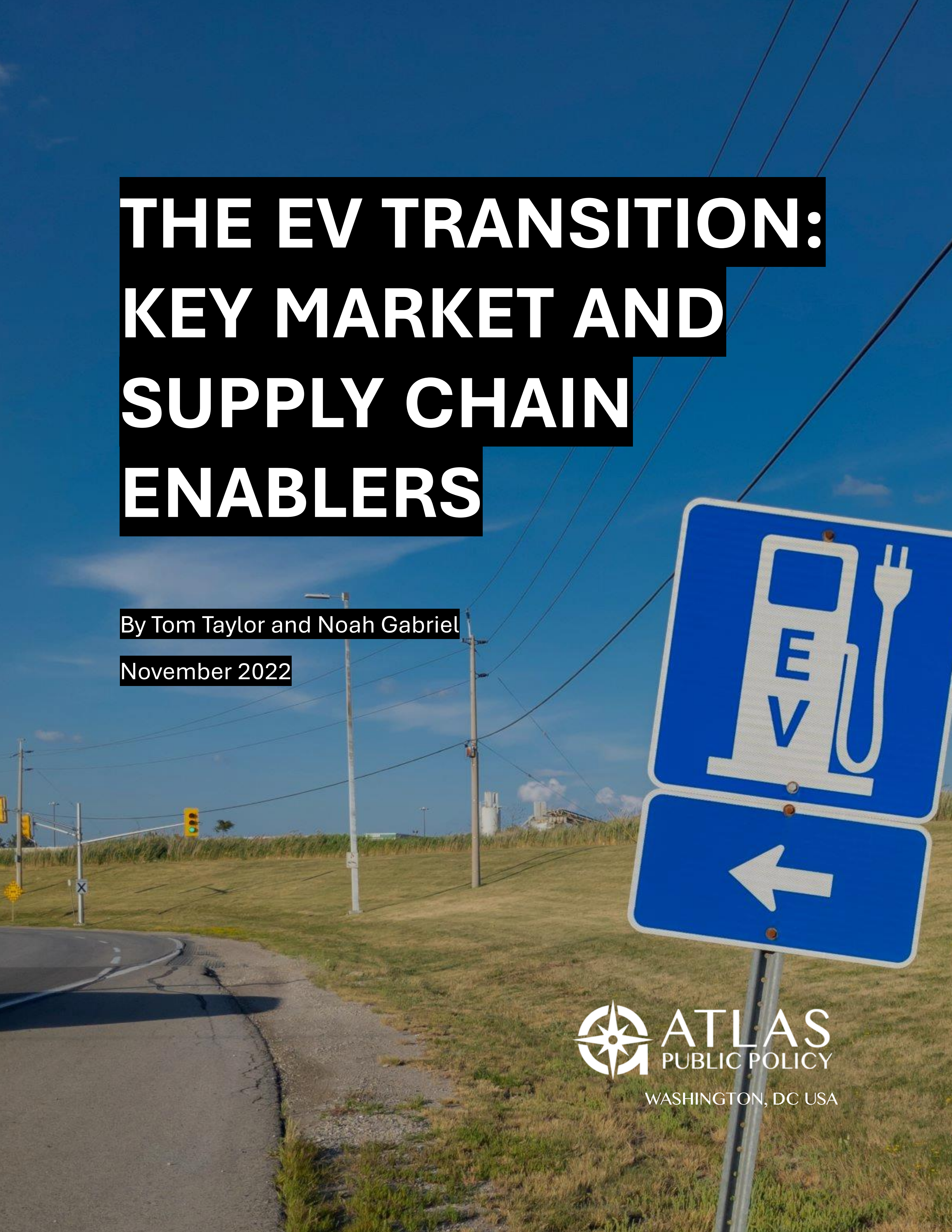

THE EV TRANSITION: KEY MARKET AND SUPPLY CHAIN ENABLERS

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ATLAS PUBLIC POLICY

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Introduction

The United States (U.S.) continues its march toward transportation electrification. Bloomberg analysts predicted that the U.S. had passed a pivotal tipping point in EV adoption, as more than five percent of new light-duty vehicle sales were electric in Q1 2022 and nearly seven percent in Q2 [1]. The analysis found that the U.S. was on track to follow the 18 other countries that have also crossed the five percent threshold, from early adopters into mainstream adoption. The analysts anticipated that a quarter of all light-duty vehicles sold by the end of 2025 could be electric.

Other signs also point to a transition that is growing momentum. Many manufacturing sites are being announced domestically, creating jobs and opportunities across the country. Utilities continue to invest in critical infrastructure to support EV charging, and government support is bolstering electrification efforts. The Infrastructure Investment and Jobs Act (IIJA), signed into law by President Biden in November 2021, set aside $7.5 billion for EV charging, including $5 billion for an EV charging formula grant program and a further $2.5 billion for fueling stations (including EV charging, hydrogen, and other alternative fuels). Then, in August 2022, Congress passed the Inflation Reduction Act (IRA), which included the largest climate spending ever appropriated by the Federal Government. These two packages will deliver considerable funding to support decarbonization efforts and grow economic development and jobs. States likewise are investing billions in vehicle incentives and charging to support light-duty, medium and heavy-duty vehicle electrification.

In addition, new regulatory frameworks, like California's Advanced Clean Cars II (ACC II) regulations, will speed up the transition to EVs. The ACC II rule, adopted on August 25, 2022, will require that 35 percent of vehicle sales be EVs in 2025, ramping up to 68 percent in 2030 and 100 percent in 2035 (see Box 4). These requirements are expected to be adopted by other states and will put significant pressure on automakers, the adopting states, and the U.S. to progress innovative and effective policies to make the transition.

To decarbonize the transportation sector, uptake must continue to grow rapidly. As uptake grows, there will be new challenges and tailored solutions required to ensure the benefits of electrification accrue to all. Challenges include charging quality and availability, the affordability of EVs, equitable charging access, and supply chain issues. Supply chain constraints leave the U.S. dependent on high levels of imports for key critical minerals since domestic extraction of critical minerals is minimal and faces significant challenges. Likewise, domestic processing capabilities for those critical minerals are limited. These supply chain pressures may drive up prices and limit growth.

This report will focus on key market and policy developments and key supply chain enablers for light-duty electric vehicles. Although production depends on strong global cooperation, the focus of this report is on the U.S.

Data

Data used in this report is primarily derived from the Atlas EV Hub. The data source is noted when data are not derived from EV Hub.

EV Sales are sourced from light-duty passenger EV sales provided by IHS Markit (2019-present) and the former Alliance for Automobile Manufacturers (2011-2018). Aggregated EV sales data for all states are provided by vehicle make and model since 2019, including light-duty battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). Sales data includes new vehicle sales only. Data included in this report are current as of the end of June 2022.

EV Charging tracks all deployed publicly available EV charging infrastructure and is sourced from U.S. Department of Energy's Alternative Fueling Station Locator. Atlas only counts individual ports that can be used simultaneously. These numbers are current as of the end of June 2022.

Electric Utility Investment tracks EV-related investments and is sourced from investor-owned electric utility dockets filed to state utility regulators. The investment data includes both EV programs proposed by utilities that await commission approval as well as investments approved or denied by commission orders. Data included in this report are current as of the end of June 2022.

Public Funding for EVs tracks federal and state government funding programs dedicated to transportation electrification, including funding allocated through the Volkswagen Settlement. Data included in this report are current as of the end of June 2022.

EV and EV Charging Manufacturing Employment and Investment measures the number of direct manufacturing jobs and investment supported by light, medium and heavy-duty EV, and EV battery production as well as EV charging. This figure is tied to specific facilities and is typically reported directly in press releases. Data included in this report are current as of the end of June 2022.

Critical Mineral, Battery Recycling and Processing Facilities tracks critical mineral extraction and processing sites, as well as battery recycling facilities. The data is sourced from the USGS Mineral Commodity Summaries 2022, National Renewable Energy Laboratory's Lithium-Ion Battery Supply Chain Database and User Guide report, reporting and press releases. The summaries only include those facilities (either announced or operational) based in the United States, with a proposed location and company lead announced. The data is limited, and for many of the projects, key details are not readily available. Another challenge in the data is connecting the materials to the production of electric vehicles. We have endeavored to only include facilities where there is the potential for those materials to be used in EVs, though due to limited information that remains a challenge. Data are through the end of August 2022, however Processing Facilities data was updated in November 2022 after a significant announcement of funding allocated by the Department of Energy.

Market Summary

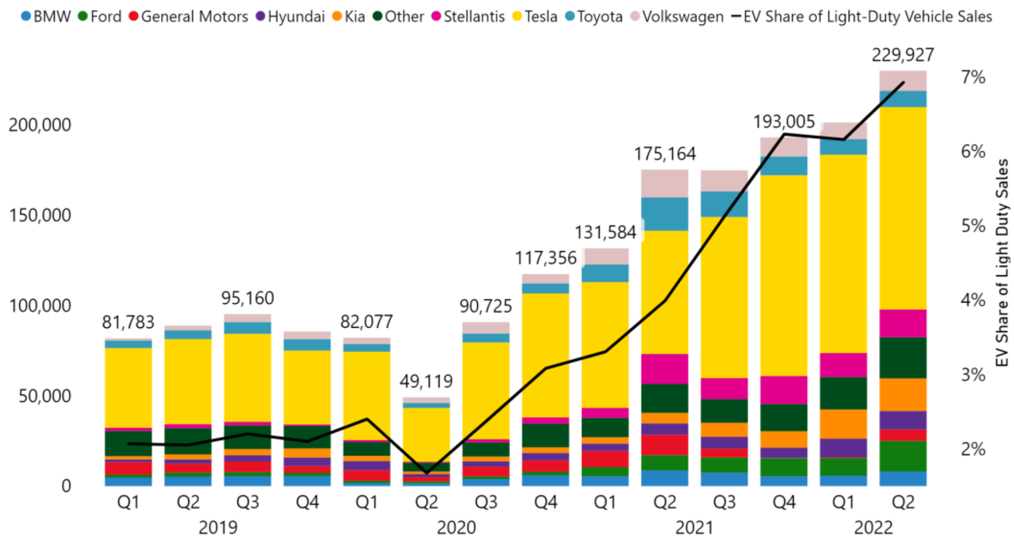
Electric Vehicle Sales

EV Sales

The EV market continues to grow in the U.S. As of June 30, 2022, there have been more than 2.9 million cumulative EV sales in the United States (including Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs) and fuel cell electric vehicles (FCEVs). The second quarter of 2022 saw a record 230,000 EVs sold, 14 percent more than the record. In Q2 (Figure 1), EVs made up seven percent of the light-duty market. This is a more than 70 percent growth in market share year over year from Q2 2021 (four percent).

The market and competition have shifted considerably over the past few years. There was a critical inflection point in 2018 with the release of the Tesla Model 3. Through the end of June 2022, PHEVs make up a third of all EV sales though, in the first half of 2022, PHEVs made up just 22 percent of EV sales. If the trend in Figure 2 continues, that proportion will continue to shrink. In Q2 2022, of the top 10 EV models by sales, only one was a PHEV.

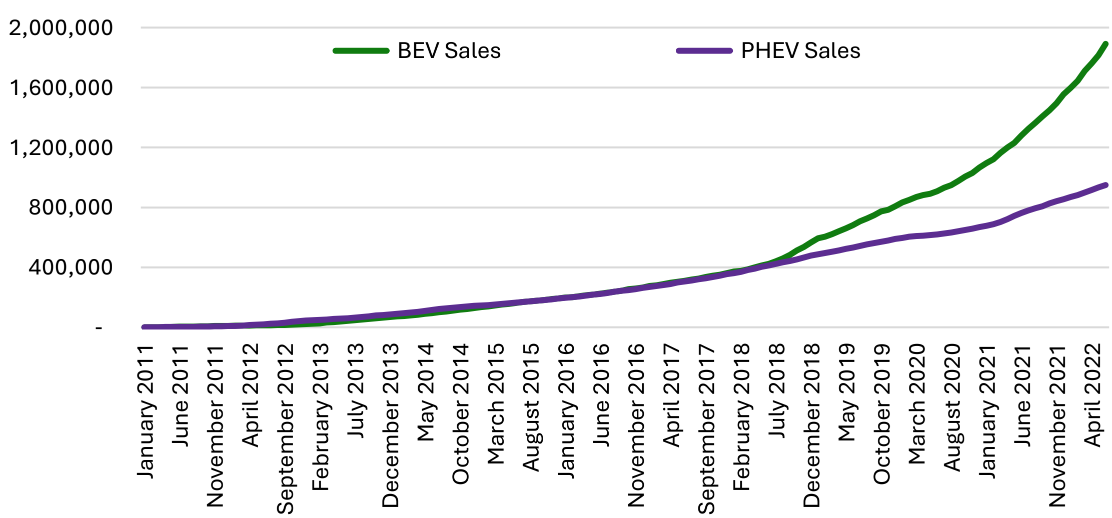
Figure 1: U.S. EV Sales and Market Share from Q1 2019 through Q2 2022



This data captures sales of plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) by parent company[1]. Hyundai and Kia were split into two companies for the purpose of this report.

