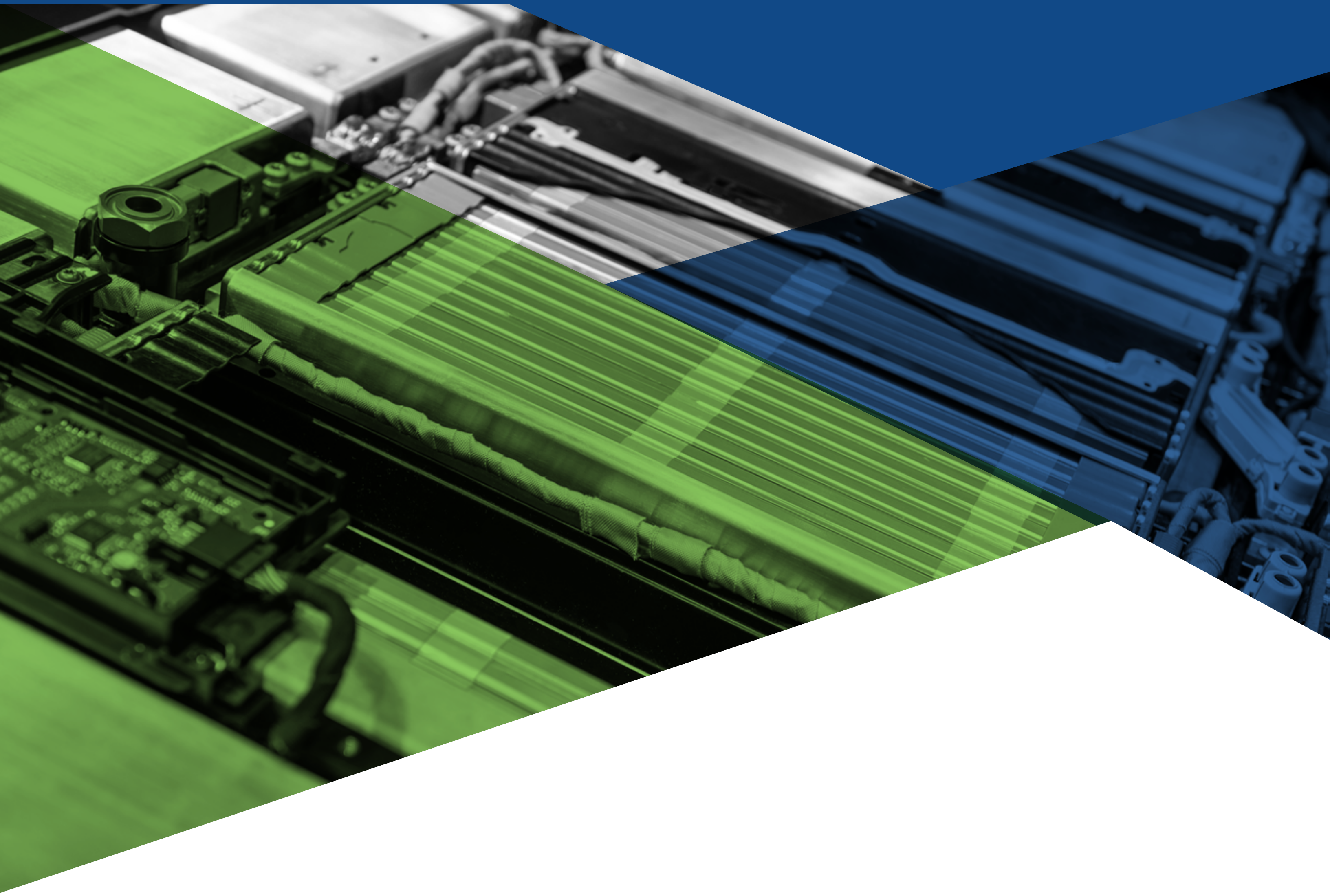
# THE MACROECONOMIC IMPACT OF INCREASED U.S. ELECTRIC VEHICLE BATTERY PRODUCTION



CALSTART

EV BATTERY INITIATIVE

CONTROLLED THERMAL RESOURCES

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RETRIEV TECHNOLOGIES

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# List of Acronyms

| Acronym | Definition |
|---|---|
| BEV | battery electric vehicle |
| CARB | California Air Resources Board |
| EV | electric vehicle |
| EVBI | CALSTART's U.S. Electric Vehicle Battery Initiative |
| GDP | gross domestic product |
| GHG | greenhouse gas |
| GWh | gigawatt-hours |
| ICCT | International Council for Clean Transportation |
| ICE | internal combustion engine |
| IRA | Inflation Reduction Act |
| kWh | kilowatt-hour |
| LDV | light-duty vehicle |
| M/HDV | medium- and heavy-duty vehicle |
| MT | metric tonnes |
| PHEV | plug-in hybrid electric vehicle |

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# Executive Summary

The transition to electric vehicles (EVs) in the light-, medium-, and heavy-duty sectors is a key component of U.S. efforts to reduce greenhouse gas emissions. Building a robust battery supply chain is critical to the growth of the domestic EV market. This report documents the economic benefits that will stem from a robust domestic EV battery supply chain, providing a cradle-to-grave assessment of the jobs, labor compensation, and gross domestic product (GDP) that will result from mining battery materials all the way through battery recycling. The assessment covers 20 years, from 2021 through 2040, and assumes that current federal policies (specifically the Inflation Reduction Act) will stay in place for the next 10 years, until 2032.

The analysis estimates the economic contribution of the U.S. EV battery industry under two alternative market growth scenarios. The Moderate EV adoption scenario assumes that annual new sales of light-duty vehicles (LDVs) and medium- and heavy-duty vehicles (M/HDVs) transition to 75 and 45 percent electric, respectively, by 2040. The High EV adoption scenario is more aggressive, reaching 100 percent for LDVs in 2038 and 74 percent for M/HDVs in 2040.

Conducted using REMI PI+ economic forecasting software, the analysis focuses on five components of a cradle-to-grave assessment of the domestic EV battery life cycle: EV battery metal and mineral production, EV battery manufacturing, EV manufacturing, internal combustion engine vehicle manufacturing, and EV battery material recycling.[1] The model estimates that by 2040, depending on the EV adoption scenario:

- Annual U.S. battery capacity produced will increase from approximately 44 gigawatt-hours (GWh) per year in 2021 to 1,500 GWh/year (Moderate scenario) or 2,100 GWh/year (High scenario), over a hundredfold increase on the high end;
- Jobs supported will increase by 570,000 to 740,000 jobs, a 0.2 to 0.3 percent increase over the expected level of employment in 2040 without the modeled transition to EVs;
- Labor compensation will increase by $40 to $50 billion (2020$), a 0.2 to 0.3 percent increase; and
- GDP will increase by $110 billion to $150 billion (2020$), a 0.4 to 0.5 percent increase.

[1] The analysis does not include impacts to energy industries (due to the switch from petroleum products to electricity), charging infrastructure and gas stations, or automotive maintenance and repair.

# 1. Introduction

The shift from conventional gasoline and diesel vehicles to electric vehicles (EVs) is crucial to reducing greenhouse gas (GHG) emissions and limiting the impacts of climate change. The transportation sector is currently the largest emitter of GHGs in the United States. While tremendous growth in EV and battery manufacturing is required to meet the targets set out by state and federal governments, this transition also provides an opportunity for U.S. manufacturing. A robust EV battery manufacturing industry would bring jobs to the United States, and it is important to understand how this burgeoning industry might impact the U.S. economy.

ERM was commissioned by CALSTART's U.S. Electric Vehicle Battery Initiative (EVBI) to conduct modeling using REMI PI+, an economic forecasting software, to understand the potential national economic impacts (jobs and gross domestic product (GDP) associated with the domestic growth in industries necessary to provide the materials, manufacturing, and end-of-life management of the batteries necessary for EV adoption within the United States.

The next section of the report provides background on the current state of the supply chain for EV batteries as well as the regulatory context for changes to these industries due to the passage of the Inflation Reduction Act (IRA) in August 2022. Section 3 introduces the economic impact analysis model, and Section 4 describes the analysis inputs and assumptions. Finally, Section 5 provides the model results, and Section 6 details the critical conclusions from this study.

# 2. Background

## 2.1 Battery Supply Chain

The supply chain for EV batteries is complex and made up of multiple components. The first component is the extraction and refining of the raw materials that make up batteries. Next, these materials are transformed into electrode active materials. The active materials are then used in the manufacturing of battery cells. Battery cells are subsequently used in the configuration of battery modules. Finally, battery modules are assembled into finished battery packs to be used in EVs. The last component is EV battery recycling, which is a nascent but increasingly important component of the EV battery supply chain. Many key processes of the supply chain presently occur largely outside of the United States.

