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SUMMARY

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# Critical Minerals in Electric Vehicle Batteries

Expected growth of electric vehicle (EV) sales has led to concern about securing mineral inputs used in EV batteries. Various countries and companies have stated policies to accelerate the adoption of EVs in the transportation sector. Such public and private commitments suggest that EV sales could continue into the expected future, with some estimates indicating 200 million total EVs sold by 2030. More than 16 million total EVs have been sold worldwide, with about 6.6 million EVs sold in 2021. The U.S. EV market is small when compared to those in China and Europe: new U.S. EV registrations were slightly less than 10% of new global EV registrations in 2021, while registrations in China were 50% of the global total and European registrations were 35%.

As the majority of EV manufacturing and sales occur outside the United States, so does the majority of EV battery production. While China accounts for over 70% of global EV battery production capacity, the United States has developed battery supply chains for some of its demand. China's dominance in EV battery manufacturing is similar to its dominance in mining and extraction of the minerals used in EV batteries. The potential for an accelerating global transition to EVs leads some to question the domestic availability of the minerals and materials for the domestic manufacture of EV batteries.

Currently, lithium-ion batteries are the dominant type of rechargeable batteries used in EVs. The most commonly used varieties are lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium iron phosphate (LFP), lithium nickel cobalt aluminum oxide (NCA) and lithium nickel manganese cobalt oxide (NMC). Graphite is currently widely used as the anode in lithium-ion batteries. These EV battery chemistries depend on five *critical minerals* whose domestic supply is potentially at risk for disruption: lithium, cobalt, manganese, nickel, and graphite. The U.S. Geological Survey designated these and other minerals as "critical," according to the methodology codified in the Energy Act of 2020.

The United States is heavily dependent on imports for these minerals for use in EV batteries and other applications. The United States currently mines some lithium, cobalt, and nickel, but it does not currently mine any manganese or graphite. Various companies have indicated plans to expand the mineral production of these minerals. Recycling products containing these minerals contributes to some domestic production, and it represents further potential contributions to domestic supply. Additional research to increase EV battery efficiencies or into new battery chemistries can reduce the requirements of these critical minerals for EV battery production.

The 117th Congress has considered, and may choose to consider further, various options related to EV adoption and enhanced domestic production of minerals used in EV batteries. Of the options considered, some have been included in enacted legislation. The Infrastructure Investment and Jobs Act (IIJA, P.L. 117-58) includes multiple sections related to EV adoption and enhancing domestic supply of the critical minerals used in EV batteries. Some examples include Section 11401, Grants for Charging and Fueling Infrastructure; Section 40201, Earth Mapping Resources Initiative; Section 40207, Battery Processing and Manufacturing; Section 40208, Electric Drive Vehicle Battery Recycling and Second-Life Applications Program; Section 40210, Critical Minerals Mining and Recycling Research; Section 40401, Department of Energy Loan Programs; Section 71101, Clean School Bus Program; Division J, and Title VIII, National Electric Vehicle Formula Program.

In addition to ongoing federal programs related to EV batteries and changes resulting from provisions in the IIJA, Congress could consider further changes related to the domestic supply of critical minerals used in EV batteries. Some additional related areas include mining on federal lands, taxes and tariffs, and EV battery chemistry research, among others.

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# Introduction

Expected growth of electric vehicle (EV) sales globally and in the United States has led to concern among some Members of Congress and various industry advocacy groups about securing mineral inputs used in EV batteries.[1] While some of these minerals are in the process of being developed domestically, some are not found in the United States in economically viable deposits. This report provides background information on EV batteries, with a focus on the minerals used in them.

The main physical differences between an EV and an internal combustion engine (ICE) vehicle lie in the power train: the major components of an EV power train include a battery, a motor, and ancillary systems, while the major components of an ICE power train include liquid fuel storage, combustion chambers (and cooling system), transmission, and an exhaust system (with emissions controls).[2] Much concern is focused on the access to or supply of critical minerals required for EV batteries, partially due to the large quantities required; less concern is focused on EV motors, which generally require small quantities of rare earth elements.[3]

This report focuses on the minerals contained in EV batteries and includes discussion of some policy issues related to securing access to these minerals. More specifically, it focuses on five minerals used in common EV battery chemistries. These five minerals have been designated as *critical minerals* by the U.S. Geological Survey (USGS), which indicates a higher potential for supply chain disruption, due in part to elevated import dependence.[4] Domestic production of some minerals for EV batteries may not occur due to depleted or uneconomical mineral reserves, while other mineral deposits have been identified and are in the process of being developed.

This report begins by providing a brief overview of EVs, the changing EV market, and the different technologies available and expected for EV batteries. The focus of the report then moves to the minerals used in EV batteries in the light-duty vehicle segment; mineral requirements for EV batteries in other vehicle segments may vary. Vehicle duty segments and other factors drive the types and quantities of minerals used in the resulting batteries.

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[1] International Energy Agency (IEA), *Global EV Outlook 2022*, 2022, p. 5, at https://www.iea.org/reports/global-ev-outlook-2022. Two sources that include statements and testimony from several Members of Congress and industry groups highlighting concerns over access to critical minerals include House Committee on Natural Resources, "American Critical Mineral Independence Act," at https://republicans-naturalresources.house.gov/legislative-priorities/american-critical-mineral-independence-act.htm, and Senate Committee on Energy and Natural Resources, "Full Committee Hearing on Domestic Critical Mineral Supply Chains," at https://www.energy.senate.gov/hearings/2022/3/full-committee-hearing-on-domestic-critical-mineral-supply-chain.

[2] For an overview of EVs and their differences from ICE vehicles, see CRS In Focus IF11101, *Electrification May Disrupt the Automotive Supply Chain*, by Bill Canis. For an overview of potential environmental impacts of ICEs and EVs, see CRS Report R46420, *Environmental Effects of Battery Electric and Internal Combustion Engine Vehicles*, by Richard K. Lattanzio and Corrie E. Clark.

[3] The average weight of anode and cathode material is about 200 kilograms (Olumide Winjobi, Qiang Dai, and Jarod C. Kelly, *Update of Bill-of-Materials and Cathode Chemistry Addition for Lithium-Ion Batteries in GREET 2020*, Argonne National Laboratory, October 2020, p. 6, at https://greet.es.anl.gov/publication-vmc_2020). The average weight of a neodymium magnet in an average EV is a little under three kilograms; neodymium is a rare earth element and a critical mineral (Eric Onstad, "China Frictions Steer Electric Automakers Away from Rare Earth Magnets," *Reuters*, July 20, 2021). Rare earth elements are a group of elements considered critical by the U.S. Geological Survey; for more information on rare earth elements, see CRS Report R46618, *An Overview of Rare Earth Elements and Related Issues for Congress*, by Brandon S. Tracy.

[4] U.S. Geological Survey (USGS), "2022 Final List of Critical Minerals," 87 *Federal Register* 10381, February 24, 2022. Section 7002 of the Energy Act of 2020 (Division Z, P.L. 116-260 ) includes provisions directing the USGS to identify critical minerals.

Federal initiatives to spur EV adoption in the United States include those from the Biden Administration. Executive Order (E.O.) 14008 aims to revitalize the federal government's sustainability efforts by using "all available procurement authorities to achieve or facilitate ... clean and zero-emission vehicles for Federal, State, local, and Tribal government fleets, including vehicles of the United States Postal Service."[5] Also from the Biden Administration, E.O. 14037 outlines a policy goal "that 50 percent of all new passenger cars and light trucks sold in 2030 be zero-emission vehicles, including battery electric, plug-in hybrid electric, or fuel cell electric vehicles."[6]

Specific to EV battery minerals, President Biden issued the "Presidential Determination Pursuant to Section 303 of the Defense Production Act of 1950, as Amended," in which he determined that "sustainable and responsible domestic mining, beneficiation, and value-added processing of strategic and critical materials for the production of large-capacity batteries for the automotive, e-mobility, and stationary storage sectors are essential to the national defense."[7] This determination directs the U.S. Department of Defense to take certain actions related to supporting domestic mining.[8]

In addition to legislation related to the general adoption of EVs, which is outside of the scope of this report, the 117th Congress has shown interest in securing and enhancing the domestic supply of EV battery minerals through proposed and enacted legislation.[9] For example, the 117th Congress passed the Infrastructure Investments and Jobs Act (P.L. 117-58), which contains various provisions that could enhance domestic EV adoption and production of EV battery minerals.

States may also target policies to enable the transition to EVs. For example, California has issued a requirement for all passenger cars and trucks sold in 2035 (and all medium- and heavy-duty trucks sold in 2045) and thereafter to be zero emissions vehicles.[10] A consideration of state-specific policies is beyond the scope of this report.

# EV Market Overview

According to the International Energy Agency (IEA), more than 16 million total EVs had been sold worldwide by the end of 2021, with about 6.6 million EVs sold in 2021, representing nearly 10% of all car sales.[11] The U.S. EV market is small when compared to those in China and Europe:

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[5] Executive Order (E.O.) 14008, "Tackling the Climate Crisis at Home and Abroad," 86 *Federal Register* 7619, February 1, 2021.

[6] E.O. 14037, "Strengthening American Leadership in Clean Cars and Trucks," 86 *Federal Register* 43583, August 10, 2021.

[7] Executive Office of the President, "Presidential Determination Pursuant to Section 303 of the Defense Production Act of 1950, as Amended," 87 *Federal Register* 19775, April 6, 2022. "E-mobility" commonly refers to electrified transportation options, often integrating rechargeable batteries.

[8] For more information on the Presidential Determination, critical minerals, and the DPA, see CRS Report R47124, *2022 Invocation of the Defense Production Act for Large-Capacity Batteries: In Brief*, by Heidi M. Peters et al.

[9] For additional information on related laws and legislation proposed during the 116th and 117th Congresses, see CRS Report R45747, *Vehicle Electrification: Federal and State Issues Affecting Deployment*, by Bill Canis, Corrie E. Clark, and Molly F. Sherlock; and CRS Report R46864, *Alternative Fuels and Vehicles: Legislative Proposals*, by Melissa N. Diaz.

[10] E.O. N-79-20, Executive Department State of California, September 23, 2020, at https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf.

