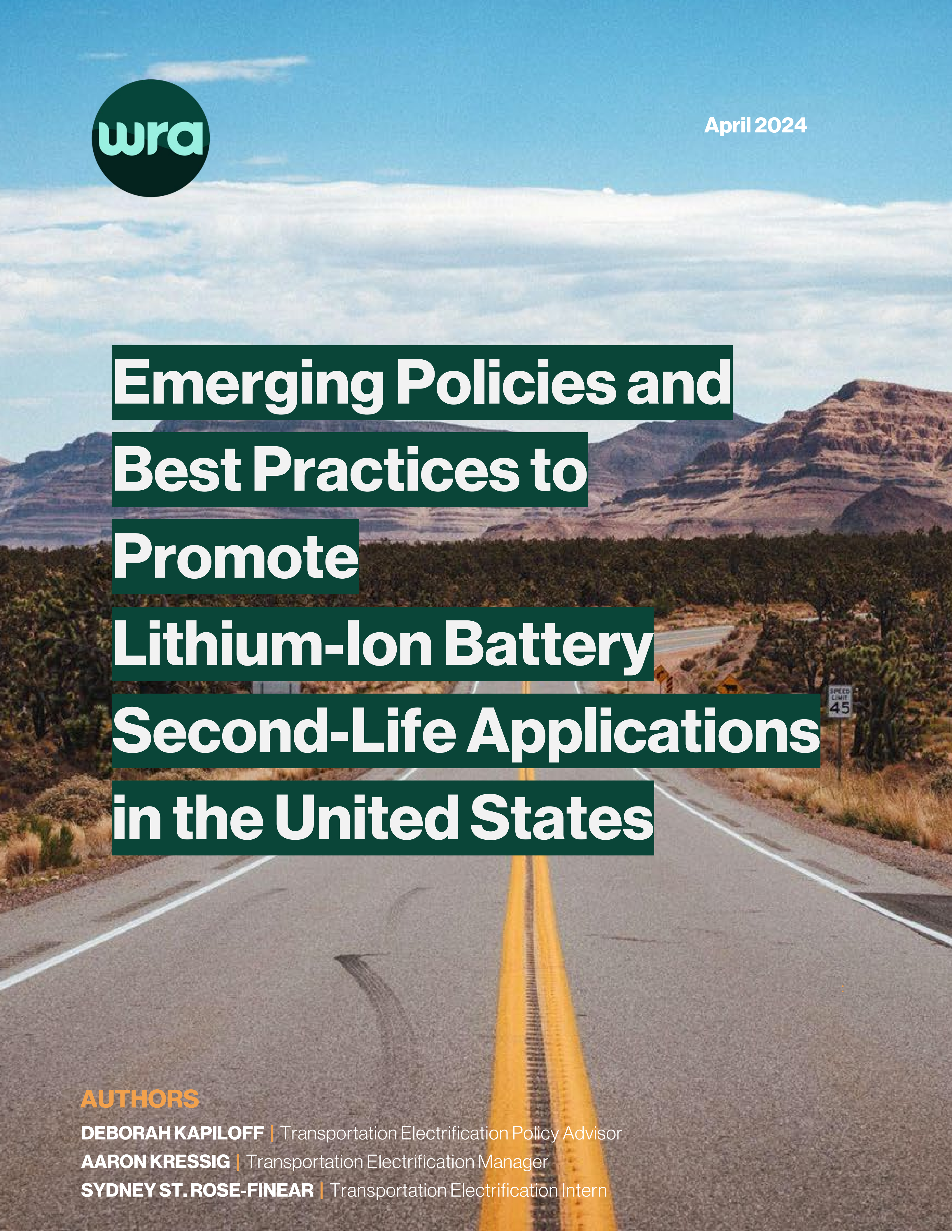

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Emerging Policies and Best Practices to Promote Lithium-Ion Battery Second-Life Applications in the United States

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Executive Summary

The purpose of this report is to outline policy that advances the reuse, repurposing, and recycling (collectively referred to as second-life applications) of lithium-ion electric vehicle (EV) batteries. The report examines policies being pursued domestically and internationally, but the ultimate focus is the presentation of key policies that state policymakers and other stakeholders can adopt to promote a circular economy for EV batteries. In addition to exploring these key policies, the report also provides a deeper look at the composition of lithium-ion batteries (LIBs) and discusses the various second-life pathways that batteries can take after an EV is retired.