Source: Atlas EV Hub.

Figure 2: Cumulative New EV Sales by Technology from 2011 through June 2022



Cumulative new light-duty vehicle sales by technology.

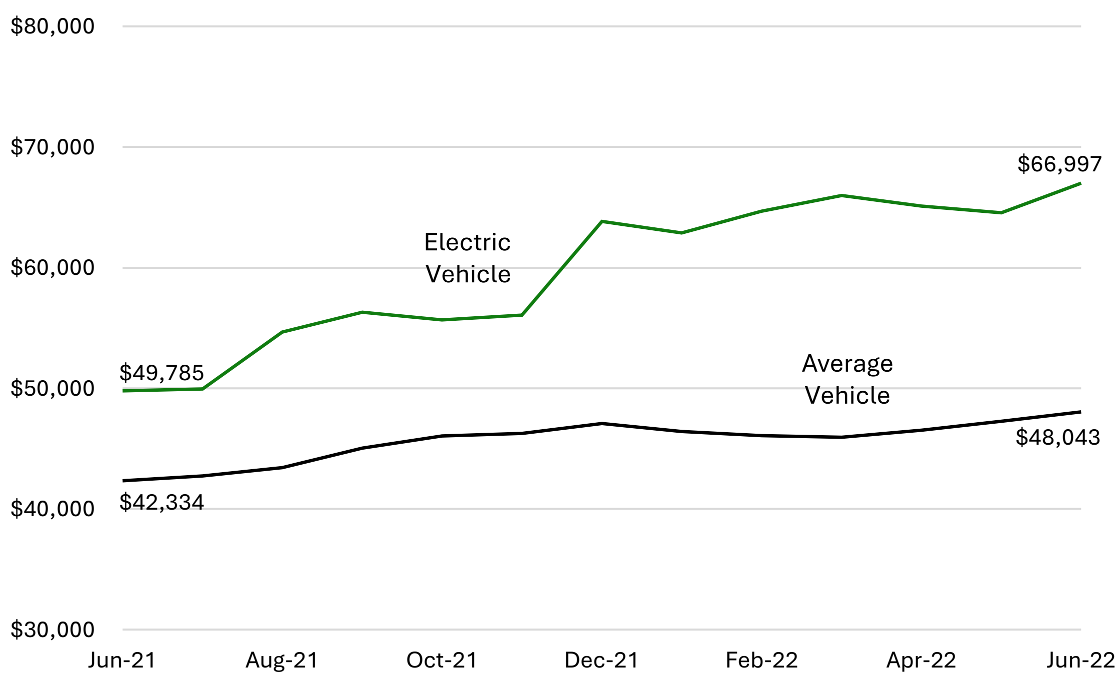
Source: Atlas EV Hub.

[1] Note that this captures national sales data and there is considerable interregional variation in EV uptake across the United States.

Electric Vehicle Costs

Electric Vehicles cost more than internal combustion engine vehicles to buy. Using Kelley Blue Book data in Figure 3, the price gap has opened further over the past 12 months, even as both EVs and internal combustion engine vehicles have experienced increased purchase costs. These average transaction prices do not necessarily account for possible federal or state rebates. Moreover, fuel costs for EVs are typically much lower than gasoline vehicles (particularly for EV drivers with access to home charging). Likewise, maintenance costs for EVs are expected to be lower than gasoline vehicles. These cost savings substantially lower the total cost of ownership over the life of an EV [2].

Figure 3: Electric Vehicle Average Price and the Market Average for New Vehicles



The average vehicle price takes the average for the market from June 2021 through June 2022.

Source: [3]

Hydrogen Vehicles

Hydrogen fuel cell electric vehicles (FCEV) draw on an alternative zero-emission drive technology to battery electric vehicles. Like plug-in EVs, they use an electric motor for propulsion. FCEVs generate electricity using a fuel cell stack that combines hydrogen from onboard containers with oxygen from the air for energy [4]. The only byproduct of this reaction is pure water. FCEVs require only about five minutes to refuel, and the range exceeds 325 miles for the three light-duty hydrogen vehicles available for lease or purchase in the United States: the Honda Clarity, the Toyota Mirai, and the Hyundai Nexo. From Q1 2019 through Q2 2022, 7,124 FCEVs were sold in the United States. As of August 2022, there were just 54 public hydrogen fueling stations around the country (53 of which were in California) [5] [6].

Box 1. California's Clean Car Programs: Clean Vehicle Assistance Program and Clean Cars 4 All

First launched in June 2018, the Clean Vehicle Assistance Program (CVAP) offers grants for income-qualified Californians to help purchase or lease a new or used hybrid or battery EV. CVAP addresses the barriers to clean vehicle ownership, such as the high upfront costs, limited access to charging infrastructure, and predatory auto loans, by providing approved applicants with a clean vehicle grant, a charging station grant, and a fair loan option that is capped at an eight percent interest rate. The issued grants do not need to be repaid. CVAP's grants support the purchase or lease of both new and used battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV). For BEVs and PHEVs, a purchase grant of up to $5,000 and a charging grant up of to $2,000 are available depending on the applicant's income [7]. For an individual applicant, the maximum qualifying income is $51,520 [8]. As of May 2022, the program has disbursed approximately $22 million in grant funding to support 4,330 vehicles including 860 grants to residents of disadvantaged communities.

The Clean Cars 4 All (CC4A) Program enables low-income drivers to upgrade to cleaner vehicles [9]. Vehicle owners living in designated zip codes with high levels of pollution who meet income and vehicle requirements are eligible. The vehicles are then traded in for more efficient, lower polluting alternatives. CC4A has awarded $127 million including 11,338 grants as of November 30, 2021. Of funds implemented, 97 percent has benefited "priority populations" per the California Climate Investments 2022 Annual Report released [10]. CC4A participants can receive up to $9,500 in grant funding toward the purchase of a new or used EV. Alternatively, participants can choose up to $7,500 in incentives to access other mobility options, such as public transit passes or electric bicycles.

EV Models

The number and variety of EV models have increased dramatically this decade as major automakers have committed to the electrification of bestselling models. Through the end of June 2022, automakers have brought 83 models to market, a 41 percent increase in EV model availability from January 2020. From sedans to SUVs and even pickup trucks, the options for light-duty vehicles are proliferating as automakers vie for EV market share in new consumer segments. Tesla remains the dominant player with 53 percent of the total EV market in the 12 months from July 2021 through June 2022.

In 2022, alongside Tesla's continued dominance, there have been other key market developments. For instance, Kia is the only other company with more than one model in the top 10 for Q2 2022. Likewise, General Motors reemerged in the top 10 for EV models in Q2 2022 after a recall of the Chevrolet Bolt. In April, Ford's F-150 Lightning went into full production after receiving 200,000 preorders [11]. The first vehicles were delivered in May 2022 [12]. Emergent automakers Rivian and Lucid continue their introduction.

Box 2. Charge Ahead (Oregon)

Oregon's Charge Ahead program provides income-qualified buyers rebates of up to $5,000 towards purchasing a used or new EV (increased from $2,500 in January 2022). The rebate stacks with Oregon's standard EV rebate when applied to new EVs, for a combined maximum of $7,500, one of the largest state incentives in the country [13]. From the program's inception in 2018 to June 10, 2022, 2,439 participants have claimed $9.9 million in Charge Ahead and Standard funding [14]. Thirty-six percent of those participants bought used vehicles – one of a select few such programs around the country in which used vehicles are eligible [13]. On average, applicants received $4,934 for the combined rebates and $2,552 for the Charge Ahead only rebates. Charge Ahead requires that recipients buy a vehicle through a dealer, register that vehicle in Oregon, and own the vehicle for at least 24 months. The standard rebate program offers $2,500 to anyone who purchases a new battery EV or plug-in hybrid for under $50,000. Income qualifications for the Charge Ahead rebate changed from 120 percent of area median income to 400 percent of the federal poverty guideline in January 2022. The Charge Ahead rebate can only be claimed after purchase. As a result, participation is potentially more challenging for low-income participants that must produce more money upfront or secure additional financing to purchase a vehicle.

EV Charging

EV Charging Needs

To accommodate the fast-growing EV market, the United States needs to continue to build out public EV charging. The Biden Administration has often referenced a target of 500,000 EV chargers. Analysis by Lucy McKenzie and Nick Nigro from Atlas Public Policy likewise found that 495,000 charging ports for light-duty vehicles[2] are needed by 2030, assuming a trajectory towards 100 percent EV sales from 2035 onward. This analysis assumed 21 percent of vehicles on the road in 2030 will be EVs and 81 percent of all new light-duty vehicle sales will be electric in 2030 [15].

McKenzie and Nigro found that $87 billion in charging infrastructure investments is needed over the next decade to achieve 100 percent passenger EV sales and carve out the path for full-scale electrification. Of that funding, $39 billion is needed for publicly accessible charging. Public charging infrastructure investments are often less attractive, mostly because the direct revenue from these services may not cover installation and operation costs. The analysis anticipated a further $22 billion in single-family home charging and $17 billion in multi-unit home charging is needed. As it stands, the current pace of investments for EV charging falls short of the $87 billion needed over the next decade to achieve complete EV sales by 2035 (further investment will be needed after that time to support EVs). Additionally, McKenzie and Nigro found that larger investments upfront can result in significant savings. Installing six to 10 fast charging ports at each site ($38.8 billion) instead of just two ($47.4 billion) will save $8.6 billion in installation costs. The authors also found savings by installing 350kW DCFC ports ($38.8 billion) rather than 150kW ports ($51.8 billion) [15].

A McKinsey and Company analysis from April 2022 found if half of all new vehicle sales in 2030 were electric, there would be a need for 1.2 million public chargers at a cost of $35 billion (this estimate does not include grid and site electrical upgrades) [16]. The estimate is in addition to workplace, depot, and home charging (the latter of which makes up most of the charging). A more conservative estimate from 2017 by the National Renewable Energy Laboratory (NREL) assumed EV uptake would be 20 percent of light-duty vehicle sales by 2030. As a result, NREL assumed there would be a need for 600,000 Level 2 chargers and 25,000 DCFCs by 2030 [17]. Across each of these three studies, from the more conservative uptake estimates to more optimistic estimates, there is a significant need for rapid growth in EV charging installation.

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[2] Note that the analysis does not consider fuel cell electric vehicles and the DCFCs in the modeling are 350kW.

Charging Deployed

There are 137,907 EV charging ports installed throughout the country, including 111,940 Level 2 chargers and 25,967 DCFC chargers as of June 30, 2022 (of those, there were nearly 26,000 Tesla proprietary chargers). This is a growth in chargers of 27 percent over the past 12 months. The total includes both public chargers and semi-private chargers that are publicly available – for instance, at a hotel. It is important to note that tracking charging installations is imprecise and that it does not include residential chargers (except some at Multi-Unit Dwellings).

Through funds allocated in the Infrastructure Investment and Jobs Act, the public EV charging network will receive a significant boost primarily from the National Electric Vehicle Infrastructure (NEVI) funding program. NEVI allocated $5 billion to states to build out a national EV charging network. The network must be built on Alternative Fuel Corridors (AFC). For NEVI, the federal government's $5 billion will cover 80 percent of the cost, requiring states or others working with states to contribute at least 20 percent of the cost. There is also a $2.5 billion discretionary grant program for EV and other alternative fueling. This funding, split between the Corridor Charging Grant Program and the Community Charging Grant Program, requires consideration of locations for underserved or low-income communities, and is available for all alternative fuels, not just electric charging infrastructure.