The supply chain for EV batteries is highly interdependent on the supply chains for the various critical minerals used in these batteries (typically lithium, cobalt, nickel, manganese, and graphite). Critical mineral resources are distributed throughout the world, though the availability and extraction of several key critical EV battery minerals are narrowly concentrated within certain countries. The United States currently produces very few of these critical minerals, and domestic EV battery manufacturing relies on imports of battery materials. Raw critical minerals must be purified and processed to be used in EV batteries. Currently, the United States has virtually no domestic capacity for mineral processing, although projects to both extract and refine EV battery metals and minerals are in development. The majority of global mineral processing, as well as secondary processing of electrode active materials, occurs in China.

## 2.2 Inflation Reduction Act

The growing EV industry in the United States has onshored some components of EV battery manufacturing, particularly the assembly of battery cells and battery packs. Today, the majority of EV battery cells and packs used in EVs sold in the United States are manufactured domestically. However, the United States needs to rapidly expand domestic manufacturing capacity to meet EV deployment goals and consumer demand.

Supporting the buildout of the domestic supply chain for EVs is a priority for the Biden Administration and is reflected in many provisions of the IRA that was passed in August 2022, including:

- The Advanced Manufacturing Production Credit provides a tax credit of 10 percent of the costs to produce critical minerals and to manufacture electrode active materials, $35/kilowatt-hour (kWh) for the manufacturing of battery cells, and $10/kWh for the manufacturing of battery modules.
- The extension of the Advanced Energy Project Credit allows for up to a 30 percent tax credit on investments in a qualified energy project, which includes the manufacturing of EVs, vehicle components, and charging infrastructure.
- The Advanced Technology Vehicle Manufacturing Credit makes $55 billion in direct loans available through 2028 for re-equipping, expanding, or establishing a manufacturing facility in the United States to produce advanced technology vehicles, including EVs.
- The Domestic Manufacturing Conversion Grants make $2 billion available, with 50 percent cost-sharing, for domestic production of efficient hybrids, plug-in hybrids, plug-in EVs, and hydrogen cell EVs.
- The extension of the consumer EV purchase credits provides tax credits of up to $7,500 and $40,000 for consumers to purchase personal or commercial EVs, respectively. The IRA includes new domestic content requirements for EVs with progressively increasing stringency over time, which will require EVs to be made with critical minerals and batteries that were produced domestically or sourced from trade partners[2] in order to receive the credit.

Combined with other actions taken by the administration such as the Infrastructure Investment and Jobs Act passed in 2021, the U.S. policy landscape makes domestic production of EV batteries more likely and more appealing for manufacturers.

[2] Countries must have free-trade agreements with the United States. This list currently comprises 20 countries, including Australia, Canada, Chile, South Korea, Mexico, Peru, and Singapore.

# 3. Model Overview

This economic impact analysis uses REMI PI+ software, a dynamic economic forecasting and policy analysis model with annual forecasts that include behavioral responses to changes in labor compensation, prices, and other economic factors. The model incorporates information on linkages between output and demand, labor and capital demand, population and labor supply, compensation and prices (and costs), and market shares (domestic versus international).[3] The model is U.S.-based (i.e., modeling only economic activity that occurs within the United States) and is run at the national level.

ERM's model is built around five interconnected modeling areas (Figure 1). The primary driver of the effects in the model is increased demand for EVs, which increases EV production—specifically of U.S.-built EVs. The EV production, in turn, increases the demand for EV batteries and U.S. EV battery production, which likewise increases metal and mineral production. Greater EV adoption also creates demand for feedstock and demand for EV battery material recycling. And lastly, more EV adoption means fewer internal combustion engine (ICE) vehicles sold. Specifically, we assume a one-to-one relationship, with one fewer ICE vehicle for every EV sold.

All five components are included in a single integrated model to show the overall impact on the economy. The model reflects the upstream[4] supply chain and support industry impacts associated with each of these model components (e.g., mining, trucking, construction, administration and management, etc.) within the borders of the United States. However, REMI PI+ does not model downstream impacts of EV adoption such as changes in gas, electricity, charging infrastructure, or vehicle maintenance consumption due to changes in the composition of the vehicle fleet. Thus, those economic components are depicted in Figure 1 as outside of the model borders; the model analysis and results do not include those impacts.[5]

[3] Regional Economic Models, Inc. (REMI). 2022. REMI PI+ v. 3.0 Users Guide.

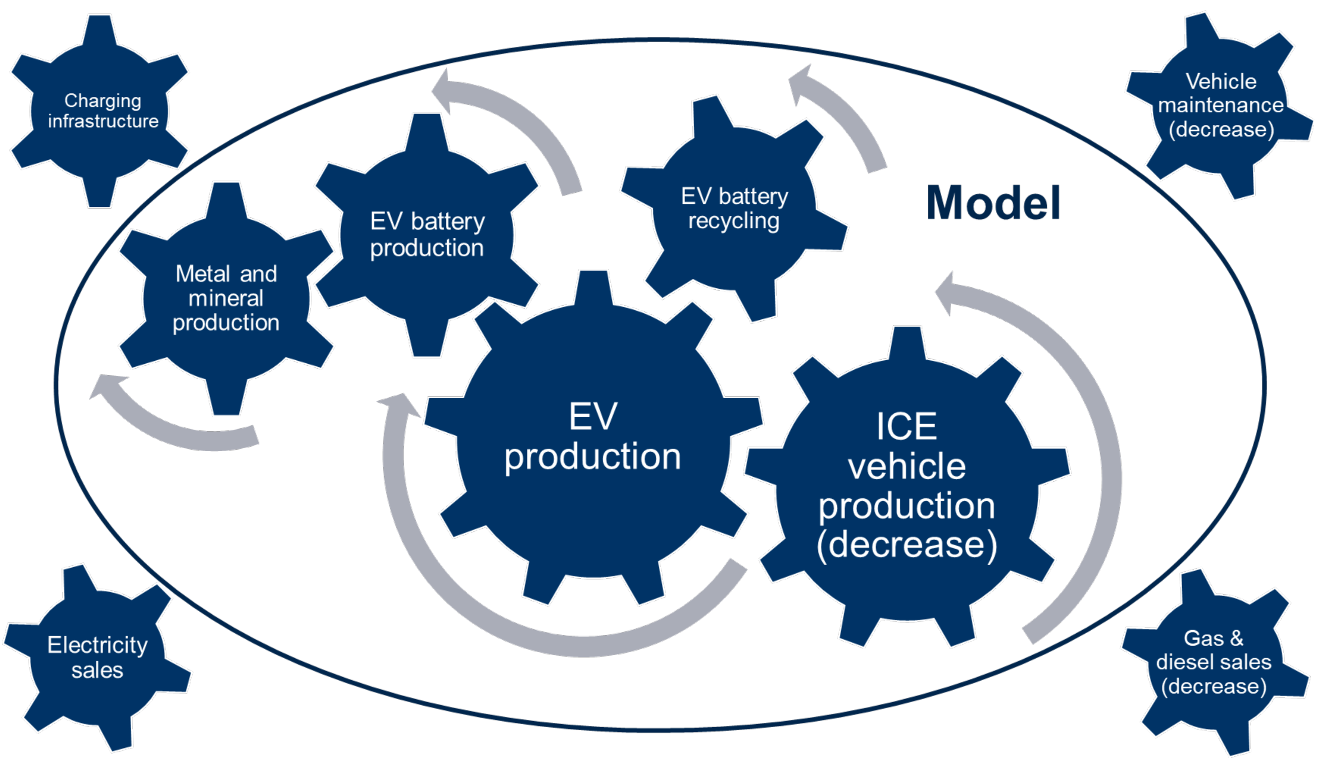
[4] Upstream refers to the industry supply chain, or all the goods and services necessary to create a product.

[5] Although the downstream impacts may be significant, REMI PI+ does not have the linkages to model those impacts. Thus, this study is focused specifically on the impacts of the EV battery supply chain.

As part of the model design, we customized the REMI PI+ supply chains of key industries for differences between the EV industry and the more general, aggregated industry category (i.e., parent industry) that includes the EV industry. For example, motor vehicle manufacturing is adjusted to remove gas engines and account for electric motors and batteries, creating an EV manufacturing industry. Similarly, the storage (i.e., rechargeable) battery manufacturing industry is adjusted to account for the different metals used in EV batteries, creating a custom industry for EV battery manufacturing.

For some industries, we include further adjustments to avoid double-counting and allow for accurate representation of U.S. activity. For example, to reflect the onshoring of mineral production due to the IRA, we modeled changes in some of the key industries based on our own projections of U.S. production rather than the model defaults, which included more imports.[6]

**Figure 1: Conceptual Economic Model Components**




[6] Although the directly modeled industries portrayed in Figure 1 represent U.S. production, industry supply chains are automatically adjusted within the model to account for import levels. For example, the storage battery manufacturing industry uses fabricated metal products, which are 77 percent sourced within the United States. The other 23 percent of fabricated metal products is imported and not included in the model results.

# 4. Model Assumptions and Inputs

The following subsections describe the model scenarios, inputs, and assumptions, starting with EV adoption estimates, working upstream through the key supply chains, and finishing with EV battery recycling.

## 4.1 Market Growth Scenarios

This analysis includes Moderate and High EV adoption scenarios to understand a possible range for the impact of EV battery production in the United States. The recent adoption of the IRA is expected to greatly impact EV adoption rates, but the extent of the impact remains unclear.

