Pacific Ocean. A recent paper by the Wilson Center highlights the scale of the resource potential on the ocean floor.[57] For nickel, there is estimated to be at least 270 million tons in polymetallic nodules; for cobalt that number is 40 million tons; for manganese, 6 billion tons. These numbers far exceed known terrestrial resources at this time.

The international organization responsible for regulating seabed mining and awarding contracts in the International Seabed Authority (ISA). However, while the United States is not a member of the ISA and therefore not part of the conversation on the regulation of seabed mining, China is highly active in the organization and has already been awarded 5 exploration contracts. Russia has been authorized three contracts. A recent report by Baron highlights the Chinese lead in this space.[58] Focusing on China's investment in deep-sea research and technology through universities, government run research institutes and State-owned enterprises (SOEs), as well as its diplomatic efforts through the ISA, the report makes a very clear case that the United States is already far behind China. Naming sea-bed minerals "the new oil," the report identifies three clear Chinese strategies to establish dominance in this emerging sector:

1. Engaging in regulatory capture and standards-setting to box out external competition;
2. Incentivizing both collaboration and competition to fuel innovation; and
3. Building extensive overseas infrastructure to strengthen supply chains.

For the United States to be able to compete, it must not only reconsider its stance on the UN Convention on the Law of the Sea (UNCLOS) and membership in the ISA, it must invest heavily in the research and technology needed to successfully match Chinese efforts. The December 2023 announcement by the Biden Administration that the US now lays claim to the extended continental shelf, massively increasing its exclusive economic zone (EEZ), especially in the Arctic, opens the potential for the US to explore for seabed minerals without having to go to the ISA. Turning the potential into a meaningful supply for the battery industry will take time, and the United States must also encourage investment in the processing and refining of these minerals. A recent Wilson Center-Hatch report identified the need for building out this capacity, both within the US and in the USMCA partners, Mexico and Canada.[59] Several jurisdictions across North America makes sense for such investment, and factors such as the cost of energy, the existence of a pCAM or CAM production facility, and the presence of an ocean-facing port are seen as key. The report makes a clear case: "Localizing processing capabilities offers the greatest opportunity to build a resilient supply chain for critical minerals domestically."[60]

Battery Chemistry

The battery of an electric vehicle is arguably the most valuable component, representing 40% of the vehicle's total value.[61] While EV technology is rapidly evolving, there are currently three primary EV battery chemistries: lithium nickel manganese cobalt oxide batteries (NMC), lithium iron phosphate (LFP), and nickel cobalt aluminum oxide (NCA) batteries. NMC batteries are the most widely used, making up 60% of the battery market, followed by LFP batteries which only hold 30% of the market share, and then NCA batteries which make up only 8% of the EV battery market.[62] Because of the high nickel content, cathodes in NMC and NCA batteries have a significant advantage in terms of driving range compared to LFP batteries. Higher levels of nickel concentration in batteries mean higher energy in the battery, positively impacting its weight and dimensions.[63] At the same time, however, the high level of nickel content entails more complex production processes and these chemistries are heavily reliant on minerals that are both more expensive and difficult to secure than those used in LFP chemistries (such as cobalt, manganese, and nickel).[64] Prior to 2015, batteries with equal ratios of nickel, manganese, and cobalt were popular.[65] However, as the demand and prices for cobalt have increased, there has been a shift toward battery chemistries that utilize lower ratios of cobalt, despite being more difficult to manufacture. Rising prices for nickel in 2022 also caused a shift toward battery chemistries less reliant on nickel, such as LFP.

Unlike nickel-based chemistries, LFP battery chemistries contain lithium carbonate. Because LFP batteries utilize a more stable chemistry, they boast a longer cycle life, have a lower risk of catching fire, and are relatively cheap compared to their NMC and NCA counterparts due to their critical minerals composition. However, LFP batteries have 65-75% of the energy density compared to NCM batteries. LFP batteries are most commonly used in medium and heavy-duty vehicles, specifically for "intensive usage and frequent charging."[66] Though LFP technology is becoming increasingly more common, its primary production is limited to China as a result of LFP patents and China's subsidies in the LFP supply chain. For example, 95% of LFP batteries were utilized in light-duty electric vehicles produced in China and over 80% of Tesla-manufactured EVs with LFP batteries were produced in China.[63] In 2022, only 3% of EVs with LFP batteries were manufactured in the US.[68] However, Chinese LFP patent and licensing fees expired in 2022, meaning that the market is likely to expand in the coming years. Non-Chinese EV manufacturers, including Tesla and Volkswagen, have announced plans to utilize LFP chemistries for "entry-level high volume EV models." In 2020, only 7% of EVs utilized LFP batteries, but that number jumped to 15% just a year later – largely in part due to increasing EVs in China.[69]