Table 1: Summary of EV Charging Available

Total Charge Ports	Level 2 Chargers	DCFC Chargers	Change Since July 1, 2021
137,907	111,940	25,967	27%

Total charging ports by type as of June 30, 2022.

Source: Atlas EV Hub.

In addition to boosting the supply of public charging, the NEVI Program has the potential to establish strong national standards. In June 2022, the Federal Highway Administration released proposed minimum standards including that each NEVI funded station must:

- Use Combined Charging System (CCS) plugs
- Provide a minimum of four DCFC ports per station, every 50 miles
- All ports must be able to deliver at least 150 kW simultaneously (minimum of 600 kW per station)

- Ensure annual uptime (the amount of time that the charger is working) requirements of 97 percent
- Ensure that it is easy to use credit and debit cards (as opposed to stations where membership payment is easy but payment with a credit card is cumbersome)

This reflects a broader standardization of charging ports and a move towards CCS ports and away from CHAdeMO. The only BEV that uses the CHAdeMO is the Nissan LEAF, and Nissan's upcoming Ariya model will have CCS [18]. Electrify America has indicated it will phase out CHAdeMO from 2022 onwards. Meanwhile, Tesla has indicated that it will open its Supercharger network of chargers to non-Tesla owners in 2022 [19]. Non-Tesla vehicles will still need an adapter to access the nearly 26,000 Tesla chargers across the nation.

Charger reliability is critical to support mass adoption of EVs. Drivers must have confidence that chargers will be available and operable when they arrive to charge. Reliability has long been a pain point for the charging industry. In a March 2022 study, *Reliability of Open Public Electric Vehicle Direct Current Fast Chargers*, Rempel et al. found that only 72.5 percent of the 657 DCFC CCS chargers tested in San Francisco were functional [20]. In 4.9 percent of cases, the cable was not long enough, and in the remaining 22.7 percent of cases, the charger did not work due to "unresponsive or unavailable screens, payment system failures, charge initiation failures, network failures, or broken connectors" [20]. If drivers are experiencing charging issues with more than a quarter of public chargers, there may be impacts on rates of adoption for EVs. Nevertheless, it is encouraging that the NEVI program is centering reliability as a core performance indicator for building out the next phase of chargers.

Finally, to ensure equity, it is crucial that public chargers are both affordable and available for low to moderate income Americans who are more likely to rent or live in a multifamily building where home charging access may be limited or nonexistent. Public charger dependence can increase fueling costs as costs-per-kWh are higher at those chargers than residential electricity rates. These chargers may also be inconvenient if the individual must wait with the vehicle as it charges. Moreover, public charging station investment has historically lagged in low to moderate income communities, creating *charging deserts* where residents must travel long distances to access public charging stations. This challenge may be even more pronounced in rural communities where drivers commute significant distances, providing a higher level of reliance on both home charging access (if installed) as well as access to public charging stations. Some of this need may be served by the $2.5 billion discretionary grant program for EV and other alternative fueling in the IIJA. This funding, split between the Corridor Charging Grant Program and the Community Charging Grant Program, requires consideration of locations for underserved or low-income communities.

Box 3. New Federal Funding for EVs

The Infrastructure Investment and Jobs Act provides funding for light-duty EVs including:

- **EV Charging**: Funding to states to "strategically" deploy EV charging, maintenance for the infrastructure and "establish an interconnected network to facilitate data collection, access and reliability". Includes $5 billion in formula funding and a further $2.5 billion in discretionary grants.
- **Battery processing and manufacturing:** Funding of $6.1 billion to support battery material processing grants and battery manufacturing and recycling grants.
- **Critical Minerals Mining and Recycling Research:** Grants worth $400 million to support supply chain resiliency that support basic research that will accelerate innovation to advance critical minerals mining, recycling, and reclamation strategies and technologies.

The Inflation Reduction Act also provides significant support for light-duty EVs including:

- **EV Tax Credit:** While it removes the 200,000-vehicle manufacturer cap, the amended $7,500 tax credit introduces new battery and critical mineral sourcing requirements and immediate application of requirements for North American assembly. In the short term, it is likely that only a number of vehicles will be eligible for the tax credit due to sourcing requirements. There are also eligibility requirements including income limits and a Manufacturer Suggested Retail Price (MSRP) cap. Finally, the credit will be available at point of purchase from 2024.
- **Used vehicle tax credit:** Starting in 2023, households earning below $150,000 ($75,000 for individuals) will now be eligible for a $4,000 or 30 percent point-of-sale credit, whichever is less. To qualify, the vehicle must be purchased from a dealer and cost less than $25,000.
- **Tax Credit for Commercial EVs:** New credit for clean commercial vehicles capped at $7,500 and $40,000, respectively.

- **Alternative Vehicle Refueling Property Credit:** Reinstates the expired credit. The funding provides up to a 30 percent tax credit for qualified stations up to $100,000.
- **Production tax credit:** This advanced manufacturing production credit provides differing amounts of support based on the component but includes qualifying battery components and any applicable critical mineral.
- **Investment Tax Credit:** Supports a “qualifying advanced energy project” which may include manufacturing that help reduce GHG emissions and projects that support electric and hybrid vehicles.
- **United States Postal Service Clean Fleets:** Provides $1.29 billion for the Postal Service to purchase electric delivery vehicles, and $1.71 billion to purchase and install charging infrastructure.

Utility Investment

Investor-Owned Utilities (IOUs) have been an important source of investment in transportation electrification. Through the end of June 2022, utility regulators have approved $3.6 billion in rate payer funded IOU transportation electrification investments. These funds could support more than 7,800 DC fast charging (DCFC) stations and more than 304,000 Level 2 charging stations. Note that this is the count of chargers approved, not a count of chargers that have been built. In addition, a number of utilities offer a wide range of consumer incentives for EVs, including purchase incentives and charging incentives.

The scale of investment by utilities is considerable. For comparison, Electrify America is the largest DCFC charging network provider in the country (aside from Tesla’s proprietary network) and has installed more than 3,400 DCFC stations since 2017, less than half the number that could be supported by approved investor-owned utility programs. California leads all states with approved investment of $1.55 billion. California IOUs have proposed a further $1.8 billion in spending that has not yet been approved by regulators. New York State has approved $712 million in funding for transportation electrification. Utilities in Florida ($278 million) and New Jersey ($266 million) have also committed significant funding to support transportation electrification. These four states make up nearly 80 percent of all approved IOU EV funding around the country.

Table 2: Investor-Owned Utility EV Investments from 2012 through June 2022

Status	States	Filings	Utilities	Investment	DCFC Stations	Level 2 Stations
Approved	34	138	55	$3,552,187,517	7,839	304,428
Pending	25	61	36	$2,040,621,863	3,716	158,428
Denied/ Withdrawn	22	47	28	$718,953,126	854	90,543

Summary of Investor-Owned Utility Investment in EVs by funding status (approved, pending, or denied).

Source: Atlas EV Hub.

Utilities are uniquely positioned to assist in the development of charging infrastructure for underserved communities. Of approved funding, $994 million has been committed to underserved communities (28 percent of total funding).[3] A recent report from Atlas Public Policy notes that in the second half of 2021, all approved utility filings included an equity provision for underserved communities [21]. Utility equity investments have included provisions such as budget carve outs, offering higher rebates (predominantly for EV charging) for income-qualified customers, creating targeted education and outreach programs, or including equity considerations in selection criteria for choosing charging sites.

There was a further $2 billion in pending investments awaiting decisions from public utility commissions as of June 30, 2022. A large portion of these filings will likely be approved given that the approval rate for utility proposals is over 80 percent.[4] Finally, nearly $719 million has either been denied by commissions or withdrawn by the utility.

Municipal utilities and federally owned utilities have also made efforts to invest in transportation electrification not captured here. Data on investment totals from those utilities is more difficult to access but these utilities continue to make commitments to transportation electrification. For instance, the Tennessee Valley Authority (TVA) is the largest federally owned power company in the country and covers Tennessee, and parts of Alabama, Mississippi, Kentucky, Virginia, North Carolina, and Georgia [22]. TVA announced in August 2021 plans to electrify the entirety of its passenger vehicle fleet and half of its pickup and light cargo truck fleet by 2030, a total of 1,200 vehicles [23]. The TVA also joined

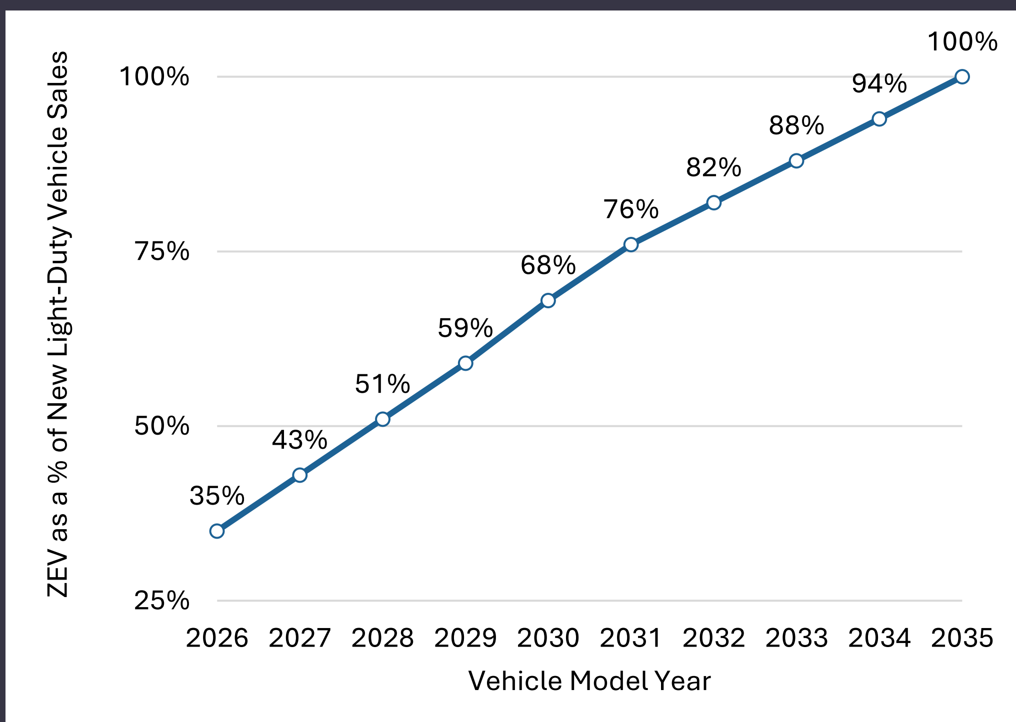
[3] Equity is defined by the utility and approved by the utility commissions. Utilities and/ or commissions define and measure equity differently.

[4] The approval rate [1] to the number of elements considered rather than the amount.

a collaboration of utilities called the National Electric Highway Coalition (NEHC), announced in December 2021. The NEHC includes more than 60 electric companies and cooperatives serving more than 120 million customers across the country. The NEHC is committed to ensuring that customers can drive “with confidence” along major corridors by 2023, knowing that there will be fast charging ports to access.

Box 4. Advanced Clean Cars II

Figure 4: New Vehicle Sales Requirements in Advanced Clean Cars II 2026-2035



Advanced Clean Cars II proposed rules through Model Year 2035.

Source: [24]

Advanced Clean Cars II (ACC II) was approved in August 2022. The Program will require all new vehicles sold in California after 2035 to be ZEVs, including PHEVs, BEVs, and FCEVs. ACC II specifies that up to 20 percent of ZEV credits can be generated by selling long-range plug-in hybrid EVs (minimum of 50 miles range by 2030), with the other 80 percent of credits generated by BEV and FCEV purchases [24].

The ACC II Standardized Regulatory Impact Assessment (SRIA) notes a suite of benefits for environmental justice communities including credits for “community car share programs, producing affordable ZEVs, and keeping used vehicles in California to support CARB’s complementary equity incentive programs” [24]. It also notes that the program will deliver more than $81 billion in net cost savings from 2026 to 2040 due to lower total costs of ownership and considerable health benefits from improved air quality. There will also be significant greenhouse gas emissions reductions as captured in analysis from the Environmental Defense Fund [25]. However, CARB staff estimates that these benefits will come at a cost of $30.2 billion to businesses and will result in a net job loss of 39,800 jobs by 2040 [24]. Section 177 of the Clean Air Act allows other states to adopt California’s standards in lieu of federal standards. To date, 15 other states have adopted the ZEV Program under ACC I, the first iteration of the ACC rules, for model years up to 2025 [26]. While it is unclear at this time how many of those states would adopt California’s new rules, the states of New York, Washington, Oregon, Massachusetts, and Vermont have indicated they will adopt ACC II.