The amount and speed of EV adoption is the key difference between the Moderate and High scenarios. Adoption rate directly affects the number of EVs sold in each year. However, the differences due to this assumption impact other components of the model, indirectly affecting ICE sales, EV battery production, and EV battery recycling. Metal and mineral production is not affected, as it is based on U.S. raw material capacities.

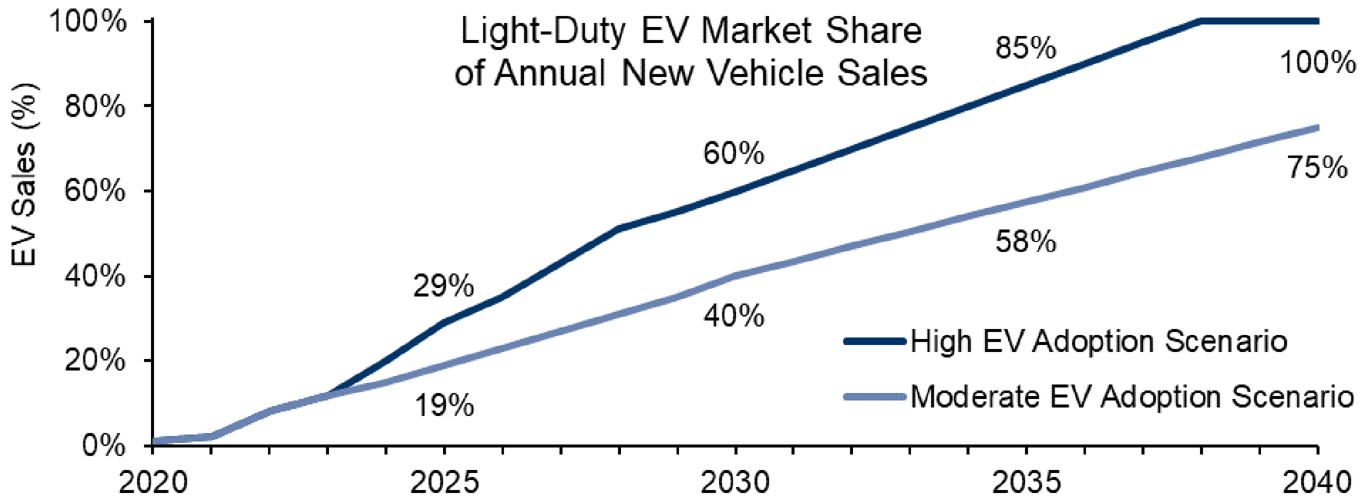
### *4.1.1 Light-Duty Vehicles*

Light-duty vehicles (LDVs) account for the vast majority of vehicles on the road. The Biden Administration announced in August 2021 a goal of 50 percent of new LDV sales being electric by 2030.[7] After the IRA was adopted, Bloomberg New Energy Finance released an updated projection of 52 percent electric sales by 2030.[8] As can be seen in Figure 2, the Moderate scenario reaches 40 percent electric sales by 2030 (7.6 million vehicles) and 75 percent by 2040 (16.1 million vehicles). The High scenario entails EV penetration reaching 60 percent of total vehicle sales by 2030 (11.4 million vehicles) and 100 percent by 2038 (21.5 million vehicles).

[7] The White House. "FACT SHEET: President Biden Announces Steps to Drive American Leadership Forward on Clean Cars and Trucks." 5 Aug 2021. https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/05/fact-sheet-president-biden-announces-steps-to-drive-american-leadership-forward-on-clean-cars-and-trucks/.

[8] Boudway, Ira. "More Than Half of U.S. Car Sales Will Be Electric by 2030." *Bloomberg*. 20 Sept 2022. https://www.bloomberg.com/news/articles/2022-09-20/more-than-half-of-us-car-sales-will-be-electric-by-2030#xj4y7vzkg.

**Figure 2: Light-Duty EV Market Share of Annual New Vehicle Sales by Scenario**




Currently, full battery electric vehicles (BEVs) account for 80 percent of EV sales and the remaining 20 percent are plug-in hybrid electric vehicles (PHEVs). The analysis assumes the share of PHEVs falls to 5 percent by 2040. This assumption is the same in both scenarios.[9]

The size of the battery going into vehicles also has a large impact on the demand for total EV battery capacity. Many factors may impact the exact size of batteries being installed in EVs in the next 20 years, including technological advances, consumer preferences, charging availability, and battery prices. Incorporating recent assessments done by the California Air Resources Board (CARB)[10] and the International Council for Clean Transportation (ICCT)[11] as well as feedback from EVBI, this analysis assumes the average light-duty BEV battery in 2022 is 70 kWh and grows to 90 kWh by 2040. Due to their ICEs, PHEVs require smaller batteries, so the analysis assumes PHEV batteries have a capacity of 25 kWh in 2022 and increases to 45 kWh by 2040.

[9] Given PHEVs require an ICE, once EVs reach 100 percent of the market share, it may no longer be economical for auto manufacturers to produce any vehicles with ICEs. As a result, in the High scenario, the PHEV share may drop to zero. Since the assumed PHEV share is quite small in the modeling, this is not expected to have a large impact on the results.

[10] California Air Resources Board. "Advanced Clean Cars II Proposed Amendments to the Low Emission, Zero Emission, and Associated Vehicle Regulations." 26 Jan 2022 (Updated: 29 Mar 2022). https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf.

[11] Slowik, Peter, et al. "Assessment of Light Duty Electric Vehicle Costs and Consumer Benefits in the United States in the 2022-2035 Time Frame." *The International Council on Clean Transportation.* 18 Oct 2022. https://theicct.org/publication/ev-cost-benefits-2035-oct22/.

### *4.1.2 Medium- and Heavy-Duty Vehicles*

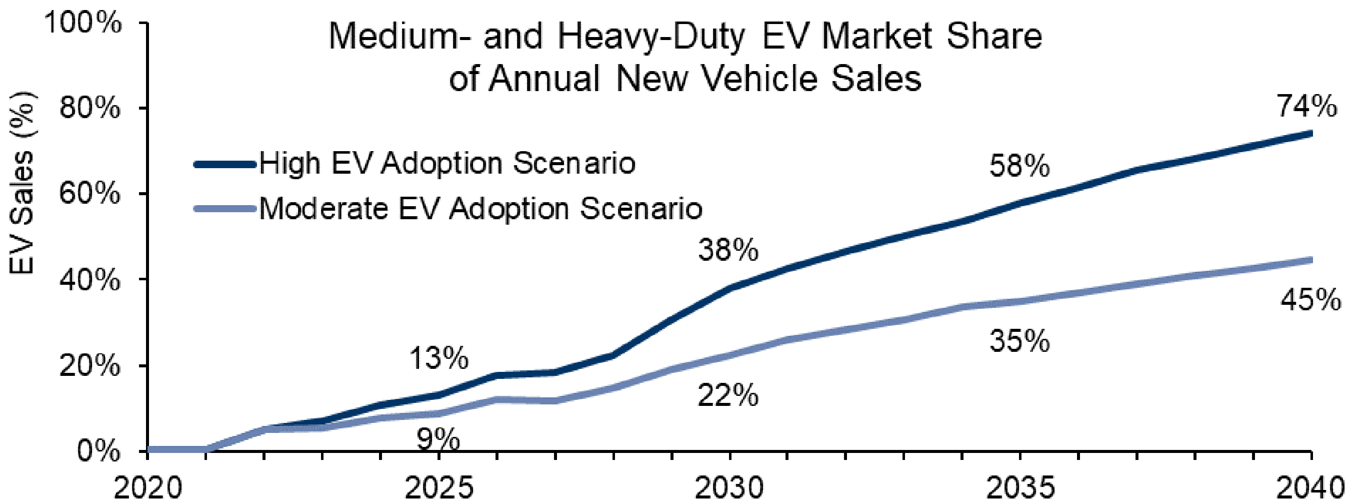
The electric medium- and heavy-duty vehicle (M/HDV) market is much less mature than that of LDVs, and adoption of electric M/HDV technology will likely lag behind. Currently EV sales make up less than 1 percent of total M/HDV sales, although those values are expected to grow as state regulations, improved total cost of ownership, and widespread charging infrastructure make EVs more desirable. While M/HDVs only account for a small share of total on-road vehicles in the United States, these vehicles generally require much larger batteries than electric LDVs.

The Moderate and High scenarios for M/HDVs used in this modeling are based on a previous analysis conducted by ERM on the impact of IRA provisions for these vehicles.[12] While the previous analysis considered all zero-emission vehicles (i.e., including fuel cell vehicles), this analysis is only considering vehicles with batteries. To account for this difference, it was assumed that 95 percent of vehicles would include batteries with the remaining 5 percent being fuel cell vehicles.

As can be seen in Figure 3, the Moderate scenario reaches 22 percent electric M/HDV sales in 2030 (370,000 vehicles) and 45 percent by 2040 (860,000 vehicles). The High scenario reaches 38 percent electric sales by 2030 (630,000 vehicles) and 74 percent by 2040 (1,430,000 vehicles).