While the main attraction of LFP batteries is that they don't contain expensive and hard-to-secure minerals of cobalt or nickel, they do require substantial amounts of phosphorous – a material used for food production which may lead to conflicting demand use as LFP batteries ramps up over time. This also poses a significant challenge in terms of battery recycling as economic viability from conventional recycling to recover iron and phosphorous is significantly lower than that of cobalt and nickel. Though recycling is more prevalent for NMC and NCA batteries, it's important to note that because LFP batteries boast a significantly longer cycle life compared to NMC and NCA batteries, recycling is less imperative for LFP batteries because they remain in use for significantly longer quantities of time. For example, the average lifetime of an NMC lithium battery is 2000 cycles, but after 1000 cycles, capacity drops to 60%.[70] An LFP battery, however, will retain 80% capacity after 3000 cycles.[71]

A tremendous evolution is underway in the EV battery sector and the progression of the lithium-ion battery is proof of the industry's rapid technological advancement. The first lithium-ion battery was invented less than half a century ago by Exxon and commercialization of the battery by companies such as Sony has completely revolutionized battery technology. Though lithium-ion batteries played a central role in the EV revolution and are currently the most widely used batteries, the development of new technologies is underway, one of which is the sodium-ion battery. The concept of sodium-ion batteries has gained significant traction in recent years and garnered lots of chatter among industry experts, but large-scale volume production has not yet proven successful. Only time will reveal which application this new battery technology will take.

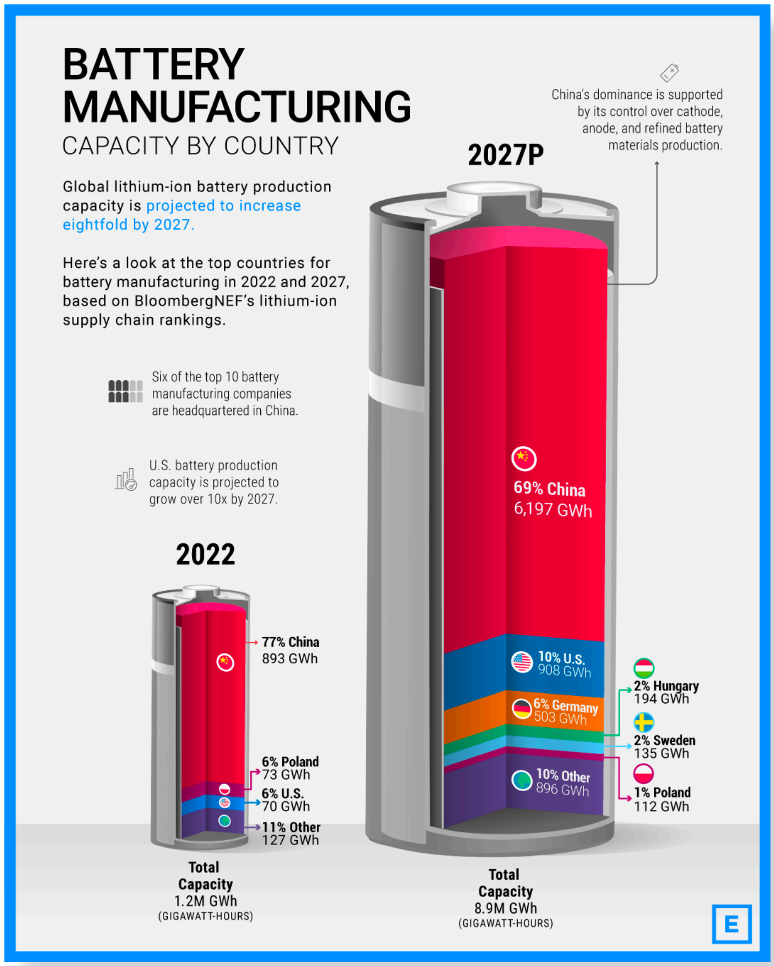
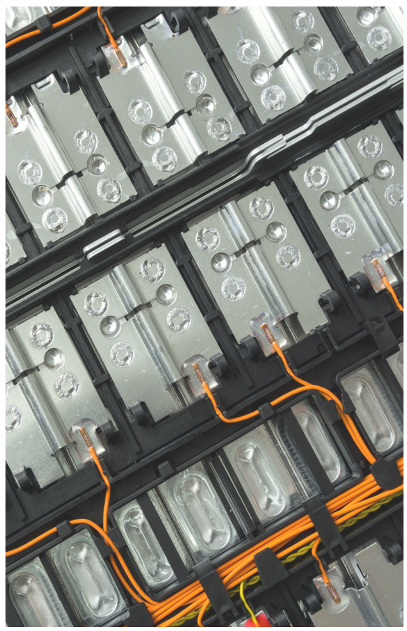