State Policies

States are continuing initiatives to drive EV adoption including EV purchase incentives and zero-emission vehicle (ZEV) regulations per Advanced Clean Cars (ACC) rule. Across the country, 14 states had an EV rebate in place to incentivize is the purchase of EVs at the end of June 2022. These rebates range from the CHEAPR program in Connecticut (a buyer may access up to $2,250 in rebates for the purchase of an EV with an MSRP of less than $50,000 or up to $4,250 for low-income residents) to the newly implemented Electric Vehicle Rebate Program in Illinois. From July 1, 2022, Illinois residents are eligible for a $4,000 rebate for a battery EV with a priority for low-income applicants.

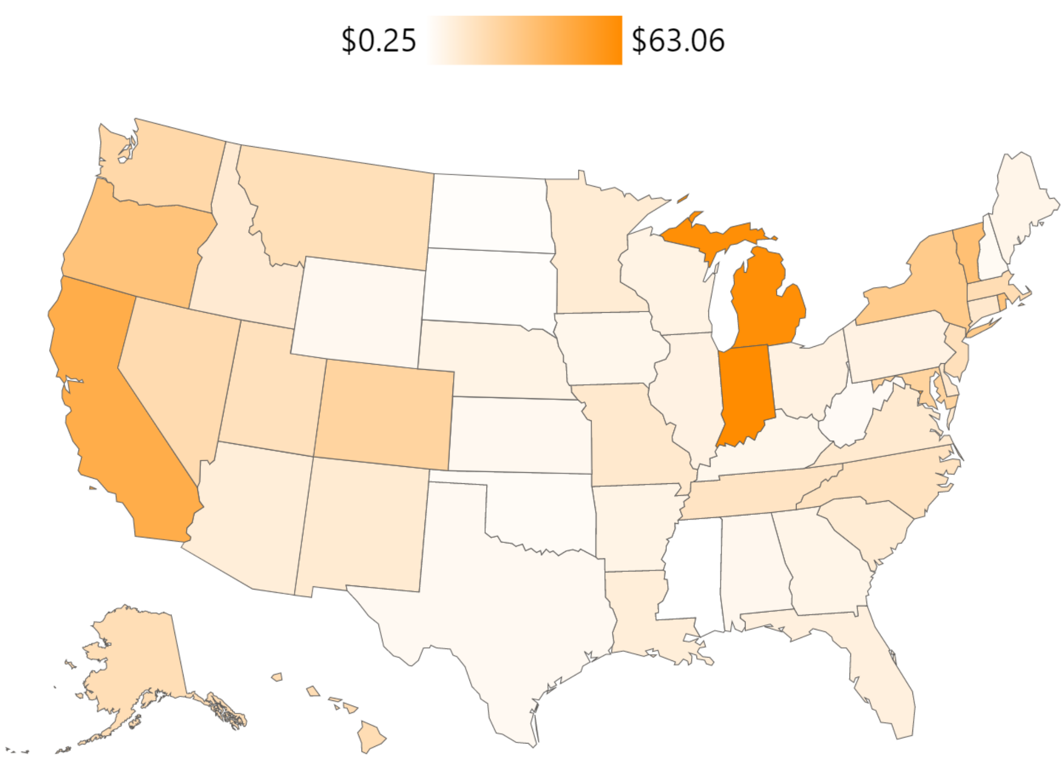
The most prominent state-led policy to date is the ZEV regulation (part of California’s ACC regulations). The ZEV regulation requires automakers to sell an increasing percentage of zero emission vehicles within markets that have adopted the regulation. The current regulation targets seven to 10 percent of new vehicle sales by 2025. California just approved the ZEV program for model years 2026 through 2035 through the ACC II standards (featured above). As of July 2022, ZEV states include California, Colorado, Connecticut, Massachusetts, Maryland, Maine, Minnesota, Nevada, New Jersey, New Mexico, New York, Oregon, Rhode Island, Virginia, Vermont, and Washington state.

Together these states constitute 35.9 percent of all light-duty vehicle sales in the country [26].

As well as supportive policies, states have also implemented policies that may hinder EV adoption. Around the country, 31 states have some form of annual fee for EVs over and above registration fees, applied as an alternative to gas taxes for internal combustion engines that help fund roadways. The highest in the country is Washington with a fee of $225, then Georgia which has a $213.70 annual fee for EVs. The annual fee is at least $200 in five other states: Ohio, West Virginia, Wyoming, Arkansas, and Alabama. In most states, there is a lower fee for plug-in hybrid vehicles.

Public Funding

Figure 5: Public Funding for Light-Duty EVs and Charging per Person by State



On a per person basis, Indiana, Michigan, and Washington DC lead all states in public funding for light duty EVs followed by California, Vermont, and Oregon. This funding may come from either federal or state government and does not include loans or the recent NEVI formula funding.

Source: Atlas EV Hub.

Public funding for EVs continues to grow. Through the end of June 2022, public funding for light-duty transportation electrification and charging equipment from both state and federal programs (including VW Settlement funding) was $1.4 billion. On a per capita basis, Indiana, Michigan, and Washington DC led all states in public funding for transportation electrification. Key sources of public funding to date include the American Recovery and Reinvestment Act of 2009, and the Federal Transit Administration's Low- or No- Emission (Low-No) and Buses and Bus Facilities grant programs and the Volkswagen (VW) Settlement.

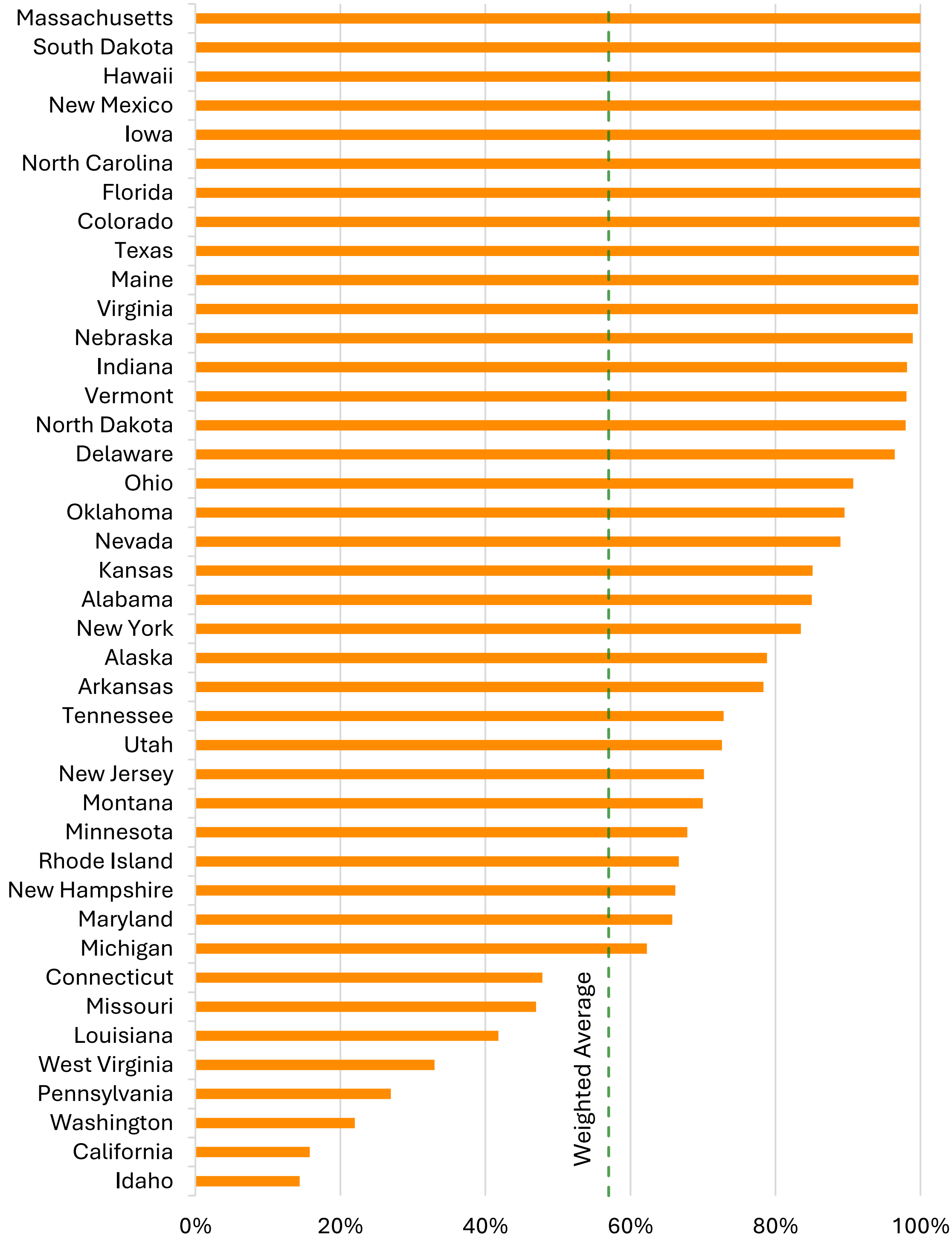
The NEVI Program will bolster funding for states. The $5 billion in formula funding will support key charging infrastructure. States may compete for the $2.5 billion available in discretionary funding for hydrogen fueling, or community and corridor charging. There is also other funding in the Infrastructure Investment and Jobs Act that will go to EV charging and transportation electrification including the $6.4 billion in formula funding for states and localities through the Carbon Reduction Program (CRP).

VW Settlement Funding for EV Charging

The 2017 Volkswagen Settlement allocated $2.8 billion to states to make grants to reduce diesel emissions. The Settlement allows states to use up to 15 percent of their allocation for light-duty EV charging. Based on plans submitted to the trust, states intend to allocate $318 million to charging, representing 75 percent of the $423 million allowable.

As of the end of June 2022, states have awarded or made available $239 million for EV charging, representing 75 percent of the planned amount. Eleven states have already awarded their full 15 percent while eight states (Arizona, Illinois, Kentucky, Georgia, Wisconsin, South Carolina, Oregon, and Wyoming) and Washington DC have not yet made any awards for EV charging.

Figure 6: Percent of Allowable EV Charging Spent per the VW Settlement by State



Arizona, Illinois, DC, Kentucky, Georgia, Wisconsin, South Carolina, Oregon, and Wyoming have not awarded any VW Settlement funds to light-duty EV charging deployment as of June 30, 2022.

Source: Atlas EV Hub.

Supply Chain

EV Manufacturing

Table 3: The Top 15 Largest Announced EV Manufacturing Facilities (by Investment)

Parent Company	State	Vehicles Produced	EV Investment	EV Employees
Hyundai	GA	Multiple Classes, Batteries	$5,540,000,000[5]	8,100
Ford	KY	Batteries	$5,800,000,000	5,000
Ford	TN	Light-Duty (Class 1-2)	$5,600,000,000	6,000
Rivian	GA	Light-Duty (Class 1-2)	$5,000,000,000	7,500
Tesla	NV	Light-Duty (Class 1-2)	$4,500,000,000	7,000
Tesla	CA	Light-Duty (Class 1-2)	$4,100,000,000	10,000
General Motors	MI	Light-Duty (Class 1-2)	$4,000,000,000	2,350
Statevolt	CA	Batteries	$4,000,000,000	2,500
SK Innovation	GA	Batteries	$2,610,000,000	2,600
General Motors	MI	Batteries	$2,600,000,000	1,700
Stellantis	IN	Batteries	$2,500,000,000	1,400
General Motors	OH	Multiple Classes	$2,300,000,000	1,100
General Motors	TN	Batteries	$2,300,000,000	1,300
General Motors	MI	Light-Duty (Class 1-2)	$2,200,000,000	2,200
VinFast	NC	Multiple Classes	$2,000,000,000	7,000

Summary of the top 15 announced EV manufacturing facilities. All facilities were announced on or before June 30, 2022. The jobs are announced jobs.

Source: Atlas EV Hub.

[5] An additional $1 billion was invested by Hyundai suppliers, which is counted separately.