[12] Robo, Ellen and Dave Seamonds. "Inflation Reduction Act Supplemental Assessment: Analysis of Alternative Medium- and Heavy-Duty Zero-Emission Vehicle Business-as-Usual Scenarios." *ERM*. 19 Aug 2022. https://www.erm.com/contentassets/154d08e0d0674752925cd82c66b3e2b1/edf-zev-baseline-technical-memo-addendum.pdf.

**Figure 3: Medium- and Heavy-Duty EV Market Share of Annual New Vehicle Sales by Scenario**




To determine the battery sizes of the various types of M/HDVs, this analysis uses a recent assessment from CARB[13] as well as feedback from EVBI that larger batteries are likely to be more attractive to consumers. The types of M/HDVs (Class 2b, Bus, Single Unit Trucks, and Combination Trucks) have different weights and drive different distances that require a wide range of battery sizes. Table 1 shows the battery sizes and the growth in size over time.

**Table 1: Projected Average Medium- and Heavy-Duty EV Battery Size**

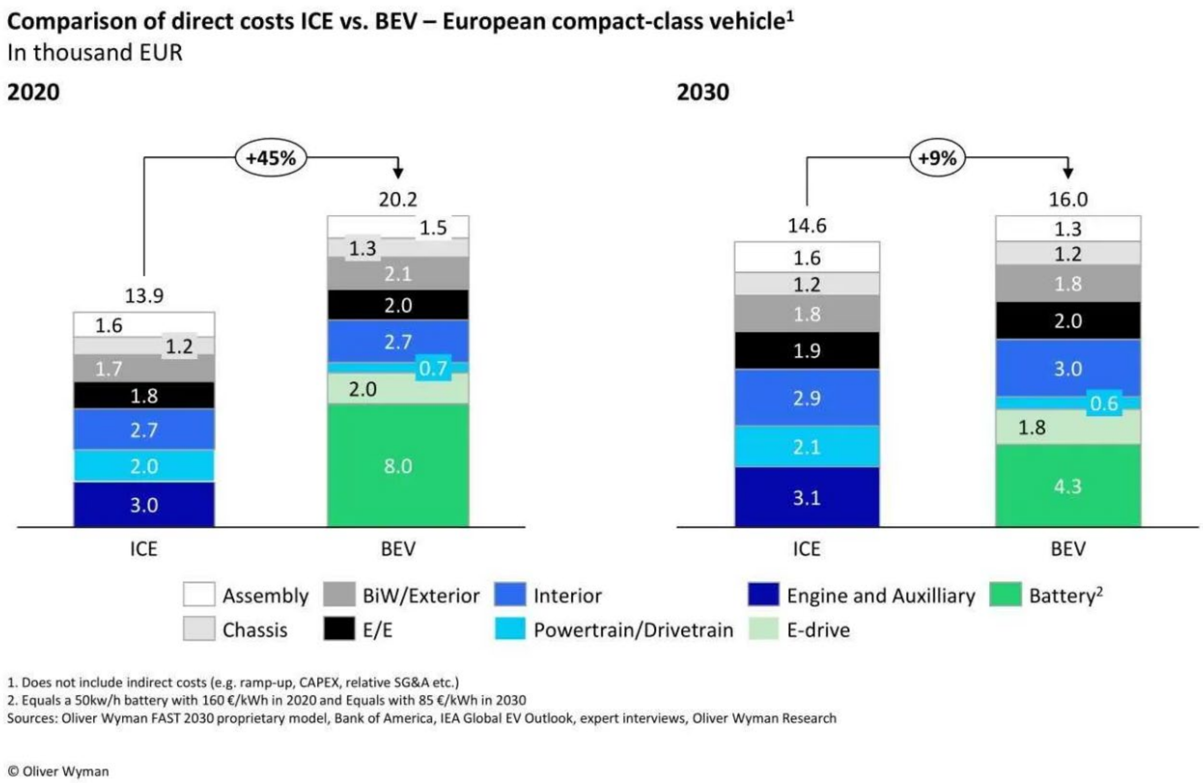
| Type of M/HDV | Battery Size (kWh) | | |
|---|---|---|---|
| | 2020 | 2030 | 2040 |
| Class 2b | 80 | 100 | 120 |
| Bus | 300 | 350 | 400 |
| Single Unit Truck | 200 | 230 | 250 |
| Combination Truck | 748 | 800 | 850 |
| Average | 225 | 255 | 280 |

[13] California Air Resources Board. "Advanced Clean Fleets Regulation Standardized Regulatory Impact Assessment." 18 May 2022. https://dof.ca.gov/wp-content/uploads/Forecasting/Economics/Documents/ARB-ACF-SRIA_2022-05-18.pdf.

## 4.2 Average Vehicle Cost by Class

To best model the impact of EV battery production in the United States, the battery costs were modeled separately from the EV costs. The EV costs minus the battery are assumed to be 80 percent of an ICE vehicle cost based on analysis developed by Oliver Wyman (see Figure 4). The savings come from reduced assembly costs and fewer moving pieces.

**Figure 4: Comparison of Costs of Electric and Internal Combustion Engine Vehicles**




*Source: Ruffo, Gustavo Henrique. "EVs Are Still 45% More Expensive To Make Than Combustion-Engined Cars." InsideEVs. 17 Sept 2020. https://insideevs.com/news/444542/evs-45-percent-more-expensive-make-ice/.*

The ICE vehicle prices for LDVs are based on the most recent Corporate Average Fuel Economy Standard Regulatory Impact Assessment from the National Highway Transportation Safety Administration.[14] The ICE vehicle prices for M/HDVs are based on the

[14] National Highway Traffic Safety Administration. "Final Regulatory Impact Analysis: Final Rulemaking for Model Years 2024-2026 Light-Duty Vehicle Corporate Average Fuel Economy Standards." U.S. Department of Transportation. Mar 2022. https://www.nhtsa.gov/sites/nhtsa.gov/files/2022-04/FRIA_CAFE-MY-2024-2026.pdf.

diesel and gasoline vehicle prices from the recent CARB assessment for the Advanced Clean Fleets regulation.[15]

## 4.3 Fraction of Total Vehicle Demand Met by Domestic Production

Current EV sales are mostly met with domestic production, with Tesla making up a large share of the production and exportation of vehicles to other parts of the world. Between 2010 and 2020, the United States produced more EVs than were sold in the country.[16] During this time period, 64 percent of all LDVs sold in the United States were produced in the United States, the same being true for 62 percent of all M/HDVs.[17] As long-standing vehicle manufacturers increase EV market share, it is expected that the current share of U.S. production of EVs will fall. For this analysis, accounting for the influence of IRA onshoring manufacturing and the existing EV manufacturing commitments and infrastructure, we assume that 80 percent of EVs sold in the United States are produced in the United States, with the remaining 20 percent being imported from other countries.

[15] California Air Resources Board. "Advanced Clean Fleets Regulation Standardized Regulatory Impact Assessment." 18 May 2022. https://dof.ca.gov/wp-content/uploads/Forecasting/Economics/Documents/ARB-ACF-SRIA_2022-05-18.pdf.

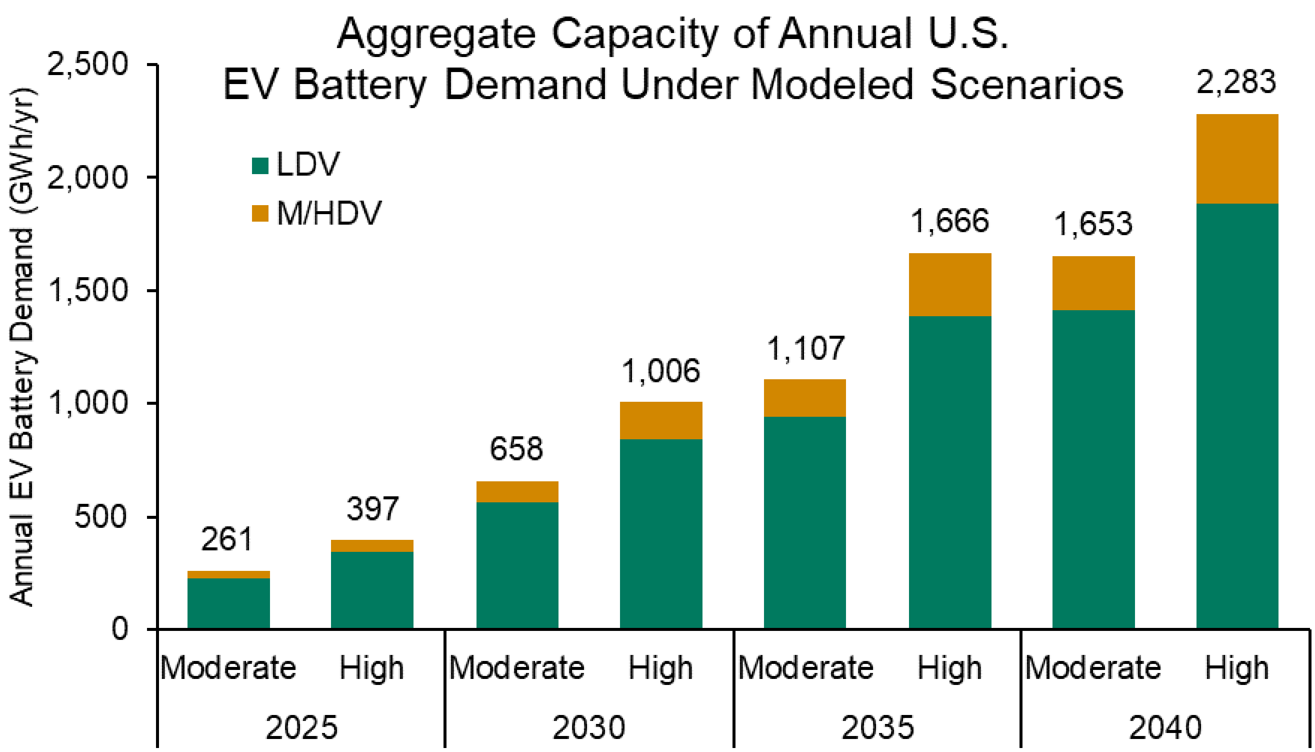
[16] Bui, Anh, et al. "Power play: Evaluating the U.S. position in the global electric vehicle transition." International Council on Clean Transportation. June 2021. https://theicct.org/wp-content/uploads/2021/12/us-position-global-ev-jun2021-1.pdf.