Figure 7: Battery Manufacturing Capacity by Country[72]

Whereas presently EV batteries are relatively similar across the board, industry experts foresee modularity becoming a key feature of EV batteries in the future, allowing customers to customize batteries for specific needs. Combination batteries – one specifically for energy density and another for power, in the same system – are also likely to emerge in the coming years. As with much of the EV supply chain, the US and Europe have fallen far behind China. China's lead is strategic and intentional. As historian Daniel Yergin puts it, the Chinese government, well aware of the country's latecomer status to the traditional automotive market competition, sought instead to dominate the EV playing field - which until recently lacked any major and well-established EV producers. EVs are just one element of the Chinese comprehensive vision of a well-connected electric transportation network within the country to include not just EVs, but also electric buses, bikes, and trains. Some experts have estimated that the US is 10-12 years behind China in manufacturing technology alone. The lack is not just in technology but also in drive and commitment to advancing the national EV industry. Technologies such as mathematical modeling and the use of AI, specifically digital twins, has significantly cut down on development cycles for the EV industry broadly, but especially in the battery portion of the EV supply chain.

End of Life Issues for EVs: Battery Recycling

Battery recycling represents a significant opportunity and challenge in the EV industry. Not only does it reduce the carbon footprint, but battery recycling also fosters greater independence and resilience within the EV supply chain as companies can use recycled materials (which, thanks to recycling, have become a national resource) rather than look abroad for said materials. While much of the conversation on battery recycling focuses on EVs, it's imperative to also consider recycling within the consumer electronic industry. For example, it takes the amount of cobalt in 166 iPhone batteries to produce one Tesla EV battery.[73] Battery recycling requires anticipatory thinking about infrastructure, facilities, public education, and workforce development training, and incentivizing public policy.



The timeframe of recycling is proving to be longer than initially imagined, extending to as much as 15 years. According to the working group experts, the automotive industry operates in cycles of approximately 10 years. After this current cycle, it is somewhat unclear what will happen next in terms of EV batteries. This uncertainty stems from two considerations: changing battery chemistries and potential changes in consumer behavior. While recycling occurs at the end-of-life stage of the battery, it's essential that recycling is an early consideration during battery design and production as the ability to separate out constituent elements as easily and as cost-effectively as possible will be key in recycling, as not all battery chemistries can be recycled together. Recycling procedures and policies must follow the demands and limitations of chemistry. For example, if anode chemistry changes, demand for graphite will decrease. Keeping the ever-evolving chemistries in mind is essential when developing policy. The inertia of the current financial system and consumer behavior leads to questions as to whether the existing system will continue or will be replaced by something new.

Several key factors must be considered when thinking about EV battery recycling. At this point, battery recycling represents a tiny fraction of total battery metals supply, namely because there has not been widespread adoption of EVs, partially because EV batteries are still significantly expensive for average consumers. One working group expert suggested that a price decrease of around 50% is necessary to reach parity at the 300-mile range level. Secondly, the North American EV battery supply chain lacks sufficient infrastructure and technology to recycle battery materials efficiently and effectively.