The Department of Energy estimates the U.S. was home to eight percent of global EV lithium-ion cell manufacturing in 2020 with 59 GWh [27]. Since then, automakers have increased their commitments to support domestic EV manufacturing. In the first six months of 2022, 35 percent of all battery manufacturing jobs to date in the United States were announced and four of the top five largest facilities in the U.S. were announced in the past 12 months. Through the end of June 2022, automakers announced more than 115,000 jobs and $82.1 billion in investment for EV manufacturing in the United States.

In September 2021, Ford and battery manufacturer SK Innovation together announced plans to invest $11 billion to build batteries and assemble EVs in Kentucky and Tennessee. According to Ford, this project will create 11,000 jobs between the two states and would be the largest private investment in Kentucky's history [28]. The investment will fund the production of the F-150 Lightning, the electric version of the top-selling vehicle in the country. As part of the announcement, Ford also announced a plan to collaborate with Redwood Materials on a closed-loop battery recycling system.

In December 2021, Toyota invested $1.2 billion in a new North Carolina battery production facility that will come online in 2025. The facility will create as many as 1,750 jobs and will be able to deliver enough lithium-ion batteries for up to 1.2 million EVs per year. In addition, in December 2021, Rivian announced a $5 billion investment in the company's second vehicle assembly plant outside of Atlanta, Georgia, that it says will eventually create 7,500 jobs. The Governor of Georgia lauded the initiative as the largest economic development project in the state's history. A few months later, Hyundai set a new record with the announcement of a facility to support 8,100 jobs in the state to build batteries and assemble EVs. Other key components of the supply chain for EVs – including Electric Motors (AC) and inverters – must be scaled up to meet surging demand for EVs.

Charging Manufacturing

The Biden Administration has a target of 500,000 charging stations in the U.S. by 2030 [29]. It is not clear how many of those charging stations will be produced domestically. Table 4 summarizes the manufacturing facilities that produce either DCFC and/or Level 2 charging stations. These manufacturers produce charging stations both for public and private use and ensure the U.S. has domestic manufacturing capabilities for EV charging equipment.

Table 4: Charging Manufacturing Facilities in the U.S. (Announced or Operational)

Site Name	State	Company	Year Operational	Charging Unit Production (Annual)	Type of charger
Innovation Park Facility	IL	EVBox	Operational	10,400	DCFC
Wendell Facility	NC	Siemens	Operational	NA	DCFC
Auburn Facility	CA	ClipperCreek	Operational	10,000	Level 2
Gigafactory 2	NY	Tesla	Operational	NA	DCFC
SemaConnect Manufacturing Facility	MD	SemaConnect	Operational	50,000	DCFC, Level 2
Auburn Hills Plant	MI	FLO	2022	50,000	DCFC, Level 2
Tarrant Facility	TX	Wallbox	2022	500,000	DCFC, Level 2
Lebanon Facility	TN	Tritium Charging	2022	30,000	DCFC
FreeWire Manufacturing Facility	CA	FreeWire Technologies	2022	NA	DCFC
Milpitas Facility	CA	ChargePoint	2026	20,000	DCFC, Level 2
Pomona eMobility Hub	CA	Siemens	NA	NA	Level 2
Grand Prairie eMobility Hub	TX	Siemens	NA	NA	Level 2

This data includes all EV charging supply equipment production factories that we were able to identify and verify through some means. NA means that the data is not available. Data source: Blue Green Alliance Foundation and press releases.

Source: [30]

Box 5. BlueLA (California)

In 2015, Los Angeles was awarded a grant from the California Air Resources Board to pilot an electric car sharing service in low-income communities. Blink Mobility now operates the service, BlueLA, in partnership with the City of Los Angeles and the Los Angeles Department of Transportation [31]. Through BlueLA, shared vehicles can be picked up and dropped off at 40 designated stations around Los Angeles, each with five charging ports. BlueLA features low monthly membership costs in addition to a lower per minute charge for rentals (25 percent off the general rental fee). Through July 2020, users had traveled more than 63,000 trips and more than 1.3 million miles. Blink estimates that the average trip length is six miles [32]. Of those trips, fifty-five percent were rides made by low-income users. Due to high utilization rates, the Los Angeles City Council voted to approve an expansion of the service. Blink Mobility plans to increase the fleet from 300 to 500 vehicles and add 300 more charging stations [32].

Batteries

Background

Nearly all EVs use lithium-ion batteries [27]. These batteries include an anode (mostly graphite) and a cathode (multiple materials, dependent on the battery chemistry). Lithium ions travel between the anode and cathode through an electrolyte [33]. The three primary battery types are nickel manganese cobalt (NMC), nickel cobalt aluminum (NCA), and lithium ferro phosphate (LFP) (also known as Lithium Iron Phosphate or LiFePo). These battery types are all named for the main components of their cathodes.

Battery capacity needed to meet new vehicle sales

The range of EVs has improved significantly in the past decade as battery prices have plummeted and energy density has improved. Only 12 years ago, the first mass-market EV hit the roads: the Nissan LEAF. The LEAF was a definitive city-commuter with a 73-mile Environmental Protection Agency (EPA) rated range [34]. Most EVs in 2022 have triple the range of a 2011 Nissan LEAF. For instance, the Ford Mustang Mach-E, one of the best-selling EVs in 2021, can travel 270 miles on a single charge [35]. Some EVs can go even further. The Dream Edition of the Lucid Air – among the most expensive EVs on the market – received a remarkable EPA rating of 520 miles [36]. To allow for this significant improvement in range, the average capacity of battery packs has increased dramatically. A

2011 LEAF sported a 22-kWh battery pack [37]. A 2021 Lucid Air Dream Edition can store 118 kWh – over five times that much energy [38].

As EVs increase in both average range and popularity, battery demand is set to skyrocket. The Argonne National Laboratory outlined the potential scenarios in a March 2021 report. The authors, aggregating existing projections, anticipate global battery demand could reach anywhere from 600 GWh to nearly 2,500 GWh in 2030 (including light-duty and medium and heavy-duty vehicles) depending on assumptions about policy and other parameters [39]. At the upper range, analysts from Argonne National Laboratory and Leiden University assumed that EVs (BEVs and PHEVs) would constitute 30 percent of all light-duty sales by 2030.

More recently, the IEA Global EV Outlook 2021 projected that global battery demand will exceed 1,600 GWh a year in 2030 under a scenario in which no new beneficial policies are introduced [40]. However if more sustainability-oriented policies are implemented, demand may reach 3,200 GWh, demonstrating the significant potential range in future demand based on markets and policy settings. For context, global production was only 160 GWh in 2020 [40]. In the United States, President Biden set a target in December 2021, that half of all new light-duty vehicle sales will be electric by 2030 [41]. Meeting that goal is made more challenging with geopolitical turmoil and will require significant growth in the extraction of critical minerals, significant battery production and that those new facilities quickly bring batteries to market at an affordable price.

Battery cost per kWh estimates

The cost of lithium-ion batteries has plummeted over the past decade. Between 2010 and 2020, the price per kWh fell from $1,100 to $137 [42]. Considering most new EVs now house batteries 60 kWh or larger, every percentage drop is critical to achieving sticker-price parity with internal combustion engine (ICE) vehicles.

Estimates for the future price of batteries, even from the most credible sources, have been imperfect. Many experts historically underestimated the impact that economies of scale and efficiency gains would have on cell costs. Looking ahead, it is important to treat price projections with caution as many variables determine future costs and supply chain challenges have the potential to slow or reverse price drops. However, estimates still provide insight into price direction and economic patterns for the battery market.

As further explained in the Battery Composition section, the cost per kWh of lithium-ion batteries varies across different chemistries. According to Bloomberg New Energy Finance (BNEF), lithium ferro phosphate (LFP) battery prices were nearly 30 percent cheaper than nickel cobalt manganese (NCM) variants in 2021 [42].

Supply chain slowdowns and rising input costs are affecting all battery chemistries. As a result, the average cost per kWh may not fall below $100 until 2024 [2]. In 2021, battery packs experienced a modest 6 percent drop from the year prior – far from the 35 percent plummet between 2014 and 2015. Looking forward, in March 2021, the National Academies of Sciences (NAS) estimated that costs would drop further to $65-$80 kWh in 2030 [24]. In addition to the rising cost of raw materials, demand from adjacent industries including stationary batteries could put pressure on battery prices. BNEF estimates that worldwide battery energy storage system deployment will demand as much as 1,028 GWh by 2030 (up from 17 to 34 GWh in 2020) [43].

Battery Composition

Several different varieties of lithium-ion batteries power modern EVs, each with its own composition. While all modern EV batteries contain lithium, the quantity of lithium and other critical minerals varies by battery chemistry [33]. In 2020, NMC batteries represented the lion's share of the market – present in 72 percent of all EVs produced that year (globally excluding China) [44]. The most common variations of NMC batteries are NMC811, NMC523, and NMC622 [44]. The numeric suffixes of these batteries represent the percentage of each mineral within the cathode [45]. For example, NMC811 is roughly 80 percent nickel, 10 percent manganese, and 10 percent cobalt.

Each battery chemistry has its advantages and disadvantages. The primary benefit of LFP batteries compared to nickel based NCAs and NMCs is that they require no cobalt [45]. LFPs are also cheaper to produce and can deliver more watt power (i.e., better acceleration) per kilogram. However, they are less energy dense – less energy (i.e., shorter range) is stored in the battery per kilogram. Thus, LFPs are better suited for EVs where the range requirement is lower (200-250 miles) or in heavy-duty vehicles where power density is particularly important. Tesla has already switched its Standard Range Model 3s to LFP chemistry, and other automakers are beginning to follow suit for non-luxury models [46].

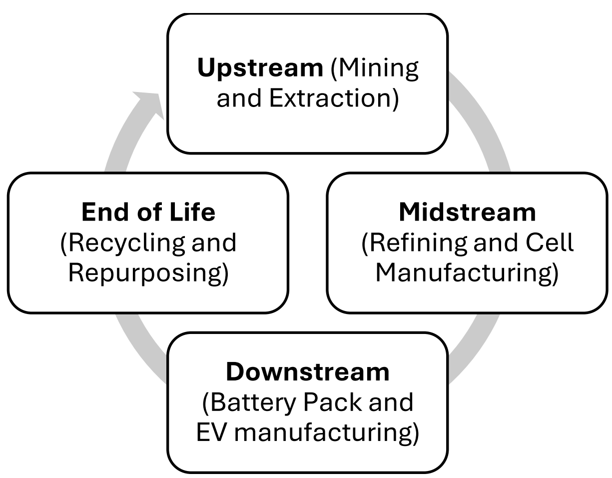
Cobalt-based chemistries are still widely employed because they can support longer ranges [47]. Achieving over 300 miles on a single charge is essential for vehicles at the higher end of the cost curve. But given concerns about cost and the ethics of cobalt production, automakers are incentivized to phase it out where possible. Even when switching to LFP batteries is not feasible, reducing mineral intensity is a secondary option. One example of this is Ford's partnership with SK Innovation to produce NMC batteries that only require five percent cobalt and five percent nickel, halving the amount needed per vehicle [33].

While current battery competition revolves around these three main types: NMCs, NCAs and LFPs, two potential disruptors could be significant to battery innovations. The first is solid-state batteries [48]. Solid-state batteries use a solid electrolyte rather than a liquid one, and therefore require no separator between the negative cathode and the positive anode. Removing the separator decreases the space the battery takes up and allows for greater energy density, and thus a greater number of kWh. Another benefit associated with a solid electrolyte is the potential for enhanced safety through the reduction of the risk of explosion or fire. Solid-state batteries are also less reliant on nickel and cobalt. Solid-state battery companies like QuantumScape and Solid Power hope to begin selling solid-state batteries over the next few years, albeit nowhere near mass-production [49]. Delivering on those ambitions and scaling up to meet market demand will be a significant challenge.

Likewise, sodium-ion batteries may prove to be an essential battery solution – either through applications in EVs or in other battery-powered objects, reducing overall demand for lithium-ion batteries. These batteries are cheaper to produce and less dependent on critical minerals. The challenge is that sodium-ion batteries can only charge so many times before they need to be replaced. CATL, the world's largest EV battery maker, has signaled it will produce sodium-ion batteries [50]. However, the technology is still years away from making any dent in the market.