[17] Board of Governors of the Federal Reserve System. "Industrial Production and Capacity Utilization–G.17 Table 3" *Originally from Ward's Communications, Chrysler, and GM*. 16 Nov 2022. https://www.federalreserve.gov/releases/g17/current/table3.htm.

## 4.4 Domestic EV Battery Demand and Production

Domestic battery demand is driven by EV sales and average battery size for LDVs and M/HDVs. Multiplying the average battery size discussed above by the U.S. demand for EVs, Figure 5 shows U.S. battery demand over time.

**Figure 5: Aggregate Capacity of Annual U.S. EV Battery Demand Under Modeled Scenarios**

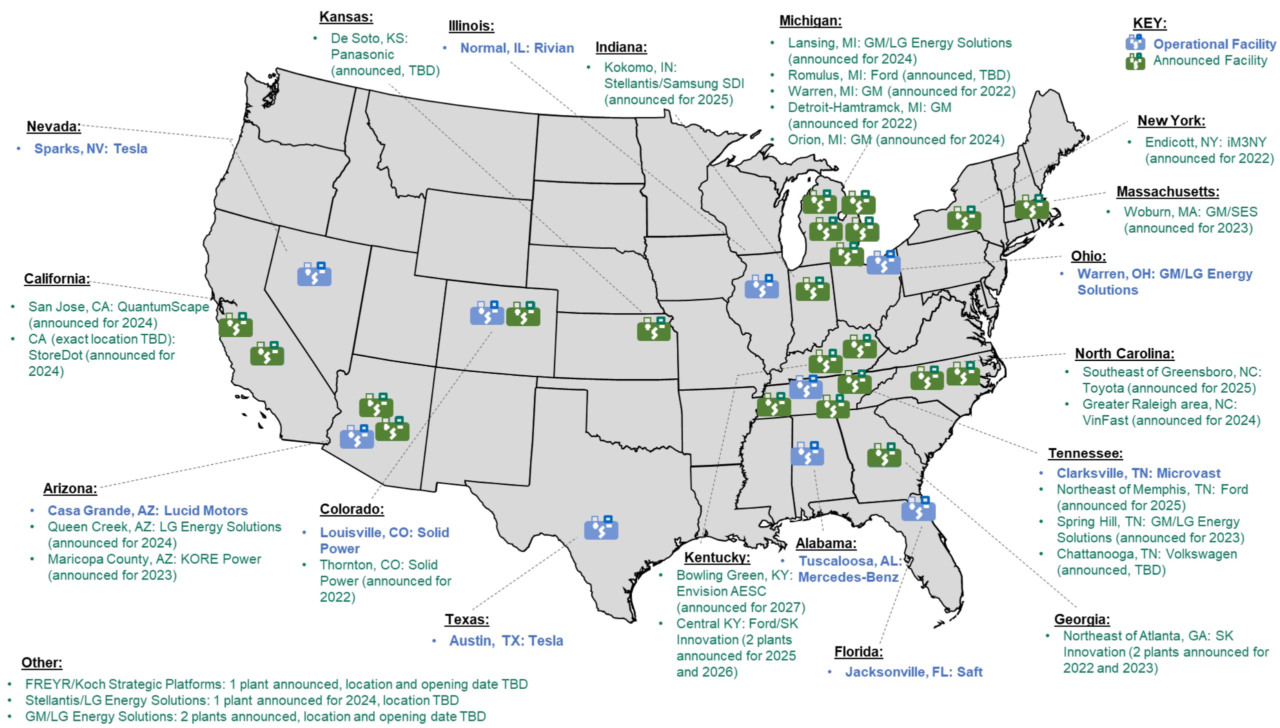



Between 2018 and 2020, 87 percent of battery packs and 70 percent of battery cells used in U.S.-produced EVs were made domestically.[18] There are several reasons to believe this trend of high U.S. production will continue, including the weight of the batteries and IRA provisions that encourage the onshoring of U.S. EV battery production through investment and production tax credits as well as loan programs.

[18] U.S. Department of Energy. (2021, March). *Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States 2010-2020*. Argonne National Laboratory. https://publications.anl.gov/anlpubs/2021/04/167369.pdf.

In 2021, the United States produced 44 gigawatt-hours (GWh) per year, and an additional 500+ GWh/year of capacity has been announced (Figure 6). Thus, the total capacity in 2025 is projected to be sufficient to meet domestic EV battery demand. The analysis assumes that U.S. battery production will continue to grow to maintain supplying 90 percent of U.S. battery demand.

**Figure 6: Operational and Announced U.S. EV Battery Cell Production Facilities**




## 4.5 Battery Price Projections

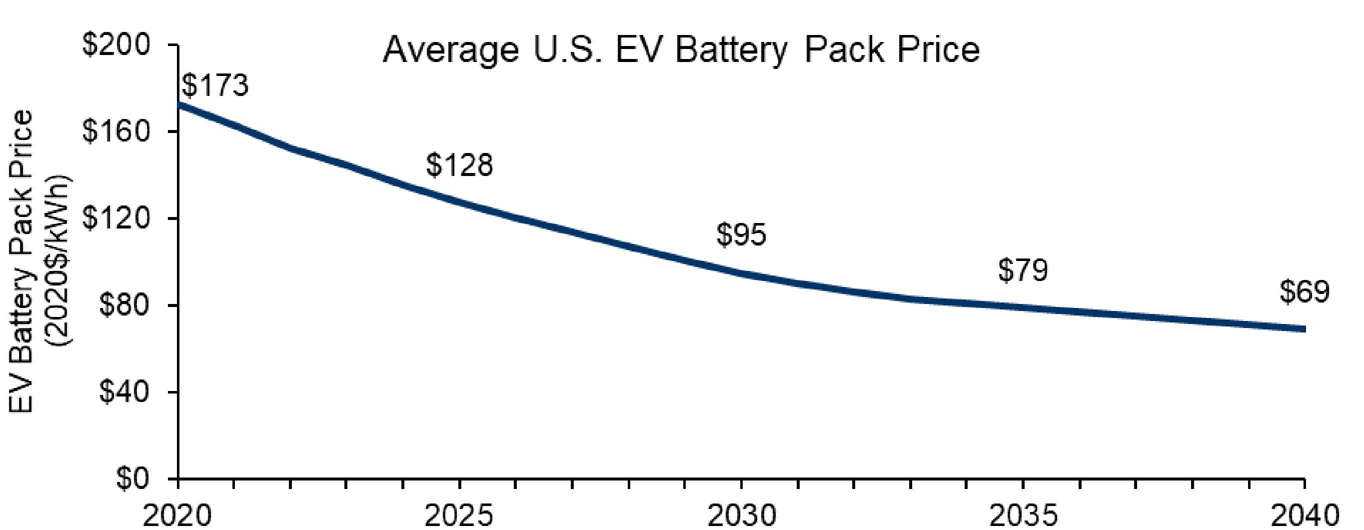
EV battery prices have fallen precipitously in the past decade and are projected to continue to fall, though recent supply chain issues and increased material prices have slowed the price decline. Many battery price projections are intended to represent global averages, although the batteries used in vehicles around the world are not all the same. This analysis uses battery price projections from CARB[19] and ICCT[20] as the starting point. We

[19] California Air Resources Board. "Advanced Clean Cars II Proposed Amendments to the Low Emission, Zero Emission, and Associated Vehicle Regulations." 26 Jan 2022 (Updated: 29 Mar 2022). https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf.