The report presents several high-level findings:

- Few EVs have been retired, but many will reach end-of-life in the coming years, making now a pivotal time to put policies in place to ensure proper management of EV batteries and promote second-life applications.
- When an EV is retired, its battery can either be directly reused in another EV, repurposed for a different application (like grid energy storage), or its critical components can be recycled and used to create new lithium-ion batteries.
- Establishing a circular economy for EV batteries will lead to a wide variety of socio-economic and environmental benefits, including:
    - **Economic**: Reused and repurposed batteries are often cheaper than new batteries, and recycling an EV battery is already estimated to produce up to $1,500 in net profit per battery recycled[1] – value which will only increase over time as the battery recycling industry grows.
    - **Workforce**: Studies have estimated that for every 1,000 tons of lithium-ion batteries collected, 15 jobs are created for collection, dismantling, and recycling.[2]
    - **Social**: Increased reuse, repurposing, and recycling reduces social injustices and harms caused by extractive mining practices.
    - **Environmental**: Reusing and recycling battery materials versus making new batteries reduces the greenhouse gas emission footprint of EVs as well as the impact on land and water resources by cutting demand for mining. One study estimated that if all lithium-ion batteries were recycled, the demand for mining could be reduced by up to 64% by 2050.[3]
    - **National Security**: The lithium-ion battery supply chain is highly complicated and global in scope, and many key materials originate from countries with a strained relationship with the United States. Promoting second-life applications will maximize the content we have domestically, reducing demand needs from other countries.
- Globally, the European Union and China have led in promoting EV battery second-life applications by establishing comprehensive frameworks for how to handle batteries when EVs reach end-of-life.

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[1] At current recycling profitability, the most common in EV globally, the Tesla Model Y, generates $1,500 in profit per recycled battery. "Financial viability of electric vehicle lithium-ion battery recycling," *iScience*, 2021, https://www.sciencedirect.com/science/article/pii/S2589004221007550?via%3Dihub.

[2] "EV Battery Recycling and Its Impact on Society," IEOM Society International, 2020, https://www.ieomsociety.org/detroit2020/papers/731.pdf.

[3] "Creating a circular EV battery value chain: End-of-life strategies and future perspective," *Resources, Conservation & Recycling*, 2022, https://www.sciencedirect.com/science/article/pii/S0921344922003275.

- In the U.S., the federal government has primarily looked to incentivize EV recycling but has not pursued policies that would create a comprehensive regulatory framework to create an EV circular economy.
- State governments are driving progress domestically, as several states and Washington, D.C., have acted to establish regulatory frameworks to promote EV battery second-life applications.
- Many policies are emerging to promote EV battery second-life applications, but the most important for states to consider is an extended producer responsibility policy which clearly defines who is responsible for handling EV batteries when a vehicle reaches end-of-life.

Introduction

Background and Overview

Demand for EVs is rapidly increasing within the United States due to the many environmental and economic benefits for consumers and society. To keep up with this growing demand, there has been a corresponding increase in the production of lithium-ion batteries to power these vehicles. By promoting the reuse, repurposing, and recycling (also collectively called second-life applications) of LIBs, we can promote a circular economy for EV batteries that reduces waste and emissions associated with mineral extraction while promoting a reliable, domestically produced supply of key minerals and materials.