A fundamental question to ask is at what level should recycling begin - the cell level or the entire battery? The ability to replace a select amount of battery cells, rather than the whole battery pack would cut down on recycling costs but would decrease access to raw, recycled materials in the short term. The option to upgrade batteries for vehicles still on the road is of interest to many auto manufacturers and consumers. However, EVs must be "pre-qualified" for certain technologies and various management systems relating to the battery, its thermal capacities, energy, and durability, thus making it extremely difficult to exchange batteries, especially those with distinct chemistries.

The recycling of post-manufacturing scrap is relatively straightforward, but recycling post-consumer scrap poses an entirely different set of considerations and challenges, such as for EVs that have been exposed to the elements. Not only is battery recycling technologically complex, but it also has significant costs and challenges in terms of transportation. Moreover, battery recycling entails two or three separate ecosystems, including dismantling, recycling, and transportation of recycled materials.

Stitching together these distinct phases, while also incorporating the needs of the auto industry, has proven to be a challenge. Not only are the batteries themselves large, meaning that they're logistically difficult and expensive to transport, but they also contain hazardous material. Transportation safety is a key concern in the battery recycling industry and one that necessitates appropriate training and workforce development for those dismantling the batteries and transporting components. The transport of these hazardous materials across borders is also a significant challenge and concern. Having a nationwide regulatory system with the government taking an active role in regulation will be essential.

A basic, but key question that requires consideration is whether recycling should be led by the private sector, more specifically, individual companies, or if the effort should be led by the government. If the latter, a nationwide approach would be preferable to avoid the differences in state-level policies and variability in the auto industry which would otherwise make the circular economy approach quite difficult (as exemplified by different requirements for critical minerals mining).

It has become clear is that to make battery recycling a functioning reality, there is a need for a regulated value chain with strict auditing protocols. The Chinese approach has been that of a surveillance state emphasizing traceability. For example, any battery sold is entered into the nationwide tracking system and always has an associated owner for the batteries' lifecycle. The European approach, on the other hand, focuses less on individual owners and more on ensuring the collection of waste at the end of the battery's lifecycle. Though still in early stages of development, the philosophy in the US tends to focus on letting market forces act independently to solve the issue and subsequently deploy necessary regulations.

Beyond the technical variables of battery recycling and the logistical challenges of material transport, a very significant consideration is whether the conception of cars and ownership will remain as is or will evolve over time. For example, might it be possible to rent or lease EV batteries? This would have significant advantages:

1. It would free the customer from the full financial burden of the vehicle, an important consideration when batteries can cost up to $25,000 to replace;
2. The automaker would retain some control over the battery itself, making recycling much easier to centralize;
3. Customers would potentially be able to switch out the battery and replace it with a new model, extending life and increasing efficiency and range (and reducing charging time).[74]

In addition to the economic and sustainability elements of battery recycling, there is also a geopolitical component, particularly when it comes to China. China dominates in the EV sector, from upstream (particularly in graphite mining), to midstream, all the way to downstream production of battery cells and EVs. China manufactures 75% of battery cells and 90% of anode and electrolyte production. In terms of pre-treatment battery recycling, China holds nearly 80% of the market share.[75] One potential vulnerability is that of the supply of black mass, or the metals comprising battery anodes and cathodes, leaving Chinese territory. Whereas China has stockpiled black mass, the United States (and North America overall) has not, leading to a significant proportion of the region's black mass being supplied from China.[76]

There are significant opportunities for North America as a bloc in the EV battery supply chain, particularly in terms of recycling. Regional collaboration and operating as a bloc, rather than individually, will be essential for success. Unlike Europe, which is tasked with the challenge of updating legacy technologies, North America stands to benefit as a largely "greenfield" region with significant opportunities for the implementation of new technologies. As both processing capacities and feedstock for recycling grow, it will be important to revisit the IRA and see how the legislation can be adapted to address challenges while also supporting a robust market.