[20] Slowik, Peter, et al. "Assessment of Light Duty Electric Vehicle Costs and Consumer Benefits in the United States in the 2022-2035 Time Frame." *The International Council on Clean Transportation.* 18 Oct 2022. https://theicct.org/publication/ev-cost-benefits-2035-oct22/.

incorporated feedback from EVBI that EV batteries in U.S. vehicles are currently more expensive than the global average and will continue to be so due to the higher energy density rating for the chemistries used in U.S. vehicles. Along with higher costs for U.S.-produced batteries, this feedback increased the assumed EV battery price (Figure 7).[21]

**Figure 7: Average EV Battery Pack Price Over Time**




## 4.6 Metal and Mineral Demand

Widespread EV adoption will require large amounts of metals and minerals, some of which are currently in short supply. The primary materials required to make batteries include lithium, cobalt, nickel, copper, graphite, iron, manganese, phosphorus, and aluminum. While evolving battery technologies, the cost of each technology, and customer needs may influence the exact battery chemistry and materials being used for EVs, many of the raw materials are considered critical and are expected to be required. The United States does not currently mine or process many of these materials domestically. However, the surge in demand as well as many provisions in the IRA make U.S. mining and production of these materials much more economical, and domestic supply is expected to grow. The IRA also influences battery chemistries, as there are various provisions that encourage sourcing metals and minerals from domestic or fair-trade agreement sources, pushing the market

[21] The IRA's Advanced Manufacturing Production Credit will provide $45/kWh for battery manufacturing, which will drive down the costs for consumers. However, to accurately model the impact of EV battery manufacturing within the United States, we used the price battery manufacturers will experience.

toward chemistries that are easier and less expensive to source from the United States or IRA-allowed countries. Ultimately, the growth in U.S. production is dependent on the available reserves of the different materials.

While the United States produced little lithium in 2021, there are many mining facilities expected to come online in the near term. Using Fitch Solutions Mining Forecast[22] for the near-term U.S. lithium projection as well as U.S. Geological Survey reserve estimates[23] and announced projects,[24] this analysis assumes lithium carbonate equivalent production will grow to 150,000 metric tonnes (MT) per year in 2030, and by 2040 lithium carbonate equivalent production will reach 300,000 MT/year.

The only U.S. cobalt mine was opened in October 2022[25] and is projected to produce nearly 2,000 MT of cobalt per year.[26] Given the United States' low cobalt reserves,[27] this analysis assumes U.S. cobalt production grows to 2,000 MT/year over the next few years and remains flat until 2040.

In 2021, U.S. nickel production was 18,000 MT,[28] with projects like Talon Metals Tamarack looking to further expand the domestic nickel supply.[29] Currently estimated U.S. nickel reserves are low, less than 1 percent of the world's supply.[30] It is unlikely large volumes of nickel will be mined in the United States, especially since Australia (a fair-trade country) has

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[22] Fitch Solutions. "United States Lithium Mining Forecast." 24 May 2022. https://www.fitchsolutions.com/mining/united-states-lithium-mining-forecast-24-05-2022.

[23] U.S. Geological Survey. "Lithium." *Mineral Commodity Summaries.* Jan 2022. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-lithium.pdf.

[24] Controlled Thermal Resources. "The power of California's Lithium Valley." https://www.cthermal.com/projects.

[25] Jervois. "Company description." https://jervoisglobal.com/company/.

[26] Holtz, Michael. "Idaho is sitting on one of the most important elements on Earth." *The Atlantic.* 24 Jan 2022. https://www.theatlantic.com/science/archive/2022/01/cobalt-clean-energy-climate-change-idaho/621321/.

[27] U.S. Geological Survey. "Cobalt." *Mineral Commodity Summaries.* Jan 2022. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-cobalt.pdf.

[28] U.S. Geological Survey. "Nickel." *Mineral Commodity Summaries.* Jan 2022. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-nickel.pdf.

[29] Talon Metal Corp. "Talon metals and steelworkers union partner to advance the Tamarack nickel project for U.S. EV battery supply chain." *Talon Metals Corp and United Steelworkers.* 29 July 2021. https://talonmetals.com/talon-metals-and-steelworkers-union-partner-to-advance-the-tamarack-nickel-project-for-us-ev-battery-supply-chain/.

[30] U.S. Geological Survey. "Nickel." *Mineral Commodity Summaries.* Jan 2022.

a very large supply. Thus, this analysis assumes that U.S. nickel production will ramp up to 25,000 MT/year in the next five years and remain flat until 2040.

The United States does not currently mine any natural graphite, though it does produce synthetic graphite. There are several planned natural graphite mines in Alabama[31] and Alaska[32] as well as several other known graphite deposits within the United States.[33] Synthetic graphite production is also expected to grow with companies like Anovion announcing expected production of 150,000 MT/year within North America specifically for EV batteries.[34] Combining the potential natural and synthetic graphite production, this analysis assumes U.S. production will grow to 600,000 MT/year in 10 years and remain steady until 2040.

For all of the assessments of potential U.S. metal and mineral production, it is assumed that current extraction technology does not improve significantly, and current reserve levels remain accurate. It is possible that advancements or discoveries change the U.S. mining potential of one or more of these materials, but it is impossible to project whether such an event will occur.

For more abundant materials that are currently widely used across industries, such as copper, iron, aluminum, and phosphorus, EV battery demand is not likely to change U.S. production, although IRA provisions may shift domestically produced materials from their current use to EV battery use to satisfy the domestic content requirements within the IRA. As a result, these materials are not explicitly modeled as a separate industry. They remain accounted for as part of the EV battery supply chain.

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[31] Westwater Resources. "Graphite Projects Overview." https://westwaterresources.net/projects/graphite/.

[32] Graphite One. "A Vertically-Integrated U.S.-Based Advanced Graphite Supply Chain." https://www.graphiteoneinc.com/mine-to-material-manufacturing/.

[33] Demas, Alex and Jeffrey L Mauk. "U.S.GS Updates Mineral Database with Graphite Deposits in the United States." *U.S. Geological Survey*. 28 Feb 2022. https://www.usgs.gov/news/technical-announcement/usgs-updates-mineral-database-graphite-deposits-united-states#:~:text=The%20largest%20known%20graphite%20deposit,7.8%20to%208%20percent%20graphite; Karl, Nick et al. "Graphite deposits in the United States." *U.S. Geological Survey*. 31 Jan 2022. https://www.usgs.gov/data/graphite-deposits-united-states.

[34] American Battery Factory. "American battery factory enters strategic alliance with Anovion to procure synthetic graphite for U.S.-made lithium-ion batteries." *Cision PR Newswire*. 3 Nov 2022. https://www.prnewswire.com/news-releases/american-battery-factory-enters-strategic-alliance-with-anovion-to-procure-synthetic-graphite-for-us-made-lithium-ion-batteries-301667654.html.

## 4.7 Battery Mineral Pricing

To better understand the macroeconomic long-term impact of U.S. EV battery manufacturing rather than the short-term volatility in prices, averages for the material prices are used in this analysis (Table 2). Where available, averages of price projections are used. Otherwise, recent average prices are used.

**Table 2: Battery Material Prices**

| Material | Price (2020$/MT) | Source |
|---|---|---|
| Lithium (LCE) | $23,262 | Benchmark Mineral Intelligence, 2020 to 2040 average |
| Nickel | $17,932 | Benchmark Mineral Intelligence, 2020 to 2040 average |
| Cobalt | $51,603 | Benchmark Mineral Intelligence, 2020 to 2040 average |
| Graphite | $935 | Benchmark Mineral Intelligence, 2020 to 2040 average |
| Copper | $8,575 | Business Insider, 2020 to 2022 average |
| Aluminum | $2,444 | Business Insider, 2020 to 2022 average |
| Manganese | $10,300 | Trading Economics, 2020 to 2022 average |

## 4.8 Battery Material Recycling

On the other end of the battery lifecycle, increased EV battery manufacturing will eventually lead to increased batteries available for recycling. The quantity of material available for recycling is based on estimates developed in Dunn et al. (2021) using the 2019 Bloomberg New Energy Finance forecast for EV adoption and the 2020 Benchmark Mineral

Intelligence Cathode Market Share forecast.[35] Although the Dunn et al. (2021) estimates are potentially overestimating recycling by assuming 100 percent collection of retired EV batteries (after a 15-year life)[36] and 95 percent recovery of cathode materials, they are also potentially underestimating recycling because the estimates use a pre-IRA forecast for EV adoption. Given these opposing forces, we believe the Dunn et al. (2021) forecasted estimates are reasonable for the Moderate scenario. For the High scenario, the availability of recyclable material is increased proportionately based on EV sales to the Moderate scenario. Finally, the battery material estimates are adjusted to include increased availability of scrap material for recycling using projected proportions from Roland Berger.[37]

[35] Dunn, Jessica, M. Slattery, A. Kendall, H. Ambrose, S. Shen. 2021. "Circularity of Lithium-Ion Battery Materials in Electric Vehicles." Environ. Sci. Technol. 2021, 55, 5189-5198. https://pubs.acs.org/doi/10.1021/acs.est.0c07030?ref=pdf.

[36] Some retired EV batteries may be diverted for secondary use such as stationary energy storage before being available for recycling.