[11] IEA, *Global EV Outlook 2022*, 2022, p. 4, at https://www.iea.org/reports/global-ev-outlook-2022.

new U.S. EV registrations were slightly less than 10% of new global EV registrations in 2021, while registrations in China were 50% of the global total and European registrations were 35%.[12]

Various countries and companies have stated policies to accelerate the adoption of EVs in the transportation sector. One study indicates that more than 40 countries have announced some form of future bans on the sales of light-duty ICE vehicles or mandates requiring future sales to be zero-emission vehicles.[13] Fourteen countries and 23 companies and organizations support the EV30@30 Campaign, which is a campaign within the IEA's Electric Vehicle Initiative with the goal of having EVs reach a 30% new sales share by 2030; the United States is not a signatory country to the EV30@30 Campaign.[14]

At least 18 vehicle manufacturers have made commitments to increase global sales of EVs, and various global companies have publicly declared commitments to incorporating EVs into their fleets.[15] Such public and private commitments suggest that EV sales could continue into the expected future, with some estimates indicating 200 million total EVs sold by 2030.[16]

The potential for an accelerating global transition to EVs leads some to question the availability of the minerals and materials needed to build EV batteries, especially as some mineral requirements (and availability) vary greatly by battery type. Some have raised questions that are beyond the scope of this report, including questions framing such growth as a potential threat to national security (if the growth is tied to imports), as a potential opportunity for increased human rights abuses, and as a potential threat for increased environmental destruction.

# EV Battery Overview

This report focuses on the critical minerals used in lithium-ion batteries, which are the dominant type of rechargeable batteries that are used in EVs.[17] Additionally, the focus of this report is on the critical minerals used in batteries for battery electric vehicles (BEVs) in the light-duty vehicle segment—namely, those vehicles without an ICE—given the dominance of BEVs in the EV market.[18]

An EV battery, commonly called a battery pack, is an assembled component generally consisting of packaging and mounting structures, an electronic and electrical control system, and battery cells. Each cell contains two electrodes (a cathode and an anode), an electrolyte (a chemical solution that allows electricity to flow between the electrodes), and a separator (a physical barrier between the cathode and anode).[19] EV batteries play important roles in EVs, and the complexity

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[12] Ibid.

[13] IEA, *Global EV Outlook 2022*, 2022, p. 60, at https://www.iea.org/reports/global-ev-outlook-2022.

[14] Ibid., p. 110.

[15] IEA, *Global EV Outlook 2021*, 2021, p. 25, at https://www.iea.org/reports/global-ev-outlook-2021.

[16] IEA, *Global EV Outlook 2022*, 2022, p. 5, at https://www.iea.org/reports/global-ev-outlook-2022.

[17] While other battery options may exist for EVs (e.g., fuel cells, sodium-ion), only lithium-ion batteries are mentioned as available in the current market in the *Global EV Outlook 2022* (IEA, 2022); review of other sources did not result in findings of other battery types in use in the current EV market. In 2021, Contemporary Amperex Technology Co., Ltd. (CATL), the world's largest EV battery manufacturer, unveiled its sodium-ion battery; however, it is unclear if any EV manufacturers have incorporated it into their vehicles (CATL, "CATL Unveils Its Latest Breakthrough Technology by Releasing Its First Generation of Sodium-Ion Batteries," press release, July 29, 2021, at https://www.catl.com/en/news/665.html).

[18] IEA, *Global EV Outlook 2022*, 2022, pp. 16-18. For background information on EVs, see CRS Report R46231, *Electric Vehicles: A Primer on Technology and Selected Policy Issues*, by Melissa N. Diaz.

[19] A cathode is the positive battery terminal, and the anode is the negative battery terminal. During use, negatively

and mineral content of EV batteries is reflected in the battery cost. Some estimates place the cost of an EV battery between 30% and 33% of the total cost of a vehicle, costing on average $6,300.[20] Further illuminating the cost drivers of EV batteries, one study indicates that "while materials are the most expensive component in battery cost, electrode manufacturing is the second most expensive piece, accounting for between 20 and 40 percent of the total battery pack cost, with between 27 and 40 percent of this cost coming from electrode preparation."[21]

## EV Battery Chemistries

Different lithium-ion battery cells can be designed to create different battery packs with varying characteristics to meet desired vehicle parameters. EV battery cells incorporate various minerals depending on the cell's specification, and the cells are combined to form the battery pack using various other materials.

The cell's cathode chemistry is commonly used for general classification, with additional classification indicated by stoichiometric ratios (i.e., the molar ratio of elements in a compound) for some cathode chemistries.[22] The IEA notes, regarding lithium-ion batteries in general, "the most commonly used varieties are lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium iron phosphate (LFP), lithium nickel cobalt aluminium oxide (NCA) and lithium nickel manganese cobalt oxide (NMC).[23] As graphite is currently widely used as the anode in lithium-ion batteries, the anode chemistry is not typically mentioned as part of an EV battery's chemistry.

Some aspects of the supply and demand for the five critical minerals used in these common chemistries are considered in greater detail in "Critical Mineral Supply for EV Batteries." The five minerals covered in that section are lithium, cobalt, manganese, nickel, and graphite. Other minerals used in EV batteries such as aluminum, iron, and phosphate are readily available through global and domestic supply chains and not considered further in this report.

The demand for specific EV battery cell chemistries is driven by an EV manufacturer's optimization of various factors, including overall cost, battery pack monitoring and cooling

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charged electrons flow from the anode to the cathode; charging the battery reverses this flow. For more information on lithium-ion batteries and their components, see Argonne National Laboratory (ANL), "Science 101: Batteries," at https://www.anl.gov/science-101/batteries. For an earlier look at the domestic EV supply chain, see CRS Report R41709, *Battery Manufacturing for Hybrid and Electric Vehicles: Policy Issues*, by Bill Canis.

[20] For example, see Adrian König, Lorenzo Nicoletti, and Daniel Schröder, et al., "An Overview of Parameter and Cost for Battery Electric Vehicles," *World Electric Vehicle Journal*, vol. 12, no. 21 (2021), at https://doi.org/10.3390/wevj12010021; Nic Lutsey and Michael Nicholas, *Update on Electric Vehicle Costs in the United States Through 2030*, International Council on Clean Transportation, Working Paper 2019-06, 2019, at https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf; and David Stringer and Kyunghee Park, "Why an Electric Car Battery Is So Expensive, for Now," *Bloomberg*, September 16, 2021, at https://www.bloomberg.com/news/articles/2021-09-16/why-an-electric-car-battery-is-so-expensive-for-now-quicktake.

[21] W. Blake Hawley and Jianlin Li, "Electrode Manufacturing for Lithium-Ion Batteries—Analysis of Current and Next Generation Processing," *Journal of Energy Storage*, vol. 25 (2019), p. 3.

[22] For example, two nickel manganese cobalt (NMC) chemistries are NMC111 and NMC811, with the three numbers after NMC indicating the stoichiometric ratio of the three elements; 'stoichiometric ratio' refers to the atomic mass ratio of the given chemistry. For the NMC111 chemistry, nickel, manganese, and cobalt would be used in equal proportions (i.e., 33.3%). For the NMC811 chemistry, the weight percentages would be 80% nickel, 10% manganese, and 10% cobalt (Kirsten Hund, Daniele La Porta, and Thao P. Fabregas, et al., *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition*, World Bank Group, 2020, p. 63, at https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the- Clean-Energy-Transition).

[23] IEA, *The Role of Critical Minerals in Clean Energy Transitions*, 2021, p. 90, at https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions. LCO is not currently suitable for use in EV batteries.

systems, battery energy and power densities, safety, and lifespan.[24] An apparently minor change to a cell's chemistry can result in seemingly large differences in the required mineral inputs and other battery characteristics. **Table 1** provides an example of varying weights for a selection of battery chemistries, for a vehicle with a 300-mile range.

**Table 1. Selected EV Battery Mineral and Component Weights (kg)**

For indicated battery chemistries

| | LMO | LFP | NCA | NMC111 | NMC811 |
|---|---|---|---|---|---|
| Cathode Material | 166 | 146 | 97 | 125 | 90 |
| Graphite (Anode) | 56 | 74 | 64 | 64 | 65 |
| Cell | 318 | 332 | 224 | 267 | 226 |
| Pack | 383 | 405 | 281 | 329 | 285 |

**Source:** Olumide Winjobi, Qiang Dai, and Jarod C. Kelly, *Update of Bill-of-Materials and Cathode Chemistry Addition for Lithium-ion Batteries in GREET 2020*, ANL, October 2020, p. 6, at https://greet.es.anl.gov/publication-vmc_2020.

**Notes:** 'kg' is kilograms; 'LMO' is lithium manganese oxide; 'LFP' is lithium iron phosphate; 'NCA' is nickel cobalt aluminum; 'NMC111' and 'NMC811' are two chemistries of nickel manganese cobalt. The cell weight includes the cathode and anode weights, plus additional system and material weights. The pack (containing multiple cells) weight includes the cell weights plus additional system and material weights. These weights are based on a 300-mile range battery pack; see source for additional pack specifications.

## EV Battery Research

Various EV battery research efforts are underway that could alter the mineral requirements of future EVs. Efforts generally aim to lower the costs of EV batteries, extend the range of EVs (by increasing battery energy and power densities), and reduce charging time, all while ensuring safe operation of the battery. EV battery research often overlaps with chemical energy storage generally, whose focus may not be on EVs.[25] Some research focuses on improving cathode or anode production processes, which could lower the production costs of some types of battery relative to others, potentially impacting mineral demands.[26] Additional research focuses on enhancing secondary supply (i.e., recycling) of critical minerals for EV batteries (discussed further in the section "Secondary Mineral Supply").

Among EV battery research efforts are federally funded programs to improve EV batteries. Much of the federal funding for this research is directed to the U.S. Department of Energy (DOE). DOE may, depending on the program and funding type, further direct these funds to national labs, academic partners, private sector grant recipients, or others. The following are examples of ongoing federal research programs within DOE.

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[24] For an example discussion of some factors facing EV manufacturers regarding battery chemistry options, see Yuanli Ding, Zachary P. Cano, and Aiping Yu, et al., "Automotive Li-Ion Batteries: Current Status and Future Perspectives," *Electrochemical Energy Reviews*, vol. 2 (2019), pp. 7-8.