Charging the Transition: Building Out the Network

Although the supply chain per se does not extend to the building out of the charging network, it is a key element in encouraging more drivers to make the change from ICE to EV technology. In some ways this is a classic chicken and egg problem. Potential EV drivers are concerned that they will not be able to find adequate charging infrastructure in place, leading to what has been labeled "range anxiety" as well as concerns about convenience, cost and time spent re-charging vehicles. However, utilities and other corporate actors who are responsible for building out the network are reluctant to do so and find it difficult to justify the need for financing to investors unless they can prove there is a critical mass of vehicles on the road.

In addition to the challenge posed by range anxiety, the concerns over convenience impact potential EV buyers in both rural and urban settings. In cities, charging must be made more accessible in all locations: at home, at work, at malls, and at traditional gas stations. Outside of cities, there has thus far been a focus on interstate highways and major routes along which people regularly travel long distances. However, to meet the needs of rural communities, more attention must be paid to availability of charging in small towns.

The speed of charging is also a major concern. Some consumers continue to worry that they will be stranded for hours if they need to re-charge out on the road, and even that charging their EVs at home will leave them without access to their vehicles during charging hours. According to the US Department of Transportation, Battery Electric Vehicles (BEVs) operating on level 1 or 2 chargers will take between 4-50 hours to get to 80% charge while Plug-In Hybrid Electric Vehicles (PHEVs) take from 1-6 hours.[77]

Overview of EV chargers: power output, plug type, and charge time for light-duty vehicles. (Adapted from the Alternative Fuels Data Center)

	Level 1	Level 2	DC Fast Charging
Connector Type[2]	J1772 connector 	J1772 connector 	CCS connector  CHAdeMO connector  Tesla connector 
Voltage[3]	120 V AC	208 - 240 V AC	400 V - 1000 V DC
Typical Power Output	1 kW	7 kW - 19 kW	50 - 350 kW
Estimated PHEV Charge Time from Empty[4]	5 - 6 hours	1 - 2 hours	N/A
Estimated BEV Charge Time from Empty[5]	40 - 50 hours	4 - 10 hours	20 minutes - 1 hour[6]
Estimated Electric Range per Hour of Charging	2 - 5 miles	10 - 20 miles	180 - 240 miles
Typical Locations	Home	Home, Workplace, and Public	Public

Figure 7: EV Charging Technologies[79]

However, using direct current fast charging (DCFC) equipment, a BEV can charge to 80 percent in just 20 minutes to one hour. This is still slower than refueling a traditional ICE vehicle with gasoline or diesel, but the technological advance has been considerable in recent years.

In a vitally important move in 2023 Tesla, the largest installer of DCFC chargers, agreed to make its technology widely available to owners of other brands, with virtually all makes of EV having access to Tesla's proprietary NACS DCFC technology in the coming years. However, recent announcements by

Tesla of cutbacks in its charging installation workforce threatens to further slow the build out of the charging network.[78]

Another hugely important development is the combination of smart chargers and off-peak charging, which can dramatically reduce the cost of charging vehicles at home. Many electricity providers and local authorities are also providing subsidies to residential consumers to install home chargers, thus defraying much of the startup costs of buying an EV.[80]

The International Experience: Chinese and European Approaches to the EV Charging Network

China boasts one of the most impressive and all-encompassing EV charging networks in the world. According to the China Electric Vehicle Charging Infrastructure Promotion Alliance, as of August 2023, there are over 7 million charging stations in China, almost 3 million of which are public.[81] Charging station operators are concentrated among five key companies that hold approximately 70% of the market share. These operators partner with auto manufacturers which has contributed to dominance of the EV charging network. In June of 2023, the Chinese government released a public strategy for strengthening and further expanding China's EV charging network with a focus on improving charging infrastructure in both rural and residential areas as well as public parking lots and highway service areas. Chinese rapid EV uptake and expansion of the charging network can partially be attributed to ambitious and long-term oriented public policy planning, such as the 2010 government subsidies for the purchase of EVs as well as the enforcement of a standard charging plug for EVs. Another key example is the 2015 "Guidelines for the Development of Electric Vehicles Charging Infrastructure," which set the goal of 4.8 million charging stations by 2020 (4.3 private and 500,000 public) to ensure a charger to auto ratio of 1:1.[82] In actuality, however, this ratio was not achieved as of 2022, China had 13 million EVs but only 5.21 million charging stations, meaning that the vehicle-to-charger ratio was 2.5 to 1.