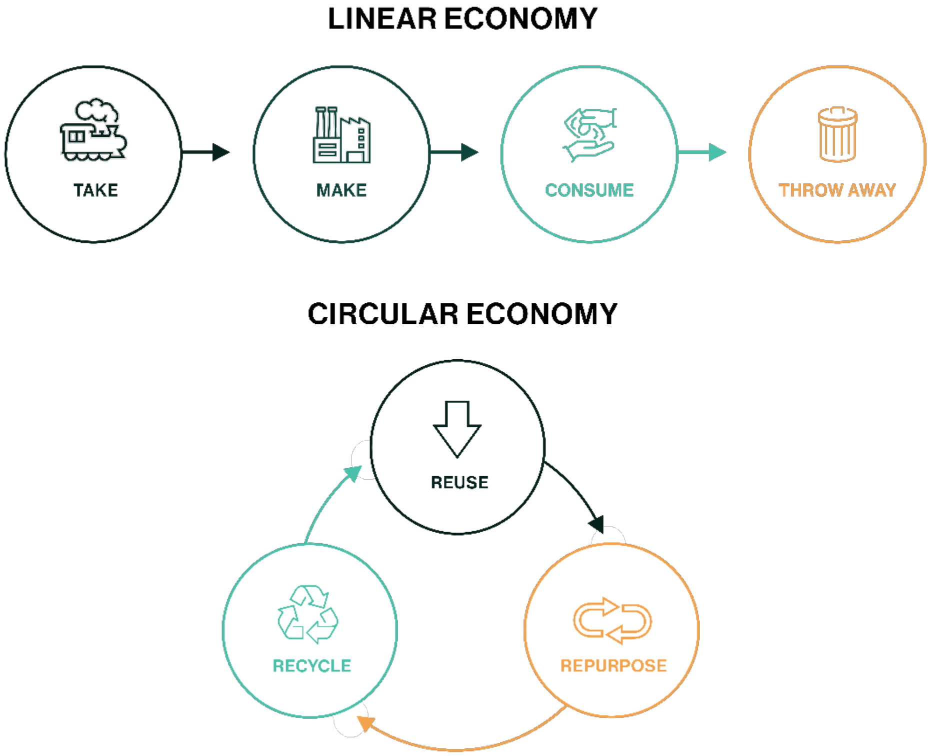

Figure 1*. Linear economy versus circular economy.*

Once EV batteries are retired in a circular economy, there are several available second-life applications: direct reuse, remanufacturing then reuse, repurposing, or recycling. Reuse refers to transferring the EV batteries directly back into another EV. Repurposing refers to using the battery in a new and different application. Recycling, in this context, means deconstructing a battery that can no longer be used in order to extract valuable minerals that can be reused in other applications.

EV BATTERY PATHWAYS

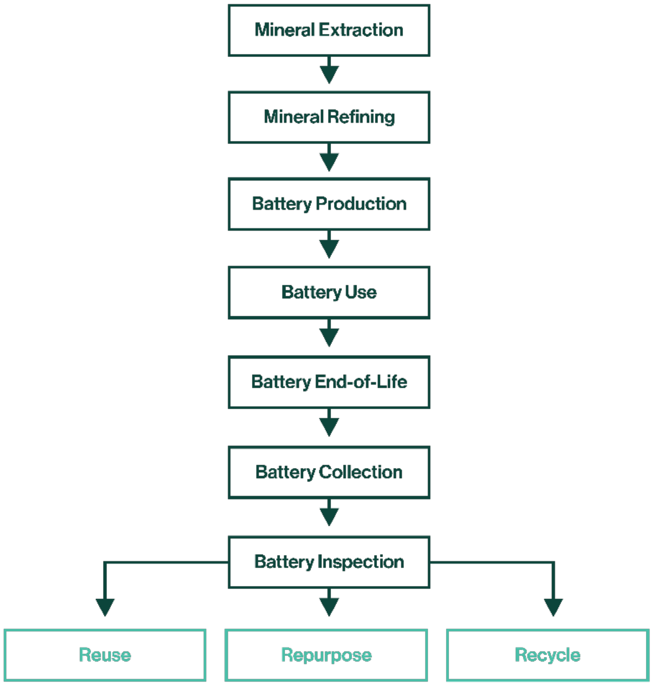

Figure 2*. Stages of an EV battery pathway.*

Policies promoting second-life applications for EV batteries are only just emerging in the United States. Some action has been taken at the federal level, including incentives for second-life applications, such as recycling and investing in a second-life supply chain.[4] At the state level, legislation has passed in several states[5] to regulate end-of-life battery management and promote second-life applications. Manufacturers have also been taking an interest in the subject; some manufacturers today partner with recycling facilities.[6] This paper will explore the various policies related to EV battery management and second-life applications including the question of who is responsible for the battery when it reaches end-of-life, standards for how batteries are treated, and incentives to encourage battery second-life applications.