[25] For a summary of a battery research panel discussion, including discussions of sodium-ion, multivalent, metal–air, and flow batteries in relation to lithium-ion batteries, see Yasin Emre Durmus, Huang Zhang, and Florian Baakes, et al., "Side by Side Battery Technologies with Lithium-Ion Based Batteries," *Advanced Energy Materials*, vol. 10 (2020), pp. 1-21.

[26] W. Blake Hawley and Jianlin Li, "Electrode Manufacturing for Lithium-Ion Batteries—Analysis of Current and Next Generation Processing," *Journal of Energy Storage*, vol. 25, (2019), Article 100862.

- *U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Vehicle Technologies Office (VTO)*. VTO's Batteries, Charging, and Electric Vehicles program aims to research new battery chemistry and cell technologies that can reduce costs, increase the range, and decrease charge time.[27] VTO also funds the Silicon Consortium Project, which aims to eliminate barriers to replacing graphite-based anodes with silicon-based anodes in lithium-ion battery cells, and the ReCell Center, which is a "national collaboration of industry, academia and national laboratories working together to advance recycling technologies along the entire battery life-cycle for current and future battery chemistries."[28]
- *Joint Center for Energy Storage Research (JCESR)*. "JCESR is a DOE Energy Innovation Hub led by Argonne National Laboratory and focused on advancing battery science and technology."[29]
- *Argonne National Laboratory, Argonne Collaborative Center for Energy Storage Science (ACCESS)*. "ACCESS is a catalyst for innovation comprised of scientists and engineers from across the lab who solve complex energy storage problems through multidisciplinary research."[30] Also within the Argonne National Laboratory is the Li-Bridge program: "Li-Bridge is a public-private alliance committed to accelerating the development of a robust and secure domestic supply chain for lithium-based batteries."[31]
- *National Renewable Energy Laboratory (NREL), Energy Storage Research*. NREL's energy storage research spans a range of applications and technologies, including electrochemical storage, stationary storage, storage for transportation, and circular economy for batteries, among others.[32]
- *Pacific Northwest National Laboratory (PNNL), Electrochemical Energy Storage*. PNNL "plays a key role in developing new materials and processes that are resulting in improvements to lithium-ion and lithium-metal batteries, redox flow batteries, and other battery chemistries."[33] PNNL also leads VTO's Battery500 Consortium, which has the goal "to improve the batteries that power electric vehicles so they have more than double the specific energy ... found in today's batteries."[34]

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[27] U.S. Department of Energy (DOE), Vehicles Technology Office, "Batteries, Charging, and Electric Vehicles," at https://www.energy.gov/eere/vehicles/batteries-charging-and-electric-vehicles.

[28] Information on the consortium can be found on national laboratory websites, including National Renewable Energy Laboratory, "Silicon Consortium Project," at https://www.nrel.gov/transportation/silicon-anode-consortium.html, and Argonne National Laboratory, "Silicon Consortium Project," at https://www.anl.gov/access/research/projects/silicon-consortium-project, among others. For an overview of some of the challenges and ongoing research into silicon anodes for lithium batteries, see Yajun Yang, Shuxing Wu, and Yaping Zhang, et al., "Towards Efficient Binders for Silicon Based Lithium-ion Battery Anodes," *Chemical Engineering Journal*, vol. 406 (2021), Article 126807. Information on the ReCell Center can be found at https://recellcenter.org/.

[29] Joint Center for Energy Storage Research, at https://www.jcesr.org/.

[30] ANL, "Argonne Collaborative Center for Energy Storage Science," at https://www.anl.gov/access.

[31] ANL, "Li-Bridge," at https://www.anl.gov/li-bridge.

[32] National Renewable Energy Laboratory (NREL), "Energy Storage Research," at https://www.nrel.gov/storage/research.html.

[33] Pacific Northwest National Laboratory (PNNL), "Electrochemical Energy Storage," at https://www.pnnl.gov/electrochemical-energy-storage.

[34] PNNL, "Battery500 Consortium," at https://www.pnnl.gov/projects/battery500-consortium.

## EV Battery Supply Chains

EV battery packs and cells incorporate numerous commodities into highly specialized products; each pack is often designed for a specific drivetrain of a specific EV model. While some of these commodities may be obtained through robust global supply chains (e.g., aluminum, copper), the supply chains of other commodities may face a higher risk to disruption (e.g., cobalt, lithium). As the majority of EV manufacturing and sales occur outside the United States, so does the majority of EV battery pack and cell production. A study from the Argonne National Laboratory (ANL) notes, "[w]orldwide, of the 13 top battery production companies, which supplied 94% of PEV [plug-in electric vehicle] battery cells in 2017, seven have headquarters in China, three in Japan, and three in South Korea."[35]

While China accounts for over 70% of global EV battery cell production capacity,[36] the United States has developed battery cell and pack supply chains for some of the U.S. demand. Approximately 20 U.S.-based companies source EV battery cells and packs for the U.S. market.[37] According to a study of data from 2020, 70% of battery cells and 87% of battery packs for EVs sold in the United States were produced in the United States.[38] "Producing" a cell or pack does not convey information on the origin of the minerals used in the cells, nor on where the chemical compounds used in the cells were produced from the refined minerals. At least 85% of the domestic EV battery cell and pack production in 2020 stemmed from the Tesla-Panasonic joint-venture Gigafactory, where both companies develop batteries; Panasonic manufactures cells for Tesla and other companies, and Tesla manufactures battery packs for Tesla vehicles to be sold in the United States.[39] In the first half of 2021, Tesla captured 66% of the domestic EV market, followed by Chevrolet, Ford, Nissan, Audi, and other companies.[40]

Public data are not available to indicate whether the mineral inputs for the battery cells are produced domestically or imported. Some research highlights U.S. dependence on foreign sources of minerals, noting the efforts of the governments of some countries to support their domestic mining companies operating in foreign countries and to enhance mineral processing capabilities, including for imported minerals.[41] In an effort to contribute to the understanding of lithium-ion battery supply chains in North America, NAATBatt International, a battery advocacy group, commissioned NREL to produce a public database of all North American companies working in the lithium-ion battery industry. According to NAATBatt,

> The database is the first attempt ever to identify every company in North America working in every aspect of the lithium-ion battery supply chain. Assembling the database required

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[35] Yan Zhou, David Gohlke, and Luke Rush, et al., *Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010-2020*, ANL, ANL/ESD-21/3, 2021, p. 1, at https://doi.org/10.2172/1778934.

[36] IEA, *Global EV Outlook 2022*, 2022, p. 6.

[37] David Gohlke and Yan Zhou, *Assessment of Light-duty Plug-in Electric Vehicles in the United States, 2010-2019*, ANL, ANL/ESD-20/4, 2020, p. xv, at https://doi.org/10.2172/1785708.

[38] Ibid.

[39] Ibid, pp. 3-7.

[40] Marty Miller, "While EV Registrations Grow Through the First Half of 2021, Non-Electric Remains Dominant," Experian, October 18, 2021, at https://www.experian.com/blogs/insights/2021/10/ev-registrations-grow-first-half-2021-non-electric-remains-dominant/.

[41] Nedal T. Nassar, Elisa Alonso, and Jamie L. Brainard, Investigation of U.S. Foreign Reliance on Critical Minerals—U.S. Geological Survey Technical Input Document in Response to Executive Order No. 13953 Signed September 30, 2020, U.S. Geological Survey, Open-File Report 2020–1127, 2020, at https://doi.org/ 10.3133/ ofr20201127.

> identifying exactly what the critical sectors of that supply chain are and then identifying each company active in every one of those sectors.[42]

# Critical Mineral Supply for EV Batteries

Industry reports and media coverage often highlight concern over the expected high demand for the minerals used in EV batteries. These concerns are generally focused on the less common materials used in the manufacture of EV battery packs and cells. This section highlights some aspects of supply and demand for five critical minerals whose supply is commonly positioned as potentially at risk for disruption: lithium, cobalt, nickel, manganese, and graphite. The selection of these minerals is based on their current use in EV batteries; new battery chemistries and types (e.g., solid-state batteries) could change future mineral requirements,[43] but are not considered at this time.

The time required to locate an economically suitable mineral deposit, acquiring capital, land, mineral rights, and permits, among other requirements, can take years. The processes to open a mine on private, state, and federal lands can vary considerably. Some legislators and industry organizations are concerned that the length of this process can affect access to mineral inputs for EVs. In a review of the process to open a mine on federal lands, the Government Accountability Office (GAO) found that the time required to reach the "mine plan approval" stage "ranged from about 1 month to over 11 years and averaged approximately 2 years."[44] The Infrastructure Investment and Jobs Act (IIJA, P.L. 117-58) includes provisions in Section 40206 to "improve the quality and timeliness of Federal permitting and review processes with respect to critical mineral production on Federal land."[45]

Different mining processes can be used to extract different minerals. The two most common mining processes are open pit mining (i.e., surface mining) and underground mining; a third mining process involves the extraction of compounds or ions from brines (typically found underground, containing salts of various elements). The characteristics of the mineral deposit usually determine the appropriate mining process. After the ore or mineral substance is mined, additional processing is usually required to produce commodity mineral substances that can be used as inputs to batteries. Common extraction processes include solvent extraction,

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[42] NAATBatt International, "NAATBatt Publishes Database of the North American Lithium-Ion Supply Chain," at https://naatbatt.org/naatbatt-publishes-database-of-the-north-american-lithium-ion-supply-chain/. The database is available from NREL at https://www.nrel.gov/transportation/li-ion-battery-supply-chain-database.html.

[43] Research on new battery chemistries is often driven by concerns over current battery mineral inputs and price; new chemistries adopted by the EV battery market would be expected to be cheaper and based on more common mineral inputs. One example is the ongoing efforts to replace cobalt, given its limited production; see Hao Jia, Xianhui Zhang, and Yaobin Xu, et al., "Toward the Practical Use of Cobalt-Free Lithium-Ion Batteries by an Advanced Ether-Based Electrolyte," *ACS Applied Materials & Interfaces*, vol. 13 (2021), p. 44339–44347. Another example is the effort to replace graphite anodes with silicon, which is cheaper and widely available; see NREL, "Silicon Consortium Project," at https://www.nrel.gov/transportation/silicon-anode-consortium.html.