Though Europe is ranked second to China in terms of its EV charging network, there is a significant gap; China's EV charging station market was valued at almost $10 billion in 2022, whereas the European market was worth $4.1 billion. According to the European Alternative Fuel Observatory, there are over 630,000 public charging points in the EU, 87% of which are AC chargers and the other 13% are DC chargers.[83] China has a significant head start over Europe in terms of EV adoption and expansion of the charging network but recent efforts by European Parliament to reduce emissions, such as the EU initiative to reduce emissions by 55% by 2030 as well as the 2022 vote on regulation for alternative infrastructure, have given the continent the impetus it needs to further promote the use of EVs and expand the charging network. In Europe, 70% of EV owners charge their vehicles at home or at work, with Nordic countries and France having the highest rate of workplace charging.[84] A study on charging stations in 28 countries found that 46% of charging stations have two charging points, 19% four charging points, and 10% of charging stations have one or three charging points.[85] In this study, 14% of charging stations have five or more chargers and only 1% of charging stations surveyed can serve 20 or more vehicles at the same time.

US Policy Approaches: The National Electric Vehicle Infrastructure (NEVI) Formula Program

Efforts to advance EV charging infrastructure in the US range from federal to state to the local level. Under the Bipartisan Infrastructure Law (BIL), a National Electric Vehicle Infrastructure Formula Program ("NEVI Formula") has been established "to provide funding to States to strategically deploy electric vehicle (EV) charging infrastructure and to establish an interconnected network to facilitate data collection, access, and reliability."[86] Administered by DOT Federal Highway Administration (FHWA), NEVI funded projects include both operational maintenance of EV charging stations as well as "acquisition, installation, and network connection" of EV charging stations for data sharing.

Between 2022-2026, the NEVI provides $5 billion in federal funding, covering up to 80% of eligible project total costs. Charging stations must consider a long list of factors to be eligible to receive funding:

- the distance between publicly available electric vehicle charging infrastructure;
- connections to the electric grid, including electric distribution upgrades;
- vehicle-to-grid integration, including smart charge management or other protocols that can minimize impacts to the grid; alignment with electric distribution interconnection processes, and plans for the use of renewable energy sources to power charging and energy storage;
- the proximity of existing off-highway travel centers, fuel retailers, and small businesses to electric vehicle charging infrastructure acquired or funded with NEVI Formula funding;
- the need for publicly available electric vehicle charging infrastructure in rural corridors and underserved or disadvantaged communities;
- the long-term operation and maintenance of publicly available electric vehicle charging infrastructure to avoid stranded assets and protect the investment of public funds in that infrastructure;
- existing private, national, State, local, Tribal, and territorial government electric vehicle charging infrastructure programs and incentives;
- fostering enhanced, coordinated, public-private or private investment in electric vehicle charging infrastructure;
- meeting current and anticipated market demands for electric vehicle charging infrastructure, including with regard to power levels and charging speed, and minimizing the time to charge current and anticipated vehicles;
- location, in general, along a designated alternative fuel corridor or, if a State determines, and the Secretary certifies, that all designated alternative fuel corridors in a State are fully built out, on any public road or in other publicly accessible locations.[87]

Despite the impressive funding available and the rising number of EVs on the road, the NEVI program has only had limited success at the time of writing. Although the available funding should be enough to build around 5,000 charging stations (with 20,000 charging spots in total), by March of 2024 only 7 charging stations had been completed.[88]

Nonetheless, a lot more investment is expected in the coming years. In part, this will be driven by the funds flowing through the NEVI, which have been slow to mobilize but are now coming online. In addition, the significant uptick in EV sales will provide a virtuous cycle in which demand for charging should drive the construction and installation of more stations.

Grid Implications: Managing the Duck Curve and Energy Storage

A commonly recognized challenge of growing solar energy generation is the "duck curve." So named after the visual representation of net electricity demand during a 24-hour period (see below), the curve has become a lot deeper in places such as California as solar power generation has increased dramatically. This poses an interesting challenge; particularly as net demand has reached zero or even negative numbers during periods of peak solar generation.