Critical Minerals Overview

Figure 7: Lithium-ion Battery Supply Chain



Source: [51]

Background

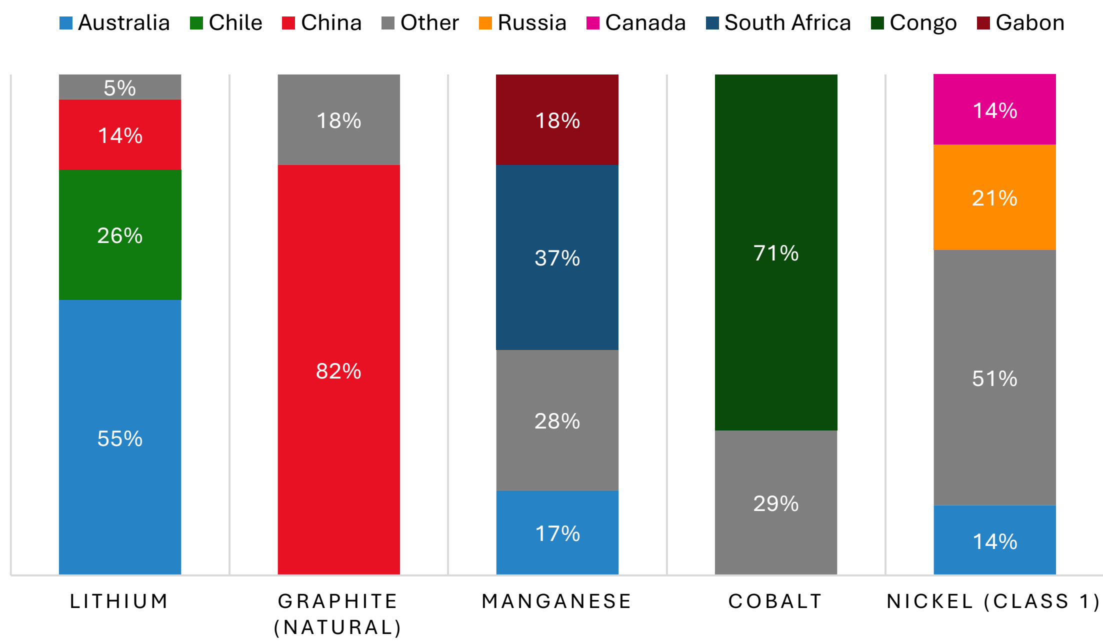
To ensure that 50 percent of all new light-duty vehicle sales are EVs by 2030, the United States will need to increase domestic production and international partnerships to secure supply of at least five critical minerals used in lithium-ion batteries: cobalt, lithium, manganese, graphite, and nickel [52]. While ICE vehicles also require manganese (for steel production), battery electric vehicles require more than twice the amount of manganese compared with ICE vehicles. More broadly, EVs require six times more critical minerals than ICE vehicles [53]. As a result, legacy automakers are rushing to secure access to these new vital battery components.

Time is of the essence. According to a press release from the White House in February 2022, global demand for critical minerals is projected to multiply four to six times over the next several decades, and even more for lithium and graphite in particular [54]. To mitigate a future supply chain crunch and potential price spikes, President Biden invoked the Defense Production Act (DPA) in March 2022 [55]. The DPA allows the President to exert greater control over funding allocation to speed up battery production at all levels of the supply chain and allocated $750 million to study ways to attain higher grade products, progress mine waste reclamation and other initiatives [56]. Further, the Infrastructure Investment and Jobs Act appropriated funding to support the U.S. Geological Survey (USGS) to map critical minerals. Key to these efforts is $64 million to support geoscience data collection of critical mineral resources across 30 states, announced in June 2022 [57].

Challenges

The United States has become dependent on foreign markets for critical minerals in this new-age gold rush. This was not always the case. For several decades following the Second World War, most of the world’s supply of lithium came from North Carolina [58]. Back then, however, demand for the metal was comparatively small. By the 1990s, lithium mining output in the United States had mostly dried up as investments were deprioritized. Similarly, graphite has not been mined domestically since the 1950s [59]. In the intervening years, the United States has become a net-importer of critical minerals. In 2021, the United States imported more than 25 percent of its lithium, 48 percent of nickel, 76 percent of its cobalt, and all its graphite and manganese [60].

Figure 8: Critical Mineral Extraction is Highly Concentrated in a few countries



Critical mineral extraction by country for 2021 (data is from 2019 for Nickel). "Other" captures countries ranked fourth in production of the critical mineral or if the value for a country is less than ten percent. Data source: USGS and McKinsey.

Source: [61] [62]

Continued reliance on foreign sources for EV-related minerals has important supply chain and domestic security consequences. In 2021, China made nearly half of all new lithium acquisitions in its attempts to capture the burgeoning critical minerals market [63]. A Chinese stranglehold over the battery mineral market could have significant outcomes (in terms of meeting climate targets and economic disruption for instance) for the U.S. automotive industry in the coming decades, given the implications of the recent U.S.-China Trade War [64]. For instance, artificial graphite imported from China into the U.S. has been subject to a 25 percent tariff because of the trade dispute [65].

A second and equally important consequence surrounds environmental sustainability and human rights. Take cobalt for instance. The silver-gray metal is still a core component of long-range EV batteries. Two-thirds of cobalt supply is currently mined in the Democratic Republic of the Congo (DRC) and is tied to a well-documented history of human rights violations and environmental degradation [66]. From miners digging by hand to radioactive waste leaking into drinking water, the use of Congolese cobalt undermines EV-related sustainability goals. As a result, the industry is seeking ways to move away from the controversial metal. Tesla, for instance, produced nearly half of its vehicles in Q1 2022 without cobalt or nickel, relying instead on iron based LFP batteries [67].

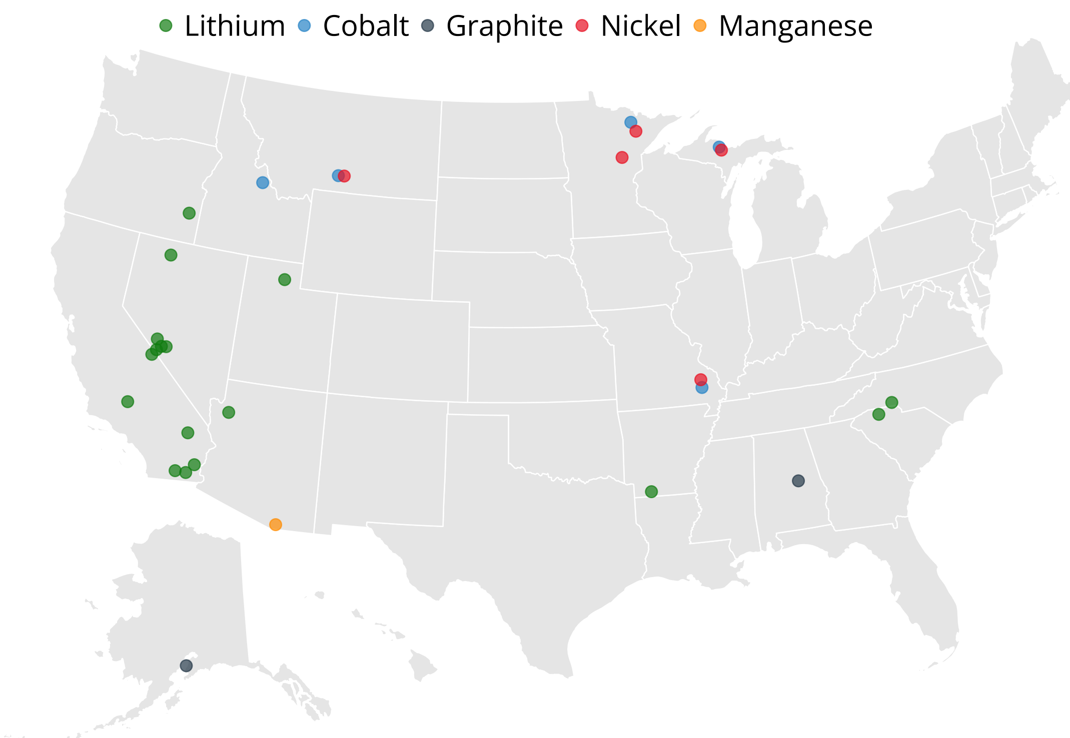
Across all five critical minerals, there are environmental justice concerns. For instance, research from MSCI found, “97% of nickel, 89% of copper, 79% of lithium and 68% of cobalt reserves and resources in the U.S. are located within 35 miles of Native American reservations” [68]. Given the long and harmful history of exploitation of Native land for mineral extraction and resistance to that extraction, it is important that the extraction of critical minerals not repeat those harms [69] [70]. Decision making must weigh the societal benefits (e.g., enabling decarbonization and reliable domestic supply of minerals) and risks to communities (e.g., risks to water sources, air quality, land fertility, and health, disruption of way of life, and desecration of sacred sites) in the extraction of critical minerals. In March 2022, the Biden-Harris Administration initiated an “Interagency Working Group on Mining Regulations, Laws, and Permitting.” The Group is expected to report back in November 2022 [71].

There have been shifts in the cost curves in 2022. Analysis from the IEA notes that the cost of critical minerals has increased significantly – lithium and cobalt prices doubled in 2021 [72]. Rising demand and supply chain challenges continue to push up costs.

Extraction of Critical Minerals

EV batteries require many critical minerals. This summary of five critical minerals reflects a review of sources, including the USGS critical minerals list for 2022, the International Energy Agency (IEA) summary of needs over the coming decades, and the report *How Technology, Recycling, and Policy Can Mitigate Supply Risks to the Long-Term Transition to Zero-Emission Vehicles* by the ICCT in December 2020 [73] [74] [75]. In May 2022, the Biden-Harris Administration directed the Department of Defense to stockpile the five minerals summarized here [52]. Many of these facilities are years off. According to analysis from Benchmark Mineral Intelligence, it takes a minimum of five years and often much longer, to build a lithium mine in the United States [76].

Figure 9: Critical Mineral Mines (current and proposed) in the United States



Where one mine is the source of more than one critical mineral, that mine is represented by one dot per critical mineral. Data source: Press releases, NREL's Lithium-Ion Battery Supply Chain Database and User Guide report, and USGS Mineral Summary for 2022.

Source: [77] [61]

Lithium

Table 5: Domestic Lithium Extraction Sites (Announced and Operational)

Site Name	State	Year Operational	Parent Company
Silver Peak Mine	Nevada	Operational	Albemarle
Hell's Kitchen	California	2024	Controlled Thermal Resources
Project ATLiS	California	2024	EnergySource Minerals
Rhyolite Ridge	Nevada	2025	Ioneer
Big Sandy Lithium Project	Arizona	2025	Hawkstone
Compass Minerals Lithium Project	Utah	2025	Compass Minerals
Berkshire Hathaway Project	California	NA	Berkshire Hathaway
Thacker Pass Lithium Mine	Nevada	NA	Lithium Americas
McDermitt project	Oregon	NA	Jindalee Resources Limited
Carolina Lithium Project	North Carolina	NA	Piedmont Lithium
NeoLith Energy pilot plant	Nevada	NA	Schlumberger
Arkansas Smackover Lithium Project	Arkansas	NA	Standard Lithium
Bristol Lake	California	NA	Standard Lithium
Kings Mountain Mine	North Carolina	NA	Albemarle
Boron Plant	California	NA	Rio Tinto
Clayton Valley Lithium Project	Nevada	NA	Cypress Development
Zeus Lithium Project	Nevada	NA	Noram Lithium

NA means that the data is not available. Data source: Press releases, NREL's Lithium-Ion Battery Supply Chain Database and User Guide report, and USGS Mineral Summary for 2022.

Source: [77] [61]

There is currently only one lithium mine in operation in the United States: The Silver Peak Mine in Nevada. According to the Idaho National Laboratory, this facility produces 4,500 metric tons a year – roughly two percent of global lithium supply [78]. Table 5 summarizes the other mines under some stage of development domestically. U.S. imports of lithium from 2017 to 2020 were predominantly from Argentina (54 percent), Chile (37 percent) and China (5 percent) [61].

Two types of lithium may be used in EVs: lithium carbonate and lithium hydroxide. Lithium hydroxide is produced from lithium carbonate that is put through a chemical process. Demand for lithium will skyrocket over the next decade, which could necessitate an increase in imports. According to a report by McKinsey & Company in April 2022, worldwide lithium demand will surge from 500,000 metric tons to between 3.3 and 3.8 million metric tons annually in 2030 [79]. The authors note they only have visibility on 2.7 million metric tons of lithium supply in 2030.