[44] U.S. Government Accountability Office (GAO), *Hardrock Mining: BLM and Forest Service Have Taken Some Actions to Expedite the Mine Plan Review Process but Could Do More*, GAO-16-165, 2016, p. 13, at https://www.gao.gov/products/gao-16-165. The "mine plan," or "mine operations plan" is a detailed document indicating the mine's facilities, locations of surface disturbances, and required infrastructure, among other specifications. The approval of the mine plan typically would occur after other federal reviews and permits are obtained; state and local requirements may still be pending at the time of approval.

[45] For an overview of mining on federal lands, see CRS Report R46278, *Policy Topics and Background Related to Mining on Federal Lands*, by Brandon S. Tracy.

electrowinning, and smelting, and vary according to the chemical composition of the ore.[46] Some research seeks to reduce the process steps—reducing time and costs—by combining previously separate steps to produce the required battery input.[47]

Each subsection below includes an overview of the indicated mineral. Information presented includes production processes, global deposits, domestic supply situation, demand, and other related topics, including net import reliance (NIR). According to the USGS, "Net import reliance (NIR) is calculated as the amount of imported material (including changes in stockpiles) minus exports and changes in government and industry stocks and is expressed as a percentage of domestic consumption."[48]

NIR may not be readily calculated from the information presented in this report. The USGS definition of NIR conveys what could be a misleading simplicity to calculating NIR. NIR calculations can be somewhat complex, as imports may be used for primary production, consumption, and/or for inputs into production that are subsequently exported. Additionally, there are various production, import, export, and consumption categories used to track mineral flows, potentially adding complexity to the NIR calculation.

The order of the minerals presented starts with cathode minerals: lithium is first, as it is used in all cathodes considered, followed by cobalt, manganese, and nickel. Graphite, the mineral used in the anode, follows the cathode minerals. The subsection "Secondary Mineral Supply" discusses EV battery recycling as a potential supply option available for the five minerals. Each mineral subheading contains information on the element's mineralization and geologic formation. While this information can be quite technical, it can provide a starting point to understanding why some minerals are found in geographically dispersed locations, while others are concentrated in limited locations.[49]

### Table 2. Selected Statistics for Five EV Battery Minerals

In metric tons, unless indicated otherwise

| | Lithium | Cobalt | Manganese | Nickel | Graphite |
|---|---|---|---|---|---|
| NIR (%) | >25 | 76 | 100 | 48 | 100 |
| U.S. Production | withheld | 700 | 0 | 18,000 | 0 |
| Global Production | 100,000 | 170,000 | 20,000,000 | 2,700,000 | 1,000,000 |
| Exports | 1,900 | 4,800 | 1,000 | 25,000 | 8,400 |
| Imports | 2,500 | 9,900 | 460,000 | 110,024 | 53,000 |
| U.S. Reserves | 750,000 | 69,000 | 0 | 340,000 | not indicated |

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[46] For an overview of metallurgy and common extraction processes, see Britannica, "Extractive Metallurgy," at https://www.britannica.com/science/metallurgy/Extractive-metallurgy. A definition of "ore" is "the naturally occurring material from which a mineral or minerals of economic value can be extracted" (USGS, "EarthWord-Ore," at https://www.usgs.gov/communications-and-publishing/news/earthword-ore).

[47] For an example of research on processes that could eliminate steps in lithium hydroxide production by eliminating the current intermediate production step of lithium carbonate, see Mario Grageda, Alonso Gonzalez, and Adrian Quispe, et al., "Analysis of a Process for Producing Battery Grade Lithium Hydroxide by Membrane Electrodialysis," *Membranes*, vol. 10 (2020), Article 198, at https://doi.org/10.3390/membranes10090198.

[48] Steven M. Fortier, Nedal T. Nassar, and Graham W. Lederer, et al., *Draft Critical Mineral List—Summary of Methodology and Background Information—U.S. Geological Survey Technical Input Document in Response to Secretarial Order No. 3359*, U.S. Geological Survey (USGS), Open-File Report 2018-1021, p. 9.

[49] For more information on geology and mineralogy, see Britannica, "Geology," at https://www.britannica.com/science/geology.

| | Lithium | Cobalt | Manganese | Nickel | Graphite |
|---|---|---|---|---|---|
| Global Reserves | 22,000,000 | 7,600,000 | 1,500,000,000 | 95,000,000 | 320,000,000 |

**Source:** USGS, *Mineral Commodity Summaries, 2022*, 2022, at https://doi.org/10.3133/mcs2022.

**Notes:** Values are estimates for 2021. NIR is "net import reliance." The USGS may withhold production data to avoid disclosing company proprietary data. U.S. production does not include secondary production (i.e., production from recycling). Values for manganese imports and exports are gross weights of ores and concentrates, not contained manganese. Nickel import and export values represent the sum of ores, concentrates, and primary production. Additional nickel production from refinery byproducts is withheld. "not indicated": U.S. reserves of graphite are described as "relatively small"; no tonnage is indicated (p. 75).

## Lithium

Lithium (atomic number 3), the lightest of all metallic elements, is highly reactive and is not found in nature in elemental form. Concentration of lithium in the Earth's crust is about 20 parts per million.[50] Lithium has been used in metallurgy, medications, and glass glazing for about 100 years, with more recent uses for military applications, grease, and cosmetics. Lithium has been used in batteries since at least 1935.[51]

Lithium deposits commonly occur in rock formations in minerals (e.g., petalites, lepidolites, spodumene), clays, and in solution in brines (e.g., salars, geothermal systems). According to the U.S. Geological Survey (USGS),

> lithium is extracted from brines that are pumped from beneath arid sedimentary basins and extracted from granitic pegmatite ores. The leading producer of lithium from brine is Chile, and the leading producer of lithium from pegmatites is Australia. Other potential sources of lithium include clays, geothermal brines, oilfield brines, and zeolites.[52]

In 2021, the United States had one lithium brine production operation, the Albemarle's Silver Peak lithium brine operation in Nevada.[53] Additionally, two companies process domestic and imported lithium inputs; USGS withheld domestic lithium production estimates for 2021 to avoid disclosing company proprietary data. Increased demand for lithium has led to increased interest in domestic lithium mining. Some companies have reported plans to begin lithium operations in the United States, including the following examples.

Noram Lithium Corporation, a Canadian company, plans to develop a lithium clay mining operation on federal land in Nevada, one mile from the Albemarle operation. The lithium would be processed near the mine site, and annual production of lithium carbonate is expected to be approximately 6,000 metric tons per year, for an initial period of 40 years.[54]

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[50] Dwight Bradley and Brian Jaskula, *Lithium—For Harnessing Renewable Energy*, USGS, 2014, at http://dx.doi.org/10.3133/fs20143035.

[51] Alessio Miatto, Barbara K. Reck, and James West, et al., "The Rise and Fall of American Lithium," *Resources, Conservation & Recycling*, vol. 162 (2020), Article 105034.

[52] Dwight C. Bradley, Lisa L. Stillings, and Brian W. Jaskula, et al., "Chapter K—Lithium," in *Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply*, USGS, ed. Klaus J. Schulz, John H. DeYoung, Jr., Robert R. Seal II, and Dwight C. Bradley (2017), p. K1, at https://doi.org/10.3133/pp1802K.

[53] Albemarle, "Silver Peak, Nevada," at https://www.albemarle.com/locations/north-america/nevada.

[54] ABH Engineering, *Preliminary Economic Assessment Zeus Project*, 2021, at https://noramlithiumcorp.com/resource/clayton-valley/technical-report/.

An Australian company, ioneer, plans to develop a lithium mine on federal land in Nevada. ioneer indicates that the mine would produce approximately 20,000 metric tons of lithium carbonate over the expected 26-year mine life.[55]

Piedmont Lithium is planning a spodumene mine and lithium hydroxide conversion operation on private land in North Carolina. Piedmont Lithium reports that the combined mine/hydroxide operation would produce 30,000 metric tons of lithium hydroxide per year, for 20 years.[56]

Piedmont Lithium and ioneer have applied for loans via the U.S. Department of Energy's Advanced Technology Vehicles Manufacturing loan program.[57]

BHE Renewables, Controlled Thermal Resources (CTR), and EnergySource Minerals, among other companies, have expressed interest in extracting lithium from geothermal brines.[58] The U.S. Department of Energy is funding a study of the potential to extract lithium from the geothermal brines in the Salton Sea region in California. Initial estimates of the lithium contained in the region indicate one of the largest global resources; however, it is not yet technologically or economically viable to extract the lithium.[59] Research considering the potential role of lithium production from geothermal brines states

> Li extraction from geothermal brines has captured substantial attention because it taps into waste brine after being used for power generation and makes use of existing geothermal facilities to lower production costs.... Electricity is generated from geothermal by using the heat from hot brine to make steam that spins a turbine. The brine is then pumped back into the ground through the injection well. Obtaining Li from the brine, before cycling back into the ground, would be a means to offset these capital costs and make electricity generation from geothermal more cost-effective.[60]

Imports of lithium during 2021 are estimated to be 2,500 metric tons, and lithium exports in 2021 are estimated to be 1,900 metric tons. NIR on lithium was calculated to be greater than 25% in 2021.[61] During the period 2017-2020, Argentina was the largest supplier of U.S. lithium imports (54%). For 2021, Australia is estimated to have the highest worldwide mineral production of lithium (55,000 metric tons); total global production is estimated to be 100,000 metric tons.[62]

The price per metric ton of lithium carbonate averaged $17,000 in 2021, which tied with 2018 for the highest price in the last five years. Lithium's lowest price in the last five years was $8,000 per metric ton in 2020.[63]

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[55] ioneer, "Rhyolite Ridge Definitive Feasibility Study (DFS)," at https://www.ioneer.com/rhyolite-ridge/dfs-summary.

[56] Piedmont Lithium, *Piedmont Lithium 2021 Annual Report*, 2021, p. 23, at https://piedmontlithium.com/investors/company-reports/.