[37] Roland Berger. "The Lithium-Ion (EV) battery market and supply chain: Market drivers and emerging supply chain risks." April 2022. https://content.rolandberger.com/hubfs/07_presse/Roland%20Berger_The%20Lithium-Ion%20Battery%20Market%20and%20Supply%20Chain_2022_final.pdf.

# 5. Results

Table 3 summarizes the estimated economic impacts from the growth of the adoption of EVs and the associated growth of the EV battery, metal and mineral, and recycling industries, as well as the decline in the manufacturing of ICE vehicles. The model results show that the Moderate scenario for EV batteries will support 570,000 jobs,[38] $40 billion in labor compensation,[39] $110 billion in GDP,[40] and $150 billion in output[41] by 2040.[42] For the High scenario, the model estimates 740,000 jobs, $50 billion in labor compensation, $150 billion in GDP, and $200 billion in output by 2040. Overall, these numbers represent an increase in U.S. employment of 0.2 to 0.3 percent, and a GDP increase of 0.4 to 0.5 percent by 2040 (relative to the expected employment and GDP levels in 2040 without the modeled changes). As discussed earlier, this analysis includes impacts to metal and mineral, EV battery, and EV production as well as EV battery recycling and a decrease in ICE vehicle production. However, it does not include downstream impacts such as changes in electricity, petroleum, charging infrastructure, and automotive maintenance consumption.

[38] Employment comprises estimates of the number of jobs, full-time plus part-time, by place of work for all industries. Full-time and part-time jobs are counted at equal weight. Employees, sole proprietors, and active partners are included, but unpaid family workers and volunteers are not included.

[39] Labor compensation includes both wages and salaries and supplements to wages and salaries (which include employer contributions for employee pension and insurance funds and employer contributions for government social insurance).

[40] The market value of goods and services produced by labor and property in the United States, regardless of nationality.

[41] Output is the dollar value of production (i.e., sales or supply), including all intermediate goods purchased as well as value added (i.e., GDP, or compensation and profit).

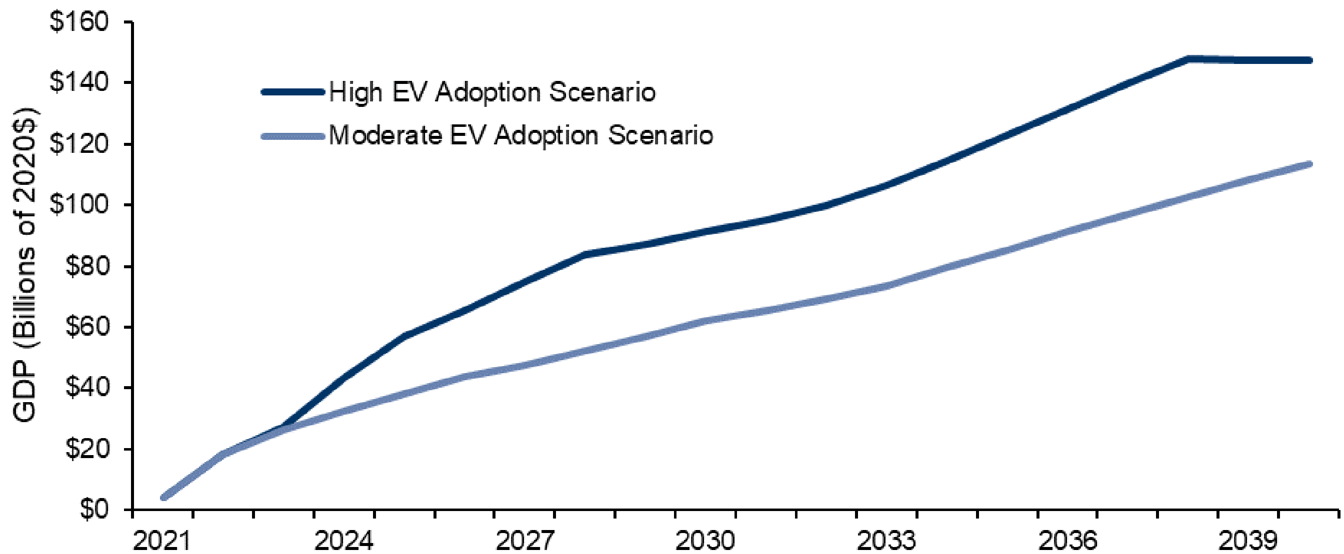
[42] All dollar values in the report are in real 2020 dollars.

**Table 3: Summary of Economic Impact Results (2020$)**

| | Impact Type | 2030 | 2040 |
|---|---|---|---|
| Moderate | Employment (jobs, thousands) | 350 | 570 |
| | Compensation (billions) | $20 | $40 |
| | GDP (billions) | $60 | $110 |
| | Output (billions) | $90 | $150 |
| High | Employment (jobs, thousands) | 510 | 740 |
| | Compensation (billions) | $40 | $50 |
| | GDP (billions) | $90 | $150 |
| | Output (billions) | $130 | $200 |

Figure 8 shows the GDP growth over time for each scenario. The High scenario flattens out toward 2040; this occurs because the battery prices continue to fall, but battery production growth slows since the United States has reached 100 percent adoption of light-duty EVs. Thus, the overall contribution of battery output is increasing only slightly.

**Figure 8: GDP Growth Over Time by Scenario**




These economic impact results incorporate three distinct impacts:

- Direct impacts reflect the initial change that occurs because of the modeled activities—for example, the increase in EV and battery manufacturing as well as mineral processing.
- Indirect impacts reflect changes that occur in the supply chain for the directly affected industries—the industries that supply the parts, materials, energy, management, transportation, etc. for the direct industries.
- Induced impacts reflect changes that occur because the payments to workers in the direct and indirect industries in turn create additional spending as those workers spend their income on food, housing, medical care, and other household goods and services. This impact captures the continuing cycle of spending as workers in the food, housing, medical, and retail sectors also benefit, in turn creating even more demand in those sectors.

Table 4 shows the direct, indirect, and induced employment impacts for each scenario for 2030 and 2040. The five key modeling sectors in Figure 2 are all direct impacts. Although batteries are an input to EVs, they are reflected in the direct impacts in this analysis. The same applies for metal and mineral production for lithium, cobalt, nickel, and graphite, and for EV battery recycling. Thus, the direct impacts are significantly larger than the indirect and induced impacts.

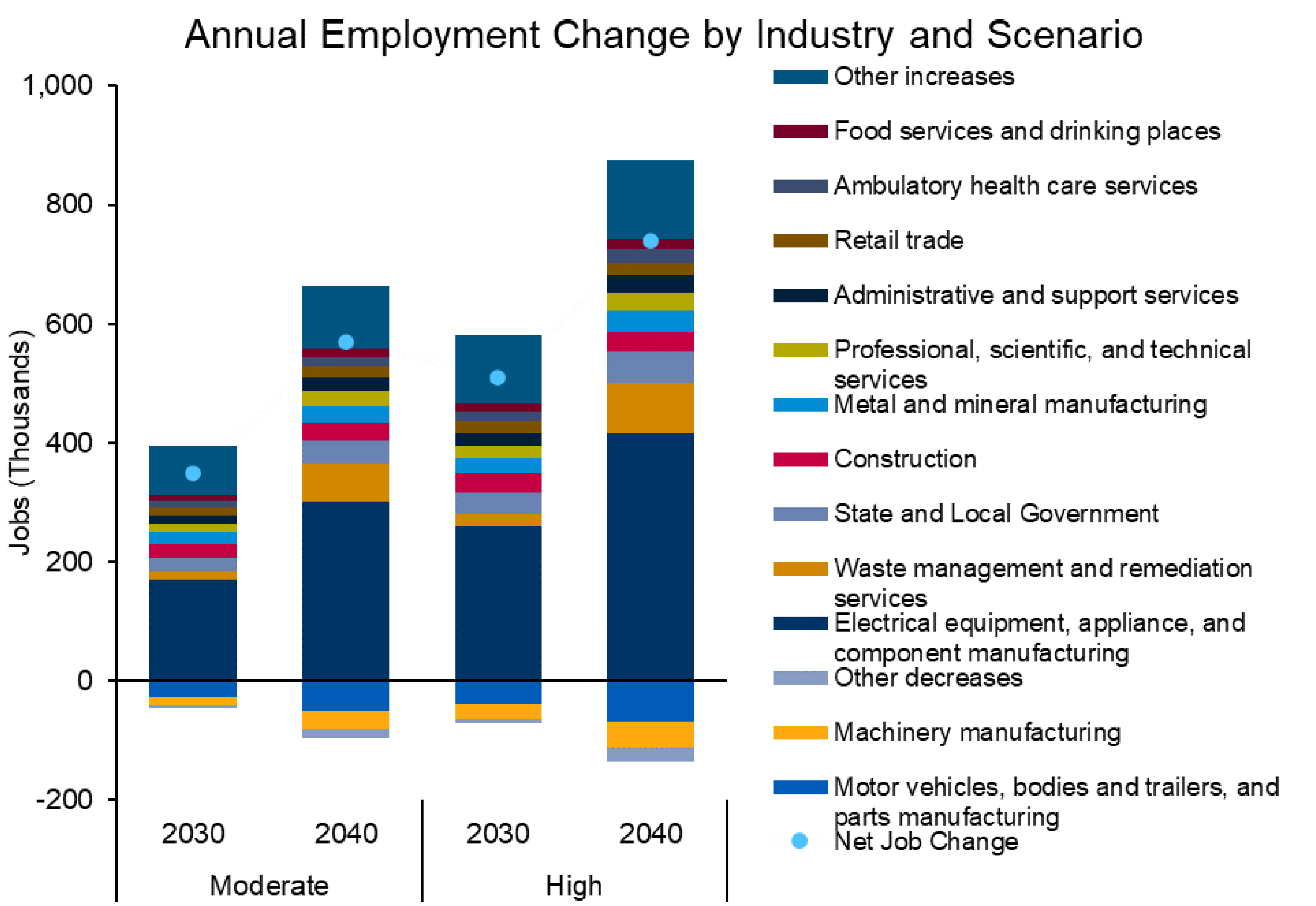
**Table 4: Employment Impacts by Type of Impact[43] (Annual, Thousands of Jobs)**