Bringing EV charging into this equation may provide a partial solution. Encouraging EV charging during the times of peak solar production has the potential to smooth out the duck curve, as it will raise net demand during those times.

One way to look at this is as a form of energy storage. By drawing down energy from the grid at times of peak production and using that energy later when solar production has dropped or even stopped (which just happens to take place during times of peak commuter driving) is one way of helping to manage the grid.

This opportunity becomes even more enticing when we add in commercial fleet charging, both for passenger vehicles and for electric freight vehicles. The massive amount of energy storage available in those vehicles provides a ready form of battery storage for green electrons. However, the fact that most of those vehicles may be on the road at times of peak solar energy generation is a serious barrier. To overcome that barrier, providing incentives to charge during lunch hours, and encouraging the movement of freight during the night could help to smooth demand further.

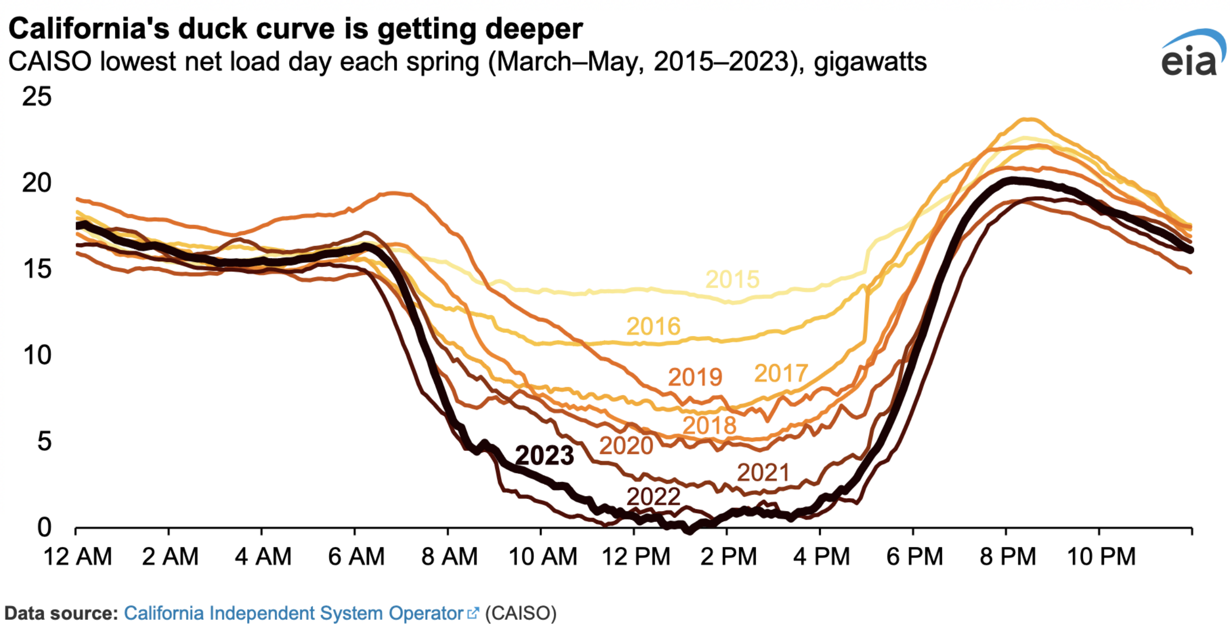


Figure 9: The Duck Curve[89]

Recommendations for the Charging Network

The working group focused on a small number of challenges and opportunities that must be considered as the charging network is built out, ranging from installation to energy sources and maintenance.