According to USGS data, the cost of lithium is also skyrocketing. Lithium carbonate prices were $75,000 per metric ton in March 2022, compared with $17,000 in 2021 [80]. The price rises may threaten the downward trajectory of battery prices seen over the past few years [42]. Production and consumption of lithium also went up, but not nearly as steeply. According to the USGS 2022 Summary for Lithium, global lithium production (excluding the United States) increased by 21 percent to 100,000 tons in 2021 while consumption was estimated at 93,000 tons, 33 percent higher than 2020 [61].

The Department of Energy (DOE) identifies the three key forms of lithium extraction:

1. Open-pit mining (predominantly Australia)
2. Brines (predominantly South America, North America, and Europe)
3. Geothermal extraction (Salton Sea, California and Rhine Valley, Germany) [81]

Lithium must then be processed. Much of this processing takes place in, and much of the mining is controlled by, China. China has stakes in lithium mines in some of the largest lithium-producing countries in the world, including 67 percent of output in Chile. In Australia, Chinese firms have secured deals for 9 of the 11 most significant projects to come and of those deals, two thirds are exclusive deals [82].

There are serious concerns about environmental justice linked to lithium mines, including the proposed Thacker Pass mine in Nevada. Local protests have centered on mining on Native land, the potential destruction of sacred sites as well as water contamination [83]. Other sites have met similar resistance. In North Carolina, there is local opposition to the re-opening of a dormant lithium hard rock mine [84]. Piedmont Lithium leads the project and has faced resistance from residents who recall earlier mining and have concerns about the impact on local water tables, pollution, and their way of life. State regulators have also expressed concern about the impact of the mine on water table levels and sewage systems [85].

There has been more muted opposition to proposed lithium extraction sites at the Salton Sea in California. The opposition often revolves around many of the unknowns in direct lithium extraction [86]. According to estimates used by the California Energy Commission, the Salton Sea could produce up to 600,000 tons of lithium per year [87]. While this form of extraction is greener as it uses renewable geothermal energy and is significantly less water intensive, it is also more expensive at this stage and has not yet been produced at a commercial scale [88] [89]. Controlled Thermal Resources, one of the companies involved at the Salton Sea, has pledged to support 220 jobs initially and 1,400 jobs in the longer term [90]. The company has also pledged that 95 percent of those jobs would be sourced locally [90]. California's Lithium Valley Commission, a state government initiative tasked with providing guidance on the region's significant lithium resources, has floated the idea of a levy on the mineral to support the local community in building infrastructure. In June 2022, the state's legislature passed a lithium tax ranging from $400 (for the first 20,000 tons they produce) to $800 per ton (for anything above 30,000 tons) [91]. The Commission released a draft report in October 2022 [86].

Automakers are also building partnerships with lithium mines, going further upstream in the supply chain including Tesla in Nevada, GM in California, and BMW in Argentina [92]. In June 2022, Ford announced a deal to source lithium from a mine in Western Australia through a partnership with Liontown. The deal would mean Ford could source more than 165,000 tons of lithium spodumene concentrate a year for five years [93].

Cobalt

Table 6: Domestic Cobalt Extraction Sites (Announced and Operational)

Site Name	State	Year Operational	Parent Company
Madison Mine	Missouri	Operational	United States Strategic Metals
Eagle Mine	Michigan	Operational	Lundin Mining Corporation
Idaho Cobalt Operations	Idaho	Operational	Jervois Global
Stillwater West Project	Montana	NA	Stillwater Critical Minerals
North-Met	Minnesota	NA	Glencore

The Idaho mine opened in October 2022. NA means that the data is not available. Data source: Press releases, NREL's Lithium-Ion Battery Supply Chain Database and User Guide report, and USGS Mineral Summary for 2022.

Source: [77] [61]

The United States imported 76 percent of all cobalt consumed domestically in 2021 according to the USGS Mineral Commodity Summaries 2022 [61]. This summary includes cobalt required for purposes other than producing EV battery cells.

The only domestic sources of cobalt in the United States are The Eagle Mine in Michigan (trace amounts only and set to close in 2026) and the Madison Mine in Missouri (from historic mine tailings). In October 2022, the Idaho Cobalt Operations site opened. According to the USGS, Minnesota has the greatest reserves of cobalt of any state in the U.S. Aside from Idaho and Missouri, any future cobalt production would be a byproduct for other minerals. As with lithium, automakers are securing deals with mines. GM has initiated a multiyear partnership with Glencore to source cobalt from Australian mines [94].

The dependence on cobalt in lithium-ion batteries is costly – estimates are that cobalt alone makes up a quarter of the cost of the battery's cathode [95]. Further, supply chains are reliant on problematic sources, principally from the DRC [96]. More than 70 percent of all cobalt globally is sourced from the DRC, and according to reporting from the *New York Times*, 15 of 19 cobalt-producing mines in DRC were owned or financed by Chinese companies [97].

The DRC has seen egregious human rights abuses linked to cobalt mining. There are two main kinds of cobalt mines in the country. First, there are artisanal mines: mostly small-scale mines where people work independently and usually by hand. Reporting has shown that these mines are dangerous and dependent on child labor [66]. The other type of mine is industrial mines, where 80 percent of cobalt is sourced in the DRC. Industrial mines are larger-scale mines where companies employ workers. A report from Rights and Accountability in Development and the Centre d'Aide Juridico Judiciaire in November 2021 highlighted abuses at industrial mines [98]. Automakers have partnerships with a number of these mining companies. The challenges are greater when companies subcontract services, which is increasingly common. The report details employees' experiences at industrial mines where they do not earn a living wage, are subject to unsafe or hostile work conditions, and either have poor health insurance or none at all [98]. The report notes that one gap in oversight is that international mining standards are voluntary and not binding.

Thanks to developments with solid-state and LFP batteries, the battery supply chain may be less reliant on cobalt over time. The Department of Energy aims to remove cobalt from EV batteries by 2030 [27], and research indicates that high levels of recycling will reduce raw cobalt demand by 26-44 percent by 2050 [27] [99].

Nickel

Table 7: Domestic Nickel Extraction Sites (Announced and Operational)

Site Name	State	Year Operational	Parent Company
Eagle Mine	Michigan	Operational	Lundin Mining
Madison Mine	Missouri	Operational	United States Strategic Metals
Tamarack Nickel Project	Minnesota	2025	Talon Metals Corp
Stillwater West Project	Montana	NA	Stillwater Critical Minerals
North-Met	Minnesota	NA	Glencore

NA means that the data is not available. Data source: Press releases, NREL's Lithium-Ion Battery Supply Chain Database and User Guide report, and USGS Mineral Summary for 2022.

Source: [77] [61]

The United States imported 48 percent of all nickel consumed domestically in 2021, according to the USGS Mineral Commodity Summaries 2022 [61]. This summary includes nickel required for purposes other than the production of EVs. There are two classifications of nickel purity: class 1 and class 2. Only class 1 nickel is suitable for EV batteries [100]. Around 17 percent of the global supply of Class 1 nickel comes from Russia [72].

There are two nickel mines in operation in the United States: The Eagle Mine in Michigan and the Madison Mine in Missouri. It is difficult to determine if those nickel mines produce or will produce class 1 nickel. There are several mines under development, including the North Met project in Minnesota. The project has received permits, although it currently faces multiple legal challenges [101]. One legal challenge to a permit revolves around the Environmental Protection Agency's assessment that dredging for the project "may affect" the waters of the Fond du Lac Reservation [102] [103].

As with other critical minerals, automakers are building partnerships with mining companies to secure supply. Tesla has secured deals with BHP and Vale, the Tamarack Mine in Minnesota and other companies [104]. Meanwhile, the Department of Energy aims to remove nickel from EV batteries by 2030 to "reduce U.S. lithium-battery manufacturing dependence on scarce materials" [27]. Tesla produced nearly half of its vehicles in Q1 2022 without cobalt or nickel [67]. According to some experts, nickel is one of the highest CO_2-emitting elements of the battery [105].

Manganese

Table 8: Domestic Manganese Extraction Sites (Announced and Operational)

Site Name	State	Year Operational	Parent Company
Hermosa Project	Arizona	2027	South32

NA means that the data is not available. Data source: Press releases, NREL's Lithium-Ion Battery Supply Chain Database and User Guide report, and USGS Mineral Summary for 2022.

Source: [77] [61]

The United States imported 100 percent of all manganese consumed domestically in 2021, according to the USGS Mineral Commodity Summaries 2022 [61]. This summary includes manganese required for purposes other than the production of EV battery cells.

There are no manganese mines currently in operation in the U.S. However, there is presently one mine in the exploration phase in Arizona. The manganese in the United States is generally low grade, has high extraction costs, and has high waste outputs and energy inputs [61]. No manganese has been produced domestically since 1970 [61].

Manganese was predominantly sourced from South Africa, Gabon, and Australia in 2021 [61]. The 100-Day Reviews under Executive Order 14017 released in June 2021 by the White House of supply chain materials noted that while there is no domestic production of manganese, the wide distribution of the mineral and the good relationships that the United States has with those countries make it "less of a concern" than other critical minerals on this list [106].

The same review anticipated that manganese may grow in prominence in EV batteries due to the relatively low cost, safety, and abundance of the mineral. The Department of Energy aims to remove cobalt and nickel from EV batteries by 2030, in which case there will be greater demand for manganese [27]. Manganese helps batteries to perform more safely at higher temperatures and is present in many cathodes [107].

Graphite

Table 9: Domestic Graphite Extraction Sites (Announced and Operational)

Site Name	State	Year Operational	Parent Company
Coosa Graphite Project	Alabama	2028	Westwater Resources
Graphite Creek	Alaska	NA	Graphite One Inc.

NA means that the data is not available. Data source: Press releases, NREL's Lithium-Ion Battery Supply Chain Database and User Guide report, and USGS Mineral Summary for 2022.

Source: [77] [61]

The United States imported 100 percent of all-natural graphite consumed domestically in 2021, according to the USGS Mineral Commodity Summaries 2022 [61]. This summary includes graphite required for purposes other than the production of electric vehicle battery cells. Graphite was sourced mainly from China, Mexico, and Canada in 2021 [61].

There are no graphite mines currently in operation in the United States however, there are presently two mines in the exploration phase. The largest deposit in the country is the Graphite Creek deposit in Alaska, according to the USGS Survey [60]. The United States has not produced graphite domestically since the 1950s [108]. Both natural graphite and synthetic graphite are used in batteries and though synthetic graphite is more expensive, costs are coming down.

The 100-Day Reviews under Executive Order 14017 released in June 2021 by the White House noted that graphite is not as significant a concern for supply chains as lithium, nickel (Class 1) and cobalt given "the growing synthetic graphite production and price reduction domestically, as well as advancements in fundamental understanding of the applicability of substitutes" [106]. Graphite is the go-to for lithium-ion battery anodes as it is cheap, abundant, and can hold a charge for a long time. While the battery cathodes can be made up of a variety of mineral compositions, anodes are almost always comprised of graphite. Developments with silicon batteries however may reduce reliance on graphite in the future [109].

Processing

In the midstream of the EV supply chain is the processing and refining of critical minerals into battery-ready materials. Processing plants generally produce either anode or cathode materials. The materials are then developed into battery cells. EV batteries require high levels of mineral purity to ensure the batteries are effective.

Table 10: Critical Mineral Processing Facilities in the U.S.