[57] "ioneer Says US Government Loan Application Moves Forward," *Reuters*, December 20, 2021, at https://www.mining.com/web/ioneer-says-us-government-loan-application-moves-forward/.

[58] White House, "FACT SHEET: Securing a Made in America Supply Chain for Critical Minerals," press release, February 22, 2022, at https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/22/fact-sheet-securing-a-made-in-america-supply-chain-for-critical-minerals/.

[59] Valentina Ruiz Leotaud, "New Project to Investigate If California's Lithium Valley Is World's Largest Brine Source of Lithium," *Mining.com*, February 20, 2022, at https://www.mining.com/new-project-to-investigate-if-californias-lithium-valley-is-the-worlds-largest-brine-source-of-lithium/.

[60] Ange-Lionel Toba, Ruby Thuy Nguyen, and Carson Cole, et al., "U.S. Lithium Resources from Geothermal and Extraction Feasibility," *Resources, Conservation & Recycling*, vol. 169 (2021), Article 105514, pp. 1-2.

[61] USGS, *Mineral Commodity Summaries, 2022*, 2022, p. 100, at https://doi.org/10.3133/mcs2022.

[62] Ibid., p. 101.

[63] Ibid., p. 100.

## Cobalt

Cobalt (atomic number 27), "is a silvery gray metal that has diverse uses based on certain key properties, including ferromagnetism, hardness and wear-resistance when alloyed with other metals, low thermal and electrical conductivity, high melting point, multiple valences, and production of intense blue colors when combined with silica."[64] Concentration of cobalt in the Earth's crust is about 10 parts per million.[65] Cobalt is used in many applications, including batteries, superalloys, cutting tools, magnetic alloys, animal feed additives, bonding agents, industrial catalysts, drying agents for paint, and glass decolorizers, among others.[66]

Cobalt deposits are found in various geologic formations and minerals; mineral deposits containing cobalt can include sulfides found in igneous rocks, and sulfides and oxides found in sedimentary rocks. Some sea floor nodules and crusts are known to contain cobalt.[67] One study of cobalt ores and metallurgy states

> The bulk of world cobalt output usually arises as a by-product of extracting other metals, mostly nickel (Ni) and copper (Cu), from a wide variety of deposit types mostly Cu-Co sediment-hosted deposits, but also Ni-Co laterites, Ni-Cu-Co sulphides or hydrothermal and volcanogenic deposits. Significant differences in ore properties (geochemistry, mineralogy, alteration and physical properties) exist between cobalt-containing deposits, as well as within a single deposit, which can host a range of ore types. Variability of cobalt ores makes it challenging to develop a single extraction or treatment process that will be able to accommodate all geometallurgical variation. Overall, there is a lack of fundamental knowledge on cobalt minerals and their processability. The recovery efficiency for cobalt is generally low, in particular for processes involving flotation and smelting, leading to significant cobalt losses to mine tailings or smelter slags.[68]

In 2021, Eagle Mine in Michigan was the only domestic mining operation producing ore containing cobalt. The cobalt occurs in minor quantities in the mine's ore, which is mined for its nickel and copper content; the mineral reserves contain an estimated total of 4.2 metric tons of cobalt.[69] Another operation, United States Strategic Metals (formerly Missouri Cobalt), produces a cobalt concentrate from mine tailings. One report indicates that United States Strategic Metals plans to install a hydrometallurgical facility for production of battery-grade cobalt and nickel.[70]

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[64] John F. Slack, Bryn E. Kimball, and Kim B. Shedd, "Chapter F—Cobalt," in *Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply*, USGS, ed. Klaus J. Schulz, John H. DeYoung, Jr., Robert R. Seal II, and Dwight C. Bradley (2017), p. F1, at https://doi.org/10.3133/pp1802F. Ferromagnetism is the "physical phenomenon in which certain electrically uncharged materials strongly attract others" (Britannica, "Ferromagnetism," at https://www.britannica.com/science/ferromagnetism).

[65] Ibid., p. F6.

[66] Ibid., pp. F1-F2.

[67] Ibid., p. F1.

[68] Quentin Dehaine, Laurens T. Tijsseling, and Hylke J. Glass, et al., "Geometallurgy of Cobalt Ores: A Review," *Minerals Engineering*, vol. 160 (2021), Article 106656, p. 1. For more information on cobalt reserves, mining, and its recovery rate, see Wouter Heijlen, Guy Franceschi, and Chris Duhayon, et al., "Assessing the Adequacy of the Global Land-Based Mine Development Pipeline in the Light of Future High-Demand Scenarios: The Case of the Battery-Metals Nickel (Ni) and Cobalt (Co)," *Resources Policy*, vol. 73 (2021), p. 102202.

[69] Lundin Mining Corporation, *Technical Report on the Eagle Mine, Michigan, USA*, Technical Report NI 43-101, 2017, at https://lundinmining.com/site/assets/files/3640/2017-04-26-eagle-ni-43-101.pdf, p. 1-3.

[70] Jeff Lewis, "Exclusive: U.S. Nickel-Cobalt Miner Missouri Cobalt Hires Bank to Go Public Through SPAC," *Reuters*, June 18, 2021, at https://www.reuters.com/article/us-usa-mining-missouricobalt-exclusive/exclusive-u-s-nickel-cobalt-miner-missouri-cobalt-hires-bank-to-go-public-through-spac-idUSKCN2DU23A.

The USGS indicates that approximately 70% of domestic production of cobalt is from recycling. Total domestic cobalt production during 2021 is estimated to be 2,300 metric tons.[71] Imports of cobalt during 2021 are estimated to be 9,900 metric tons, and cobalt exports in 2021 are estimated to be 4,800 metric tons. NIR on cobalt was calculated to be 76%. During the period 2017-2020, Norway was the largest supplier of U.S. cobalt imports (20%). For 2021, Democratic Republic of Congo is estimated to have the highest worldwide mineral production of cobalt (120,000 metric tons); total global production is estimated to be 170,000 metric tons.[72]

The price of cobalt averaged $22 per pound in 2021. The highest price for cobalt in the last five years was $32.94 per pound in 2018, and cobalt's lowest price in the last five years was $14.21 per pound in 2020.[73]

## Manganese

Manganese (atomic number 25), has an average concentration in the Earth's crust of around 1,000 parts per million, with concentrations varying greatly among different types of rocks.[74] According to the USGS, "manganese is ubiquitous in soil, water, and air. It occurs most often in solid form but can become soluble under acidic conditions."[75] The USGS also notes

> [M]anganese is used predominantly as an alloying addition in steel ... [and] in refining iron ore to metallic iron prior to the steelmaking process. Manganese has no known substitutes in the overall conversion of iron ore to steel.... Steel and cast iron production together provide the largest market for manganese (historically accounting for 77 to 90 percent of manganese consumption in the United States), although manganese is also used as an alloy with nonferrous metals, such as aluminum and copper.
>
> Nonmetallurgical applications of manganese include battery cathode production ...; soft ferrites ... used in electronics; micronutrient additives in fertilizers and animal feed ...; water treatment chemicals ...; and other chemicals.... [76]

Some economically viable deposits of manganese ores formed in the oxygen-depleted waters of the deep oceans, while others formed in shallow ocean basins. Less common are economically viable deposits formed on or under surface lands in oxygen-poor conditions, such as in deep tropical soils.[77] Manganese is also known to exist on ocean floors as nodules or crusts. According to the USGS,

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[71] USGS, *Mineral Commodity Summaries, 2022*, 2022, p. 52, at https://doi.org/10.3133/mcs2022. For additional information on by-production or co-production of cobalt from copper ores, see Wouter Heijlen, Guy Franceschi, and Chris Duhayon, et al., "Assessing the Adequacy of the Global Land-Based Mine Development Pipeline in the Light of Future High-Demand Scenarios: The Case of the Battery-Metals Nickel (Ni) and Cobalt (Co)," *Resources Policy*, vol. 73 (2021).

[72] Ibid., pp. 52-53. Due to the prominent production of cobalt in the Democratic Republic of the Congo, cobalt is frequently considered a "conflict mineral"; for more information on conflict minerals, see CRS Report R42618, *Conflict Minerals in Central Africa: U.S. and International Responses*, by Nicolas Cook.

[73] Ibid., p. 52.

[74] William F. Cannon, Bryn E. Kimball, and Lisa A. Corathers, "Chapter L—Manganese," in *Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply*, USGS, ed. Klaus J. Schulz, John H. DeYoung, Jr., Robert R. Seal II, and Dwight C. Bradley (2017), p. L4, at https://doi.org/10.3133/pp1802L.

[75] Ibid., p. L1.

[76] Ibid., p. L2.

[77] Ibid., pp. L6-L9.

> The amount of manganese in known nodule fields dwarfs that found in traditional continental deposits, but its availability as a source of ore is uncertain in the near term. Considerable technological issues of mining at abyssal depths in the oceans, the economic competitiveness of seabed mining versus traditional mining, and legal issues of ownership and control of resources in international waters are still being addressed.[78]

The United States does not produce manganese ore, and it does not have any known economically viable reserves. Manganese ore was last produced in the United States in 1970. Six companies utilize imported manganese inputs. Manganese imports and exports are often reported in three different commodity categories, including ores/concentrates, ferromanganese, and silicomanganese. NIR was 100% during each of the last five years. During the period 2017-2020, Gabon, Australia, and Georgia were predominant suppliers of various types of U.S. manganese imports. For 2021, South Africa is estimated to have the highest worldwide mineral production of manganese (7.4 million metric tons); total global production is estimated to be 20 million metric tons.[79]

The price per metric ton of manganese averaged $5.20 in 2021. The highest price for manganese in the last five years was $7.16 per metric ton in 2018, and its lowest price was $4.59 per metric ton in 2020.[80]

## Nickel

Nickel (atomic number 28), is found in the Earth's upper continental crust at an approximate average concentration of 44 parts per million.[81] Nickel is primarily used in stainless steel; nickel is also used in alloys (for its resistance to corrosion), coinage, plating, chemicals, and batteries.[82]

Nickel can be found in different ore types. According to the USGS,

> The bulk of the nickel mined comes from two types of ore deposits: laterites where the principal ore minerals are nickeliferous limonite ... and garnierite (a hydrous nickel silicate), or magmatic sulfide deposits where the principal ore mineral is pentlandite.... Nickel sulfide deposits are generally associated with iron- and magnesium-rich rocks called ultramafics and can be found in both volcanic and plutonic settings. Many of the sulfide deposits occur at great depth. Laterites are formed by the weathering of ultramafic rocks and are a near-surface phenomenon.[83]

The United States has one mining operation that produces a nickel concentrate, Eagle Mine owned by Lundin Mining in Michigan. Ore containing nickel and copper from Eagle Mine is trucked to the Humboldt mill, where it is processed into separate concentrates; the concentrates are exported for additional processing.[84] Eagle Mine has indicated and inferred nickel resources of 177,900 metric tons.[85] The USGS also reports that the United States has one operation

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[78] Ibid., p. L10.