1. **A Common North American standard.** As Tesla has agreed to share its charging network with other automobile brands, the need for a unified approach to charging tech that increases the number of available chargers to consumers has become abundantly clear. Making sure that sufficient chargers are available to customers means that there must be interoperability between different systems, or the emergence of a common standard across all car brands, and ideally throughout the North American market. It is also worth exploring the implications of Chinese activity in building out the charging network in other parts of the world. To take advantage of Chinese investments in charging infrastructure, North American EV exports must be able to utilize that charging technology.
2. **Scaling up outside of cities.** An easy way to grow the charging network outside of major urban areas will be to encourage OEMs to work with car dealerships to install charging stations on their lots. This will not only help overcome the dearth of charging stations in rural areas, it will also both encourage EV sales for the dealers, and potentially provide them with an extra source of revenue. A partnership between the dealership, energy provider and the local community will help to overcome resistance in rural areas.
3. **Building out the network.** In cities, the options are seemingly endless for building out the network. From curbside charging using streetlights as an access point, to developing new architectural guidelines so that charging points are built into new office and condominium construction, including the requisite electrical wiring, to the widespread installation of rooftop solar to lower costs and carbon footprint will all be game changers in this space.
4. **Sustaining long-term health of the charging network.** This means considering not just the construction of charging stations but also the maintenance, repair and upgrading of those stations. One of the most common complaints among current EV customers is that they will find a charging location on their GPS system, but when they get to it, it has been damaged and is unusable. This increasingly common problem points to the importance of ongoing and prompt maintenance to build confidence among existing and potential EV users. As one participant in the study group put it, "the biggest challenge isn't scale, its reliability."
5. **Focus on the human capital element of the equation.** Connected to this concern is the need for a labor pool that includes both the building out of the charging network and its maintenance. This labor pool must be properly trained, and there must be ongoing training available to keep the workforce up to date with new technologies and innovations.
6. **Managed charging.** Existing policies for preferential electricity rates for EV charging in states such as Minnesota show the importance of incentives for EV charging. However, pricing is only one part of this equation. We must also consider encouraging EV users to charge their vehicles at times of lower overall electricity consumption as well as at times when renewable energy sources are at peak production. Understanding the duck curve, which in recent years has become deeper as solar energy production has grown rapidly in the US (especially in California), may provide clues as to how to optimize charging times for the benefit of the grid in general.

Conclusion

As the United States faces the combined challenges of climate change and geopolitical competition with China, recent administrations have leaned into a protectionist stance for boosting US competitiveness, providing significant tax and production credits, and also focusing on tariffs on EV imports and critical minerals.

. . . a more comprehensive and holistic strategy for building competitiveness in national and global EV markets is needed

This report has argued that, although these steps are helpful to the industry in the short term, a more comprehensive and holistic strategy for building competitiveness in national and global EV markets is needed. The implications for carbon emissions are overwhelmingly important, given the percentage of emissions that come from transportation. Moving rapidly towards EV adoption will not only mitigate emissions in the short-term, but this will strengthen in the medium term as opportunities for recycling battery metals grow exponentially, further reducing the carbon footprint of EVs. However, in the short-term US OEMs face significant threats from Chinese manufacturers, who have already built a dynamic and booming domestic market and are now actively engaged in conquering global markets.

Greater attention must also be paid to the development of incentives for battery recycling. Policy recommendations include the implementation of a battery passport system, co-location and/or regional recycling hubs, and convenient collection infrastructure for obligations and liabilities. Members of the working group advocated for open loop systems, particularly in terms of non-economic factors. Digitalizing the circular economy will also prove to be crucial to facilitate data availability and processing.

As for the charging network, several issues need to be addressed. First, the wholesale building out of the charging network must be a priority to overcome the chicken and egg problem of consumer reluctance to buy because of concerns over the availability of charging stations, and the lack of charging station investment due to low levels of EV sales. Proposals from the working group addressed both urban and rural solutions, focusing on using existing electrical infrastructure such as street lighting and new office and condominium construction in cities, as well as using EV dealerships in rural areas to increase charging opportunities. Furthermore, creative solutions involving pricing and grid management will be essential to smooth out the growing challenge of the duck curve as solar energy generation increases. Lastly, ensuring an adequate supply of talent will be critically important in both building out the charging network and maintaining it.

Despite the impressive progress that has been made in recent years, the EV industry in the United States still faces significant challenges to be able to compete with Chinese counterparts. The decade-long head start achieved by Chinese manufacturers presents US OEMs and the government with a long list of priorities to be able to catch up. However, despite the scale of the challenge, the United States has the tools to compete. A focus on innovation, an incentive-based system and on public-private cooperation at home and abroad offer the potential for the US to not only match Chinese advances, but ultimately surpass them.

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