Facility Name	State	Product Type	Company	Year Operational
Amsted Graphite Materials	West Virginia	Anode Materials	Anovion	Operational
Elyria Lithium-ion Battery Material Manufacturing Plant	Ohio	Cathode Materials	BASF Toda America LLC	Operational
Battle Creek Lithium-ion Battery Material Manufacturing Plant	Michigan	Cathode Materials	BASF Toda America LLC	Operational
Synthetic Graphite Anode Production Facility	New York	Anode Materials	Anovion	Operational
Syrah Vidalia Facility	Louisiana	Anode Materials	Syrah Technologies	Operational
Spokane Facility	Washington	Anode Materials	Anovion	Operational
Humboldt Mill	Michigan	Cathode Materials	Lundin Mining	Operational
Bessemer City	North Carolina	Cathode Materials	Livent Corporation	2022
Novi Plant	Michigan	Cathode Materials	Battery Resourcers	2022
Alabama Graphite Products	Alabama	Anode Materials	Alabama Graphite Products LLC	2023
Graphex Michigan I	Michigan	Anode Materials	Graphex Technologies	2023

Chattanooga Facility	Tennessee	Anode Materials	Novonix	2023
Anode Pilot Plant	New York	Anode Materials	Li-Metal Corporation	2025
NA	Alabama	Anode Materials	Anovion	2025
Tennessee Lithium	Tennessee	Cathode Materials	Piedmont Lithium	2025
Moses Lake Facility	Washington	Anode Materials	Sila	2026
Advanced Graphite Anode Facility	Washington	Anode Materials	Graphite One Inc.	NA
Tahoe-Reno Industrial Park facility	Nevada	Cathode Materials	Redwood Materials	NA
Kings Mountain Lithium Materials Processing Plant	North Carolina	Cathode Materials	Albemarle	NA
NA	Nevada	Cathode Materials	American Battery Technology Company	NA
Carondelet Plant	Missouri	Cathode Materials	ICL-IP America	NA
NA	Nevada	Cathode Materials	Lilac Solutions	NA
St Gabriel Facility	Louisiana	Cathode Materials	Koura	NA
Battery Minerals Processing Facility	North Dakota	Cathode Materials	Talon Nickel	NA

Facilities that are announced, under development, or in operation. NA means that the data is not available. The product types “cathode materials” and “anode materials” includes materials that will require further refining / processing to become a cathode or anode. Note that facilities provide minimal data publicly about their operations or facility capacity and so this list includes only those facilities – proposed or operational – where there is some evidence that they may process EV materials. Data source: NREL’s Lithium-Ion Battery Supply Chain Database and User Guide report, as well as press releases.

Source: [77]

China is the leader in processing critical minerals. According to the 100-Day Review under Executive Order 14017 released in June 2021 by the White House, China is the “world’s major processor of lithium carbonate into lithium hydroxide, cobalt into cobalt sulfate, manganese refining, and uncoated spherical graphite refining” [106]. Regarding lithium, there are five companies that dominate global lithium processing: Albemarle, Gangfeng Lithium, Tanqi, Livent, and SQM [110]. Albemarle and Livent have a presence in the United States. Albemarle currently operates a lithium mine in Nevada, is scoping out re-opening a lithium mine in North Carolina and the company has announced a new lithium processing facility in North Carolina. Per Table 10 there is some processing capabilities domestically though there is limited public data available on the capacity of these facilities.

In October 2022, the Department of Energy announced recipients of the Battery Materials Processing and Battery Manufacturing Grants Program funded by IIJA (updated November 1, 2022) [111]. Given the size of this support, those projects that have an announced location and processing anode or cathode materials are included in Table 10. Some of these facilities are expansions of existing facilities and others are new facilities.

There are environmental hazard risks with processing materials. For example, in 2014, a nickel processing facility in New Caledonia spilled 100,000 liters of acid-tainted effluent, contaminating local waterways, and enraging the local community [112]. In Russia, Norilsk Nickel (the largest producer of class 1 nickel in the world) has caused the “worst sulfur dioxide pollution in the world” according to reporting [113]. However, measures can align mineral processing with the greater sustainability goals of the EV transition [114]. Renewable energy (including geothermal) can be utilized to power facilities and mitigate emissions. Materials can be transported using electric medium- and heavy-duty vehicles. Tailings (the toxic slurry waste from processing) can be better stored to reduce the risk of harm. Though there is a long history of degradation due to mining and processing, EV production does not have to repeat historical injustices. Strong domestic laws and binding international standards are crucial to delivering more sustainable outcomes.

Battery Recycling

Battery recycling can reduce dependence on raw materials. EV batteries are also promising in their potential to produce good batteries. Research from October 2021 found that batteries made from recycled materials not only perform well, but some recycling techniques mean the batteries will perform even better than batteries manufactured from primary materials due to the “unique microstructure of recycled materials” [115]. See Table 11 for facilities that have either been announced or are in operation to recycle EV batteries in the U.S.

Table 11: EV Battery Recycling Facilities in the U.S.

Site Name	State	Target Capacity (tons/year)	Facility Product	Year Operational	Company
St Louis Facility	IL	24,000	Battery Grade Materials	Operational	Interco
Spoke Facility	NY	5,000	Black Mass	Operational	Li-Cycle
Worcester, Pilot Plant	MA	15	Cathode materials	Operational	Ascend Elements
Fairfield County Facility	OH	NA	NA	Operational	Cirba Solutions
Wistron Greentech facility	TX	500	Direct Recycling	Operational	Princeton NuEnergy
Spoke Facility	AL	10,000	Black Mass	Operational	Li-Cycle
Spoke Facility	AZ	10,000	Black Mass	Operational	Li-Cycle
Recycling Facility	GA	30,000	Cathode materials	2022	Ascend Elements
Spoke Facility	OH	15,000	Black Mass	2023	Li-Cycle
Hub Facility	NY	35,000	Battery Grade Materials	2023	Li-Cycle
Apex 1	KY	NA	Battery Grade Materials	2023	Ascend Elements
SungEel Recycling Park	GA	50,000	NA	2024	SungEel Materials
Carson City facility	NV	20,000	Battery Grade Materials	NA	Redwood Materials
Lithium-Ion Battery Recycling Pilot Plant	NV	20,000	Battery Grade Materials	NA	American Battery

					Technology Company
Lithium-Ion Battery Recycling Plant	WA	NA	NA	NA	Lab 4 Inc

NA means that the data is not available. Note the Winstron Greentech facility in Texas and the Li-Cycle facility in Alabama both opened in October 2022. This table lists all EV battery recycling facilities that are announced, under development or in operation and includes both hub and spoke facilities. Many facilities provide little data about their operations. This list includes only those facilities for which there was enough information to determine with some confidence that they recycle EV batteries (as opposed to lithium-ion batteries broadly). Source: *NREL's Lithium-Ion Battery Supply Chain Database and User Guide report*, the California EPA, and press releases.

Source: [116] [77] [77]

Currently, five percent of lithium-ion batteries are recycled in the United States per DOE figures (2019) [117]. However, this number includes all lithium-ion batteries, not just EV batteries. There is a precedent of recycling lead-acid batteries for internal combustion engine vehicles. Given the high rate of recycling of lead-acid batteries (around 99 percent), a business case based on recycling other types of batteries at scale may be possible with the right policy settings and economic incentives [118].

Many recycling facilities are partnering with automakers and locating facilities close to large battery manufacturing centers. For example, the Li-Cycle facility in Warren, Ohio is co-located with Ultium Cells' battery cell manufacturing mega-factory (currently under-construction). The CEO of Li-Cycle said that the co-location will "substantially optimize costs and logistics." [119] Mercedes has indicated its intention to partner with battery recyclers in the US. Likewise, new players in recycling batteries continue to arise, including an announcement in May 2022 that a recycling company, Blue Whale Materials, aims to build five recycling facilities across the U.S. and Europe [120] [121]. Northvolt, a battery maker in Sweden, already has batteries using 100 percent recycled nickel, manganese, and cobalt [122].

In June 2022, Toyota announced it would partner with battery recycling company Redwood Materials. Redwood Materials also has partnerships with Proterra, Ford, Volvo, and Panasonic (Panasonic supplies batteries to Tesla) [123]. Redwood claims it can recover 95 to 98 percent of critical minerals from recycled batteries (this claim refers to all lithium-ion batteries and not just EV batteries). Redwood is looking to expand into the battery materials business more broadly by also producing batteries from raw materials in the United States.

Recycling Challenges

There are some key challenges to expanding battery recycling as described in Table 12.

Table 12: Challenges in Recycling EV Batteries

Barrier	Description
Labelling	Batteries are not well labeled and so it is challenging for recyclers to know how to recycle a battery without knowing the components.
Accessing	At present, it is difficult and time-consuming to dismantle the battery to recover the materials.
Transporting	Transporting combustible EV batteries to recycling or production facilities is expensive and presents safety challenges.
Lack of Regulations	A lack of regulations including producer responsibility and recycled content requirements slows progress.
Low value minerals/ lack of market	Some minerals may not be worth recycling at this stage. That said, with economies of scale and as raw material prices increase, the economic case for recycling improves.

This table summarizes key barriers to greater levels of EV battery recycling to meet the expected increase in EV adoption in the coming years. The barriers mentioned here were principally sourced from research including reporting in *Science* magazine by Ian Morse.

Source: [124] [125]

Analysis by McKinsey indicates that excitement about the potential for EV battery recycling should be tempered. The company notes in a 2022 report, "By 2030, such secondary supply is expected to account for slightly more than 6 percent of total lithium production" [79]. An analysis by Wood McKenzie agreed with the McKinsey assessment that recycling will not be a significant factor in battery materials until at least 2030, in part because the market is still small and EVs have an increasingly long-life span, meaning there are limited materials available to recycle [126]. Other estimates point to more recycling in the near term.

A report by researchers Dominish, Florin and Wakefield-Rann at the University of Technology Sydney (UTS) in April 2021 found high potential rates of recycling of critical minerals. The researchers found it is technologically possible to recover at least 90 percent of cobalt, nickel, copper, and lithium through recycling [127]. Due to the issues associated with cobalt, many battery manufacturers are working to phase the metal out of newer battery designs. However, because cobalt is one of the more valuable minerals in EV batteries, the recycling business case becomes less lucrative without it [128]. A similar issue exists with nickel.

Recycling Initiatives

Several federal government initiatives have supported battery recycling. The Infrastructure Investment and Jobs Act includes funding for EV battery recycling. For instance, the Battery Manufacturing and Recycling Grants Program includes $3 billion in appropriated funding to support "Demonstration projects, construction of commercial-scale facilities, and retrofit or retooling of existing facilities for battery component manufacturing, advanced battery manufacturing, and recycling" [129]. There was also $125 million in the Act to support the Battery and Critical Mineral Recycling Program.

In the Inflation Reduction Act, signed into law in August 2022, one of the requirements for the revised Clean Vehicle Tax Credit is that an EV battery must be recycled in North America and/or source critical minerals domestically or from a free trade partner. This incentive may boost domestic recycling efforts [130]. Elsewhere, the Federal Government has supported the ReCell Center for battery recycling, which opened in 2019 with a $15 million grant and funds the Battery Recycling Prize and the Defense Production Act will avail funds for battery recycling [131].

The *National Blueprint for Lithium Batteries 2021–2030,* released by the Department of Energy, identifies recycling batteries as a key priority [27]. The Blueprint lays out short and long-term objectives. These short-term objectives (by 2025), include designing battery packs to enable easier recycling, increasing recovery rates of critical minerals, and federal recycling policies. Longer-term objectives (by 2030) include creating incentives to achieve a 90 percent recycling rate of EV batteries and requiring materials to be recycled in cell manufacturing materials streams.

At the state level, an Advisory Group to the California Environmental Protection Agency released a report in March 2022, *Lithium-ion Car Battery Recycling Advisory Group Final Report* [116]. The Advisory Group recommended two key policies. The first policy was a core exchange with a vehicle backstop. A vehicle backstop policy means that the entity that is the last to handle the battery has a responsibility to properly reuse, repurpose or recycle the battery. The second policy the Group recommended was producer take-back. A producer take-back policy ensures that it is the producer's responsibility to take back the battery at the end of life at no cost to the consumer. The Report will go to the state legislature, where some recommendations may become law. Several other states have begun efforts to look at battery recycling, and thus far, the auto industry continues to support the core exchange program under consideration in California.

Repurposing

EV batteries are expected to last between 10 and 15 years. Given concerns about acceleration and range, batteries may reach the end of their useful life for vehicles but still be able to perform other energy storage functions, such as backup power for buildings or assets for the electrical grid [132]. Repurposed batteries[6] have around 70 to 80 percent of their original capacity [99]. The challenge is to ensure these batteries can feasibly, safely, and affordably be repurposed for other functions.

The startup B2U based in California reuses Nissan Leaf batteries to store solar energy [133]. The company purchased batteries that reached the end of their useful life in Nissan EVs far below the market rate for new batteries. The startup remains small, but the company is quadrupling its storage capacity on-site. Researchers note that repurposing battery materials delays them from re-entering the recycling loop, decreasing the supply of recycled materials [99]. However, their use in other settings reduces demand for new batteries, and once they are no longer useful as repurposed batteries, they may be recycled.

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