[79] USGS, *Mineral Commodity Summaries, 2022*, 2022, pp. 106-107, at https://doi.org/10.3133/mcs2022.

[80] Ibid., p. 106.

[81] Scott McLennan, "Relationships Between the Trace Element Composition of Sedimentary Rocks and Upper Continental Crust," *Geochemistry Geophysics Geosystems*, vol. 2 (2001).

[82] USGS, "Nickel Statistics and Information," at https://www.usgs.gov/centers/national-minerals-information-center/nickel-statistics-and-information.

[83] Ibid.

[84] Lundin Mining, "Eagle," at https://lundinmining.com/operations/eagle/.

[85] Lundin Mining Corporation, *Technical Report on the Eagle Mine, Michigan, USA*, Technical Report NI 43-101, 2017, at https://lundinmining.com/site/assets/files/3640/2017-04-26-eagle-ni-43-101.pdf, p. 1-3.

recovering nickel from mine tailings, and one smelting operation producing some nickel products.[86]

Total domestic nickel mining production during 2021 is estimated to be 18,000 metric tons; USGS withheld additional byproduct production values to avoid disclosing company proprietary data. Nickel imports during 2021 are estimated to be 145,024 metric tons. Exports of nickel in 2021 are estimated to be 54,000 metric tons. NIR was 48% in 2021, the lowest in the last five years; the highest NIR was 52% in 2018. During the period 2017-2020, Canada was the largest supplier of various types of U.S. nickel imports. For 2021, Indonesia is estimated to have the highest worldwide mineral production of nickel (1 million metric tons); total global production is estimated to be 2.7 million metric tons.[87]

The price per metric ton of nickel averaged $18,000 in 2021, which was the highest price in the last five years. Nickel's lowest price in the last five years was $10,403 per metric ton in 2017.[88]

## Graphite (Carbon)

Carbon (atomic number 12) can occur naturally as—or be transformed into—a crystalline structure called graphite. Natural graphite and synthetic graphite are forms of pure carbon.[89] Carbon has an estimated crustal concentration between 180 and 270 parts per million, and it can occur as carbonate minerals (80%-90%), dissolved in the atmosphere and oceans, and in living or fossilized organisms. Natural graphite is estimated to be less than 0.5% of the crustal concentration of carbon.[90]

Graphite forms include fine powders, flakes, and lumps. Natural graphite is commonly grouped into three commercial commodities or categories, based on crystallinity, grain size, and morphology. The three commodity categories of graphite are amorphous, crystalline (flake), and crystalline (lump or chip). Synthetic graphite can be manufactured for use in any of these commodity groups. Graphite is used in many applications, including electronics, lubricants, metallurgy, steelmaking, fuel cells, batteries, and lightweight high-strength composite applications. Natural graphite is typically used in most applications, including EV batteries, due to its cost advantage; the price of synthetic graphite can be multiples of the price of natural graphite.[91]

Graphite can be found in different ore types. According to the USGS,

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[86] USGS, *Mineral Commodity Summaries, 2022*, 2022, p. 114, at https://doi.org/10.3133/mcs2022.

[87] USGS, *Mineral Commodity Summaries, 2022*, 2022, pp. 114-115, at https://doi.org/10.3133/mcs2022.

[88] Ibid., p. 114.

[89] For more information on synthetic graphite and how it can be produced from coal, see Ming Shi, Changlei Song, and Zige Tai, et al., "Coal-Derived Synthetic Graphite with High Specific Capacity and Excellent Cyclic Stability as Anode Material for Lithium-Ion Batteries," *Fuel*, vol. 292 (2021), Article 120250. Another overview of synthetic graphite is provided by a synthetic graphite manufacturer; see Asbury Carbons, "Synthetic Graphite," at https://asbury.com/resources/education/science-of-graphite/synthetic-graphite/.

[90] Gilpin R. Robinson, Jr., Jane M. Hammarstrom, and Donald W. Olson, "Chapter J—Graphite," in *Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply*, USGS, ed. Klaus J. Schulz, John H. DeYoung, Jr., Robert R. Seal II, and Dwight C. Bradley (2017), p. J5, at https://doi.org/10.3133/pp1802F.

[91] Ibid., pp. J1-J2.

> Natural graphite is mined from deposits in metamorphic rocks, such as marble, schist, and gneiss, and from accumulations in vein deposits. Natural graphite typically forms as a result of metamorphism ... of accumulations of organic matter in sedimentary rocks.[92]
>
> Thermally metamorphosed coal is the usual source of amorphous graphite. Disseminated crystalline flake graphite is mined from carbonaceous metamorphic rocks, and lump or chip graphite is mined from veins in high-grade metamorphic regions.[93]

According to USGS, the United States did not mine any natural graphite in 2021, and no mineral reserves are indicated.[94] One company, Graphite One, reports plans to develop an integrated natural graphite mine and extraction facility on 28,160 acres of state lands in Alaska.[95] Another company, Westwater Resources, reports plans to develop an integrated natural graphite mine and extraction facility on 41,965 acres of private land in Alabama.[96]

The USGS indicates that recycling graphite is feasible, but low prices and ample supply limit recycling activities; information on domestic recycling is not available.[97] A report from the Bureau of Mines in 1994 describes

> a processing method developed by the U.S. Bureau of Mines to produce high quality flake graphite from the steelmaking waste known as kish.... It is estimated that the graphite content of kish discarded by U.S. steel plants is more than sufficient to meet the total U.S. demand for flake graphite. That need is now filled by natural graphite from foreign sources.[98]

Imports of natural graphite during 2021 are estimated to be 53,000 metric tons, and natural graphite exports in 2021 are estimated to be 8,400 metric tons. NIR on natural graphite was calculated to be 100%. During the period 2017-2020, China was the largest supplier of U.S. natural graphite imports (33%). For 2021, China is estimated to have the highest worldwide production of natural graphite (820,000 metric tons); total global production is estimated to be 1,000,000 metric tons.[99]

The price of natural graphite flake, which represented 57% of imports in 2021, averaged $1,600 per ton in 2021. This was the highest price for natural graphite flake in the last five years. The lowest price in the last five years for natural graphite flake was $1,350 per ton in 2019.[100]

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[92] Ibid., p. J3.

[93] Ibid., p. J1.

[94] USGS, *Mineral Commodity Summaries, 2022*, 2022, pp. 74-75, at https://doi.org/10.3133/mcs2022.

[95] Natalie King, Chris Valorose, and William Ellis, *2019 NI 43-101 Mineral Resource Update for Graphite Creek, Seward Peninsula, Alaska, USA*, Alaska Earth Sciences, Inc., 2019, p. 18 (available among company associated documents hosted by Sedar, at https://www.sedar.com/DisplayCompanyDocuments.do?lang=EN&issuerNo=00025247).

[96] WestWater Resources, *Coosa Graphite Project Business Plan*, 2020, p. 88, at http://westwaterresources.net/wp-content/uploads/2021/01/Westwater-Resources-Business-Plan-October-2020-public-V10.pdf.

[97] USGS, *Mineral Commodity Summaries, 2022*, 2022, p. 74, at https://doi.org/10.3133/mcs2022.

[98] P. D. Laverty, L. J. Nicks, and L. A. Walters, *Recovery of Flake Graphite From Steelmaking*, U.S. Department of the Interior, Bureau of Mines, Report of Investigations 9512, 1994, p. 1, at https://stacks.cdc.gov/view/cdc/10221/cdc_10221_DS1.

[99] USGS, *Mineral Commodity Summaries, 2022*, 2022, pp. 74-75, at https://doi.org/10.3133/mcs2022.

[100] Ibid., p. 74.

## Secondary Mineral Supply

Secondary mineral supply includes supply paths for minerals from sources other than mining, namely from recycling. The minerals contained in EV batteries could be extracted and reused (i.e., recycled) for new batteries, if the process is economically viable.[101] The growing number of EV batteries expected to reach their end of life (EOL) represents opportunities and challenges. Domestically, 200,000 metric tons of EV batteries are expected to reach EOL by 2027, or 800,000 metric tons globally that year, with accelerating growth as EV penetrate vehicle markets.[102] An EV battery that has reached its EOL may be suitable for applications other than in a vehicle; such uses are commonly called "second life" uses.

Conceptually, the steps involved in recycling the minerals in EV batteries can be grouped as follows: collection, separation, and extraction.[103] The collection step involves physically aggregating batteries that have reached the end of their useful life. This step requires that the battery be removed from the vehicle, and that it be transported to the battery recycling facility; transporting lithium-ion batteries can be dangerous and is often regulated.[104] The separation step involves physical separation of the battery components through mechanical grinding or shredding of the entire EV battery. Once ground, the cathode and anode material (commonly called black mass) can be separated from plastics, copper, aluminum, and other materials. The extraction step involves pyrometallurgy and/or hydrometallurgy to chemically extract the targeted mineral(s) from the battery cell material.[105]

Some groups have noted some of the challenges and opportunities related to recycling of EV batteries and of the minerals they contain.[106] One review of the literature on these challenges and opportunities notes that

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[101] Examples of studies of recycling the following minerals from EV batteries include, for all five minerals: Chengetai Portia Makwarimba, Minghui Tang, and Yaqi Peng, et al., "Assessment of Recycling Methods and Processes for Lithium-Ion Batteries," *iScience*, vol. 25 (2022), Article 104321; for cobalt and nickel: Guillermo Alvial-Hein, Harshit Mahandra, and Ahmad Ghahreman, "Separation and Recovery of Cobalt and Nickel from End of Life Products via Solvent Extraction Technique: A Review," *Journal of Cleaner Production*, vol. 297 (2021), Article 126592; for manganese: Xin Sun, Han Hao, and Zongwei Liu, et al., "Insights into the Global Flow Pattern of Manganese," *Resources Policy*, vol. 65 (2020), Article 101578; for graphite: Qian Cheng, Barbara Marchetti, and Xuanyi Chen, et al., "Separation, Purification, Regeneration and Utilization of Graphite Recovered from Spent Lithium-Ion Batteries—A Review," *Journal of Environmental Chemical Engineering*, vol. 10 (2022), Article 107312.