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[4] The Inflation Reduction Act has included a clause to incentivize recycling; manufacturers who use recycled materials in their batteries are eligible for the $7,500 tax rebate – IRA Section 13401 – Clean Vehicle Credit, https://iratracker.org/programs/ira-section-13401-clean-vehicle-credit. The federal government, overall, has invested heavily in the domestic battery supply chain; $7 billion was allocated to the battery supply chain in the BIL, and $74 million was directly allocated toward new recycling facilities – "DOE intends to award up to $37M to advance EV battery recycling, transportation and design," Green Car Congress, 2023, https://www.greencarcongress.com/2023/08/20230824-doebil.html.

[5] California Senate Bill 615, Vehicle traction batteries, https://legiscan.com/CA/text/SB615/id/2778091.

[6] See producer and recycling facilities partnerships in Table 2.

Understanding EV Batteries

LITHIUM-ION BATTERIES

Currently, the batteries that power EVs are primarily lithium-ion batteries. While some companies are researching the use of other types of batteries, such as lithium-iron-phosphate batteries or solid-state batteries,[7] LIBs are the most prominent batteries on the market.

Several critical minerals are used in LIBs. Critical minerals are those identified by the U.S. government to be at a crucial risk of limited supply compared to their current and future demand. Within EV battery production, five minerals are identified as critical:[8] lithium, cobalt, manganese, nickel, and graphite. Due to an increase in EV production, the demand for many of these minerals is also rapidly increasing. Take lithium, for example. From 2021 to 2022, lithium production increased 21% and lithium consumption increased 41%.[9] Demand is growing for other critical minerals, as well; nickel production increased by 20% in 2022 and graphite imports to the U.S. increased by 55%, in part due to demand from EVs.[10]

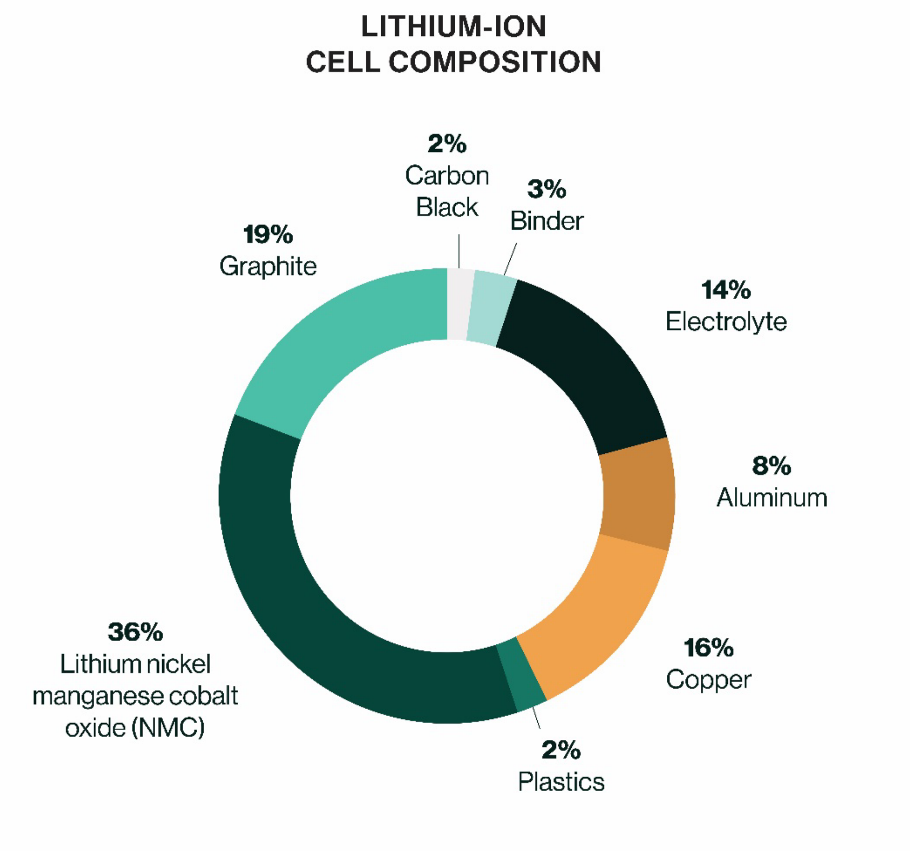

***Figure 3**. Breakdown of a lithium-ion battery cell.*

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[7] "6 New Battery Technologies to Watch," Built In, 2023, https://builtin.com/hardware/new-battery-technologies.