| | Impact Type | Jobs (Thousands) 2030 | 2040 |
|---|---|---|---|
| Moderate | Direct | 170 | 320 |
| | Indirect | 70 | 130 |
| | Induced | 110 | 120 |
| | Total | 350 | 570 |
| High | Direct | 250 | 440 |
| | Indirect | 100 | 170 |
| | Induced | 160 | 130 |
| | Total | 510 | 740 |

[43] Table values are rounded; individual impacts may not sum to total due to rounding.

Figure 9 shows the net employment impacts by industry, including the areas with the most job growth over time and the industries that experience the largest employment decreases. For both increases and decreases, there is an "Other" category in the figure for industries with small changes. The markers in the figure show the net change in jobs when all the industries are added together.

**Figure 9: Annual Model Employment Change by Industry and Scenario (Thousands of Jobs)**



The information in Figure 9 is presented in tabular form in Tables 5 and 6. Table 5 includes the 10 industries that experience the largest job growth by number of jobs. Other industries that experience growth are grouped together. Not surprisingly, electrical equipment manufacturing supports the most jobs because that industry encompasses EV battery manufacturing. These jobs will be necessary to support the increase in U.S. battery capacity produced from approximately 44 GWh/year in 2021 to 1,500 GWh/year (Moderate scenario) or 2,100 GWh/year (High scenario) in 2040, over a hundredfold increase on the high end. The electrical equipment industry also includes other types of electrical equipment, appliances, and components, including the electric motors used in EVs. The additional jobs associated with EV battery manufacturing account for more than 80 percent of the net increase in jobs in the electrical equipment industry.

The waste management and remediation services industry also has high job growth; that industry reflects the increase in battery recycling. There are increases in construction to account for building the factories and facilities. Metal and mineral manufacturing (including three different industries: primary metal manufacturing, chemical manufacturing, and non-metallic mineral manufacturing) also has notable gains due to the demand for metals and minerals to build batteries and the onshoring of jobs (further encouraged by IRA incentives).

Several other industries that show high employment gains are support industries that help businesses operate: government, professional/scientific/technical services, and administrative and support services. There are also jobs supported in the induced industries because workers from all these industries are spending their money in many of the same places: health care, retail, and food services.

**Table 5: Top 10 Annual Model Employment Net Increases by Industry and Scenario (Thousands of Jobs)**

| Industry | Jobs (Thousands) | | | |
|---|---|---|---|---|
| | Moderate | | High | |
| | 2030 | 2040 | 2030 | 2040 |
| Electrical equipment, appliance, and component manufacturing | 171 | 302 | 261 | 416 |
| Waste management and remediation services | 13 | 64 | 19 | 85 |
| State and local government | 25 | 38 | 37 | 51 |
| Construction | 23 | 29 | 33 | 34 |
| Metal and mineral manufacturing | 19 | 29 | 26 | 35 |
| Professional, scientific, and technical services | 14 | 24 | 21 | 31 |
| Administrative and support services | 14 | 23 | 20 | 29 |
| Retail trade | 13 | 17 | 19 | 21 |
| Ambulatory health care services | 12 | 17 | 18 | 22 |
| Food services and drinking places | 8 | 13 | 12 | 16 |
| Other increases | 84 | 107 | 115 | 134 |

Table 6 includes the industries with the largest net decrease in employment for 2030 and 2040. The largest impacts are to the motor vehicle manufacturing industry, which is projected to lose 50,000 to 68,000 jobs by 2040, a 4 to 6 percent decrease (Moderate and High scenario results, respectively). This loss is partially because the electric motors and batteries that are replacing the gas engines are produced by the electrical equipment industry, and thus engine and transmission manufacturing jobs are being shifted to the electrical equipment industry. To the extent that vehicle manufacturers vertically integrate their production activities to include motor production, battery cell manufacturing, or battery pack assembly, this loss may ultimately be offset within the vehicle manufacturing industry. However, a portion of the job loss is also due to the model assumption that EVs require less assembly. The motor vehicle manufacturing industry employment losses are partially but not entirely offset by the onshoring of vehicle manufacturing through IRA incentives and the growth of domestic EV manufacturing. Notably, the losses to this industry are more than offset by gains in other industries, resulting in the net employment gains reported in Tables 3 and 4.

**Table 6: Top Annual Model Employment Net Decreases by Industry and Scenario (Thousands of Jobs)**

| Industry | Jobs (Thousands) | | | |
|---|---|---|---|---|
| | Moderate | | High | |
| | 2030 | 2040 | 2030 | 2040 |
| Motor vehicles, bodies and trailers, and parts manufacturing | -26 | -50 | -39 | -68 |
| Machinery manufacturing[44] | -15 | -30 | -24 | -45 |
| Other decreases | -5 | -15 | -7 | -23 |

Table 7 shows the industries with the largest modeled percent change in industry employment due to the increased adoption of EVs and demand for EV batteries. Note that these percentages depend on how many people are projected to be employed by that industry without the shift to EVs, using the REMI PI+ standard control projection. Thus, the industries included and their ranking are different than in Table 5 above. The massive increase in EV battery production will support a 47 to 65 percent increase in employment in the electrical equipment industry by 2040. Similarly, the development of EV battery material recycling will cause a notable increase in waste management industry employment, of about 11 to 14 percent by 2040. Primary metal manufacturing and mining also see substantial increases in employment. The majority of the changes in other industries are more minor—less than 1 percent of the projected baseline employment.

[44] Machinery manufacturing includes North American Industry Classification System's "Other engine equipment manufacturing," which contains diesel engine manufacturing.

**Table 7: Annual Model Percent Change in Employment by Industry (Top 10 Industries)**

| Industry | Moderate | | High | |
|---|---|---|---|---|
| | 2030 | 2040 | 2030 | 2040 |
| Electrical equipment, appliance, and component manufacturing | 34% | 47% | 52% | 65% |
| Waste management and remediation services | 2% | 11% | 3% | 14% |
| Primary metal manufacturing | 3% | 4% | 4.4% | 5.8% |
| Mining (except oil and gas) | 0.8% | 1.2% | 1.1% | 1.4% |
| Chemical manufacturing | 0.5% | 0.8% | 0.5% | 0.7% |
| Nonmetallic mineral product manufacturing | 0.5% | 0.4% | 0.5% | 0.4% |
| Support activities for mining | 0.3% | 0.4% | 0.5% | 0.5% |
| Utilities | 0.2% | 0.3% | 0.3% | 0.4% |
| Truck transportation | 0.2% | 0.3% | 0.3% | 0.3% |
| Construction | 0.2% | 0.3% | 0.3% | 0.3% |
| **All Industries** | **0.2%** | **0.3%** | **0.2%** | **0.3%** |

# 6. Conclusion

Like many industries on the road to decarbonization, it is an exciting time for vehicle manufacturing and all its components as technologies evolve quickly. To reach the ambitious climate goals set out by states, the federal government, and the international community, as well as meet growing customer demand, EV and EV battery manufacturing needs to grow at a tremendous pace. The current policy landscape, including the provisions of the IRA, positions the United States to be a major producer of batteries and vehicles, although a significant amount of work remains to reach that potential.

In this analysis we modeled the possible job impacts of increased EV demand in the United States being met by primarily U.S-produced vehicles and batteries. The model estimates that by 2040, depending on the EV growth scenario:

- Annual U.S. battery capacity produced will increase from approximately 44 GWh/year in 2021 to 1,500 GWh/year (Moderate scenario) or 2,100 GWh/year (High scenario), over a hundredfold increase on the high end;
- Jobs supported will increase by 570,000 to 740,000 jobs, a 0.2 to 0.3 percent increase across all affected industries;
- Labor compensation will increase by $40 to $50 billion (2020$), a 0.2 to 0.3 percent increase; and
- GDP will increase by $110 billion to $150 billion (2020$), a 0.4 to 0.5 percent increase.