[102] Qiang Dai, Jeffrey Spangenberger, and Shabbir Ahmed, et al., *EverBatt: A Closed-Loop Battery Recycling Cost and Environmental Impacts Model*, ANL, ANL-19/16, 2019, at https://doi.org/10.2172/1530874.

[103] These generalized steps apply to commercially available recycling operations. Direct recycling of EV batteries, which maintains the cathode and anode material intact (i.e., chemical extraction of the minerals is not needed), is technically feasible but no examples of commercial use can be identified. For more information on the processes used to recycle EV batteries, see Chengetai Portia Makwarimba, Minghui Tang, and Yaqi Peng, et al., "Assessment of Recycling Methods and Processes for Lithium-Ion Batteries," *iScience*, vol. 25 (2022), Article 104321.

[104] For example, the U.S. Department of Transportation regulates lithium-ion batteries as a hazardous material (Pipeline and Hazardous Materials Safety Administration, "Transporting Lithium Batteries," at https://www.phmsa.dot.gov/lithiumbatteries).

[105] For more information on technical and environmental aspects of industrial processes available to recycle minerals from EV batteries, see Mohammad Abdelbaky, Lilian Schwich, and Eleonora Crenna, et al., "Comparing the Environmental Performance of Industrial Recycling Routes for Lithium Nickel-Cobalt-Manganese Oxide 111 Vehicle Batteries," *Procedia CIRP*, vol. 98 (2021), pp. 97-102.

[106] For a discussion of the recycling of various metals, see IEA, *The Role of Critical Minerals in Clean Energy Transitions*, 2021, pp. 175-180; and Kirsten Hund, Daniele La Porta, and Thao P. Fabregas, et al., *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition*, World Bank Group, 2020, p. 63, at https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-

> various process combinations of mechanical, pyrolytic and hydrometallurgical recycling techniques are possible to improve metal separation from polymer battery components.... All reports stressed the importance to consider the entire product life cycle and value chain of LIBs [lithium-ion batteries]: from battery design and manufacturing to waste collection and recycling.[107]

Noting the overall battery life cycle in conjunction with possible recycling processes highlights the role of economic viability: even if technologies exist that *can* extract minerals from recycled batteries, only those that are economically viable *will* be employed. The economic viability of recycling battery minerals can be affected by the battery pack's design: if the pack is difficult (i.e., expensive) to disassemble, shred, or process, or if disassembling the pack generates costly waste streams, the overall costs of recycling may exceed the revenues expected from the process, rendering the overall process uneconomical.[108] Alternatively, a battery pack optimized for recycling could be too expensive to compete with other designs.[109]

In addition to recycling lithium-ion batteries, cobalt, nickel, manganese, and graphite could be recycled from other products and directed towards EV battery manufacturing. Lithium, however, does not offer expected opportunities for recycling from sources other than batteries, as other uses of lithium, such as in ceramic glazing and glass manufacturing, do not readily lend themselves to recycling.[110]

The current varied uses of nickel, with its primary use in metal alloys, suggest that recycling could contribute to sources of nickel for future battery inputs. The Nickel Institute promotes nickel's high efficiency in recycling processes, and it highlights further opportunities for recycling: 17% of nickel is currently destined to landfills.[111] Cobalt consumption, while more concentrated in batteries than nickel, also offers sources of battery inputs from recycled products. Solvent extraction is commonly used to recover nickel and cobalt from battery materials, and its use could be expanded to recover these elements from other waste products.[112] Research into

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Clean-Energy-Transition. For a discussion of some EV battery recycling policies in various countries, see IEA, *Global EV Outlook 2022*, 2022, pp. 161-66.

[107] Stefan Windisch-Kern, Eva Gerold, and Thomas Nigl, et al., "Recycling Chains for Lithium-Ion Batteries: A Critical Examination of Current Challenges, Opportunities and Process Dependencies," *Waste Management*, vol. 138 (2022), p. 126.

[108] For a study that "has looked at 44 commercial [lithium-ion battery] recyclers and assessed their recycling and reclamation processes," see Roberto Sommerville, Pengcheng Zhu, and Mohammad Ali Rajaeifar, et al., "A Qualitative Assessment of Lithium Ion Battery Recycling Processes," *Resources, Conservation & Recycling*, vol. 165 (2021), Article 105219, p. 1. For a study of the "a need to develop technology to enable a resource-efficient and economically feasible recycling system for lithium-ion batteries and ... compares these [recycling] processes on technical and economic bases," see Linda Gaines, *Lithium-Ion Battery Recycling Processes: Research Towards a Sustainable Course*, ANL, 2018, at https://doi.org/10.1016/j.susmat.2018.e00068. For a life cycle analysis of lithium-ion battery recycling, see Mohammad Abdelbaky, Lilian Schwich, and Eleonora Crenna, et al., "Comparing the Environmental Performance of Industrial Recycling Routes for Lithium Nickel-Cobalt-Manganese Oxide 111 Vehicle Batteries," *Procedia CIRP*, vol. 98 (2021), pp. 97-102.

[109] An example of a federally funded research consortium in DOE's Vehicle Technologies Office is the ReCell Center, which is targeting an "economic and environmentally sound recycling process that can be adopted by industry for lithium-ion and future battery chemistries," (ReCell Center, "About," at https://recellcenter.org/about/).

[110] Alessio Miatto, Barbara K. Reck, and James West, et al., "The Rise and Fall of American Lithium," *Resources, Conservation & Recycling*, vol. 162 (2020), Article 105034, p. 5.

[111] "Nickel Recycling," Nickel Institute, at https://nickelinstitute.org/policy/nickel-life-cycle-management/nickel-recycling/.

[112] Guillermo Alvial-Hein, Harshit Mahandra, and Ahmad Ghahreman, "Separation and Recovery of Cobalt and Nickel from End of Life Products via Solvent Extraction Technique: A Review," *Journal of Cleaner Production*, vol. 297 (2021), Article 126592.

methods beyond solvent extraction demonstrates that adsorption-based methods could be viable for the recovery of nickel from some recycled material leachates.[113] EVs, excluding their batteries, also represent a source of recyclable materials for potential inputs to EV batteries given the use of various metal alloys, which can include nickel and manganese, among other elements.[114]

Generally, manganese is not currently recycled from non-battery products, other than through the recycling of iron and steel scrap: when iron and steel scrap are recycled, any contained manganese is also recycled. One study of global manganese production notes "Owing to the low manganese content of non-alloy and non-battery applications, it is not feasible to recover manganese from them."[115]

The USGS notes that graphite can be and is recycled from various products, but it is not currently recycled from kish (a waste product from steelmaking).[116] Some research highlights process improvements that would facilitate the use of graphite recycled from aluminum smelters in EV battery anodes.[117] Other research highlights potential improvements in the process to recycle graphite from refractory bricks used in steelmaking.[118]

# Legislative Topics Related to EV Battery Minerals

Other sections of this report focus on five critical minerals used in currently available EV batteries. In the discussion of legislative options, these five minerals are not distinguished: the options could be applied to any mineral of interest to Congress.

Congress has options to support or enhance the production of some domestic minerals for use in EV batteries, as some minerals used in EV batteries are not currently being produced domestically. Some options Congress could consider include enhancing mapping of domestic mineral resources; increasing mining on federal lands; tax incentives and import tariffs to enhance domestic mineral production; and funding of private and public research or production, among others.

Other options could focus on increasing access to critical minerals not available domestically, including diplomacy initiatives, seabed mining in international waters, and federal or private acquisition of foreign deposits. Congress could consider options that encourage or discourage the adoption of EVs, which could alter demand for the critical minerals used in EV batteries.[119] These options are not discussed further in this report.

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[113] Funmilola Odegbemi, Gideon A. Idowu, and Albert O. Adebayo, "Nickel Recovery from Spent Nickel-Metal Hydride Batteries Using LIX-84I-Impregnated Activated Charcoal," *Environmental Nanotechnology, Monitoring & Management*, vol. 15 (2021), Article 100452.

[114] Ben Jones, Robert J.R. Elliott, and Viet Nguyen-Tien, "The EV Revolution: The Road Ahead for Critical Raw Materials Demand," *Applied Energy*, vol. 280 (2020), Article 115072.

[115] Xin Sun, Han Hao, and Zongwei Liu, et al., "Insights into the Global Flow Pattern of Manganese," *Resources Policy*, vol. 65 (2020), Article 101578, p. 6.

[116] USGS, *Mineral Commodity Summaries, 2022*, 2022, p. 74, at https://doi.org/10.3133/mcs2022.

[117] Thomas J. Robshaw, Daniel Atkinson, and Jonathan R. Howse, et al., "Recycling Graphite from Waste Aluminium Smelter Spent Pot Lining into Lithium-Ion Battery Electrode Feedstock," *Cleaner Production Letters*, vol. 2 (2022), Article 100004.

[118] Liesbeth Horckmans, Peter Nielsen, and Philippe Dierckx, et al., "Recycling of Refractory Bricks Used in Basic Steelmaking: A Review," *Resources, Conservation & Recycling*, vol. 140 (2019), pp. 297-304.

[119] Two examples of provisions enacted to encourage adoption of EVs can be found in the Infrastructure Investment

## Enhanced Domestic Geological Mapping Efforts

Enhanced geological mapping, which can employ technologies such as geophysical mapping (the mapping of surface and subsurface materials), geospatial mapping (three-dimensional geological mapping), or updating prior geological studies, can provide more information on potential mineral deposits. This information can be used to more efficiently target mineral exploration efforts. The use of federal resources to provide increased knowledge of mineral resources may reduce the cost of some mineral exploration steps by private companies seeking new deposits. Use of federal resources for these activities could be seen as benefitting mining companies rather than the public, as the information gathered can reduce their exploration costs. However, these mapping activities could lead to the discovery of mineral deposits on private lands, and can provide non-mineral related benefits by also providing information on groundwater resources and geologic hazards.[120]

Some bills introduced in the 117th Congress would promote enhanced geological mapping of domestic mineral resources.[121] Congress included some of the provisions in these bills in the Infrastructure Investment and Jobs Act (IIJA, P.L. 117-58).[122] For example, Section 40201 of the IIJA establishes the Earth Mapping Resources Initiative within the USGS, with the purpose of accelerating efforts to provide integrated topographic, geologic, geochemical, and geophysical mapping, among other actions.[123] Provisions in this section prioritize critical minerals in this program and require data collection on abandoned mine waste sites. Appropriations totaling $320 million for fiscal years 2022 through 2026 for this section are provided by Division J, Title VI. Section 40202 of the IIJA amends the National Geologic Mapping Act of 1992 (P.L. 102-285) to establish an abandoned mine land and waste component within the USGS's National Cooperative Geologic Mapping Program, among other actions.

## Mining on Federal Lands

Mining on federal lands is a topic often mentioned in regards to domestic supply of critical minerals.[124] The federal mineral estate covers 712 million acres, approximately 30% of the total domestic surface area (2.4 billion acres).[125] Not all of the federal mineral estate is open to mineral

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and Jobs Act (IIJA, P.L. 117-58), including Section 11401, "Grants for Charging and Fueling Infrastructure," which establishes a grant program for the installation of EV charging stations and other vehicle refueling stations; and Section 71101, "Clean School Bus Program," which establishes a grant program to replace existing school buses with electric school buses or school buses using specified alternative fuel types.

[120] Warren Day, *The Earth Mapping Resources Initiative (Earth MRI): Mapping the Nation's Critical Mineral Resources*, U.S. Geological Survey, Fact Sheet 2019–3007, 2019, at https://doi.org/10.3133/fs20193007.

[121] For example, see the following bills introduced in the 117th Congress: H.R. 2153, Securing American Leadership in Science and Technology Act of 2021; H.R. 2225, National Science Foundation for the Future Act; H.R. 2637, American Critical Mineral Independence Act of 2021; and S. 381, National Ocean Exploration Act.

[122] For more information on these and related sections in the Infrastructure Investment and Jobs Act, see CRS Report R47034, *Energy and Minerals Provisions in the Infrastructure Investment and Jobs Act (P.L. 117-58)*, coordinated by Brent D. Yacobucci. For more information on the USGS provisions in the IIJA and USGS activities, congressional clients can contact Anna Normand.

[123] For more information on the Earth Mapping Resources Initiative, see USGS, "Earth Mapping Resources Initiative (Earth MRI)," at https://www.usgs.gov/special-topics/earth-mri.

[124] For an overview of mining on public lands, see CRS Report R46278, *Policy Topics and Background Related to Mining on Federal Lands*, by Brandon S. Tracy.

[125] U.S. Department of the Interior (DOI), *Public Land Statistics 2020*, vol. 205, 2021, pp. 1-8, at https://www.blm.gov/sites/blm.gov/files/docs/2021-08/PublicLandStatistics2020.pdf.

entry (i.e., new mining operations), and economically viable mineral deposits are not necessarily found on these lands. When mining of non-leasable minerals occurs on public domain lands, mineral production is not reported to the federal government.[126]

Some Members of Congress note the potential importance of increasing mineral production on federal lands as a means of addressing the supply of some critical minerals, including some of those needed for EV batteries.[127] Others note that the General Mining Law of 1872, which covers mining of non-leasable minerals on public lands, does not provide a fair return to American citizens, as the law does not authorize collection of royalties on the extraction of these minerals.[128] For critical mineral mining operations, Section 40206 of the IIJA includes provisions seeking to complete the federal permitting and review process with maximum efficiency and effectiveness.[129]

## Tax Incentives and Import Tariffs for Domestic Mineral Production

One potential option to increase domestic mineral production could be to reduce taxes assessed on related commercial activities. Investments in sectors with high initial costs, such as mines and ore refining operations, may be accelerated if tax incentives allow for earlier expected profitability. An example of this in current law is the percentage depletion allowance, where taxpayers are allowed a depletion deduction that is a percentage of gross revenue.[130] The percentage depletion rate is 22% for lithium, cobalt, manganese, nickel, and graphite. Other tax incentives could include tax credits for capital investments or special treatment allowing for accelerated depreciation.[131]

Another legislative option to potentially increase domestic critical mineral production could include imposition of a federal excise tax (i.e., a tariff) on targeted imported critical minerals or on targeted products containing critical minerals. Use of excise taxes can be challenging due to

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[126] For a comparison between locatable and leasable mining operations on federal lands, see GAO, *Federal Land Management: Key Differences and Stakeholder Views of the Federal Systems Used to Manage Hardrock Mining*, GAO-21-299, 2021, at https://www.gao.gov/products/gao-21-299.

[127] For examples of introduced legislation, see H.R. 2604, Accessing America's Critical Minerals Act of 2021, and H.R. 2637, American Critical Mineral Independence Act of 2021. Another example includes a letter sent from all Republicans on the Senate Energy and Natural Resources Committee to the President, including the recommendation to "expedite the approval of domestic mines, including mines on federal lands, which would produce critical minerals.... " (United States Senator for Alaska Lisa Murkowski, "ENR Republicans to Biden: Restore America's Energy Dominance," press release, March 2, 2022, at https://www.murkowski.senate.gov/press/release/enr-republicans-to-biden-restore-americas-energy-dominance).

[128] The Mineral Leasing Act of 1920 covers the leasing of coal, oil, natural gas, and certain other minerals (codified at 30 U.S.C. §§181 et seq.). If minerals indicated in the Mineral Leasing Act of 1920 are found on certain acquired federal lands, they are covered by the Mineral Leasing Act for Acquired Lands (codified at 30 U.S.C. §§351 et seq.). Minerals not covered by these mineral leasing laws may be subject to leasing if they are found on certain federal lands (see 43 C.F.R. §3503.13). Non-leasable minerals are those covered by the General Mining Law of 1872. See H.R. 7580, Clean Energy Minerals Reform Act of 2022, for an example of introduced legislation that intends to align mining on public lands with the Mineral Leasing Act of 1920, including by assessing a royalty rate on all mineral production.

[129] Codified at 30 U.S.C. §1607.

[130] Codified at 26 U.S.C. §613. Costs of investing in mineral production could be recovered using cost depletion, where a taxpayer determines annual depletion deductions based on the amount or value of the resource being extracted, as opposed to revenue from the resource.

[131] For additional information on tax policy and EVs, see CRS Report R45747, *Vehicle Electrification: Federal and State Issues Affecting Deployment*, by Bill Canis, Corrie E. Clark, and Molly F. Sherlock, and CRS In Focus IF11017, *The Plug-In Electric Vehicle Tax Credit*, by Molly F. Sherlock.

the potential for domestic market-distorting effects, especially in the mining sector where new or increased domestic production may not be readily feasible.[132]

## Federal Grants, Loans, and Research for Domestic Mineral Production

Federal loans and grants can be issued to private entities with the intent of increasing domestic production of critical minerals. Grants and loans can help businesses overcome certain financial constraints, which could increase mineral production. However, the mining and mineral extraction sector often faces long development time frames, due in part to project complexities and costs. These and other factors can result in loans and grants being issued to entities that are ultimately unsuccessful, or to those that would have been successful without the financial assistance.

Funding research to lower the costs of extracting critical minerals from ore or recycled products is a potential means of increasing domestic critical mineral supply. Research funding, often awarded through grant programs, can support the development of new processes or technologies related to the extraction and processing of critical minerals. Such new processes and technologies act to reduce the overall production costs, which can encourage additional production or allow a previously uneconomic deposit to be developed. Federally funded research can also identify new substitution possibilities among minerals, which can lead to equivalent or similar products containing fewer critical minerals. Federally funded research programs can draw criticism, as there are no guarantees to ensure successful development of new processes or technologies. Additional criticism could focus on these uses of federal funds, which can increase private sector profits.

Sections 40207, 40208, and 40210 in the IIJA direct the Secretary of Energy to award over $6 billion (appropriations provided in Division J) in grants related to the research, supply, processing, and recycling of battery critical materials and minerals, among other aspects. Section 40401 amends the DOE Title XVII loan guarantee program[133] to consider projects that increase the supply of domestically produced critical minerals.[134] Some aspects of these programs are to encourage increased production using existing technologies, while other aspects are to encourage the development or demonstration of new technologies.

In addition to new programs, Congress continues to fund efforts to enhance mineral extraction technologies through ongoing research programs, including through the DOE and the National Science Foundation (NSF), among others.[135] Examples of DOE research funding for critical mineral research programs and initiatives include the Argonne National Laboratory, the Critical Materials Institute (at Ames National Laboratory), and the National Energy Technologies Laboratory.[136]

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[132] For more information on excise taxes, see CRS Report R46938, *Federal Excise Taxes: Background and General Analysis*, by Anthony A. Cilluffo.

[133] 42 U.S.C. §§16511 et seq. For more information about the program, see CRS Insight IN11432, *Department of Energy Loan Programs: Title XVII Innovative Technology Loan Guarantees*, by Phillip Brown et al.

[134] For more information on these sections in the IIJA, see CRS Report R47034, *Energy and Minerals Provisions in the Infrastructure Investment and Jobs Act (P.L. 117-58)*, coordinated by Brent D. Yacobucci.

[135] For example appropriations for DOE and for the National Science Foundation, see P.L. 117-103.

[136] Example programs conducting critical mineral research with potential application to EVs include ANL, "Batteries and Fuel Cells" (at https://www.anl.gov/topic/science-technology/batteries-and-fuel-cells); Ames Laboratory, "Critical

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Materials Institute" (at https://www.ameslab.gov/cmi/); and NETL, "Critical Minerals Sustainability" (at https://netl.doe.gov/coal/rare-earth-elements).

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