[8] For more information on the individual minerals, refer to Appendix A.

[9] "Lithium," USGS Mineral Commodity Summaries, 2023, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-lithium.pdf.

[10] "Graphite (Natural)," USGS Mineral Commodity Summaries, 2023, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-graphite.pdf; "Nickel," USGS Mineral Commodity Summaries, 2023, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-nickel.pdf.

Considering the critical state of these minerals, a circular economy can help improve the domestic supply of key materials for the coming EV transition. While there are already enough minerals to sustain the EV market,[11] EV battery second-life policies can ensure a stable domestic supply and reduce the need for new mineral extraction. Currently, many minerals used in the manufacture of EV batteries are obtained from other countries, some of which are engaging in mineral extraction practices that raise concerns over socio-economic and environmental standards. Additionally, mineral reliance can cause, or exacerbate, geopolitical concerns. In response, the U.S. has implemented policy to reduce our consumption of minerals from other countries. The Bipartisan Infrastructure Law (BIL) invested millions into creating mining facilities to increase domestic production and production from free trade partners.[12]

Mining has caused, and continues to cause, injustices to Indigenous communities in the U.S. And although these injustices existed long before the first EV, the rapidly growing EV market and the minerals it requires will increase domestic extraction. This increased rate of mineral extraction runs the risk of disproportionately impacting Indigenous communities in the West, where many of these minerals are found. Federal and state governments should take this opportunity to further reevaluate our country's current mining practices, some of which have not been updated for over 150 years,[13] and make improvements where needed, including by strengthening best practices for Tribal consultations at the state and federal level.

States can make a positive impact on reducing the need for mining by requiring EV battery second-life applications. While this report does not focus on mining practices but rather policies related to battery recycling, more resources on mining practices and policies in the United States can be found in Appendix B.

EV BATTERY TREND

Increasing Electric Vehicles

Production of and demand for electric vehicles have both steadily increased over the last few years. Rising consumer demand, complemented by strong policy support, is driving this growth. Reports show that between 2020 and 2022, consumer demand for EVs in the U.S. increased by 350%.[14] Recent policy developments suggest this growth may soon accelerate even more rapidly. The federal government offers tax rebates for EVs through the Inflation Reduction Act (IRA), and many states are taking measures to increase the sale of EVs, with policies like Advanced Clean Cars II (ACCII), which requires 100% of vehicles sold in 2035 to be zero-emission vehicles.[15] As of February 2024, 14 states – representing over one third of the U.S. population – have adopted ACCII.[16]

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[11] "What you need to know about minerals and the clean energy transition," Canary Media, 2022, https://www.canarymedia.com/articles/clean-energy/minerals-and-the-clean-energy-transition-the-basics-2.

[12] Funding Notice: Bipartisan Infrastructure Law: Advanced Processing of Critical Minerals and Materials for Industrial and Manufacturing Applications, https://www.energy.gov/fecm/funding-notice-bipartisan-infrastructure-law-advanced-processing-critical-minerals-and.

[13] Mining Law of 1872, Bureau of Land Management, https://www.blm.gov/programs/energy-and-minerals/mining-and-minerals/about.

[14] "Excess Demand: The Looming EV Shortage," Consumer Reports, 2023, https://advocacy.consumerreports.org/wp-content/uploads/2023/03/Excess-Demand-The-Looming-EV-Shortage.pdf.

[15] Advanced Clean Cars II, California Air Resources Board, https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii.

[16] Clean Vehicle Programs: State Tracker, https://www.sierraclub.org/transportation/clean-vehicle-programs-state-tracker.

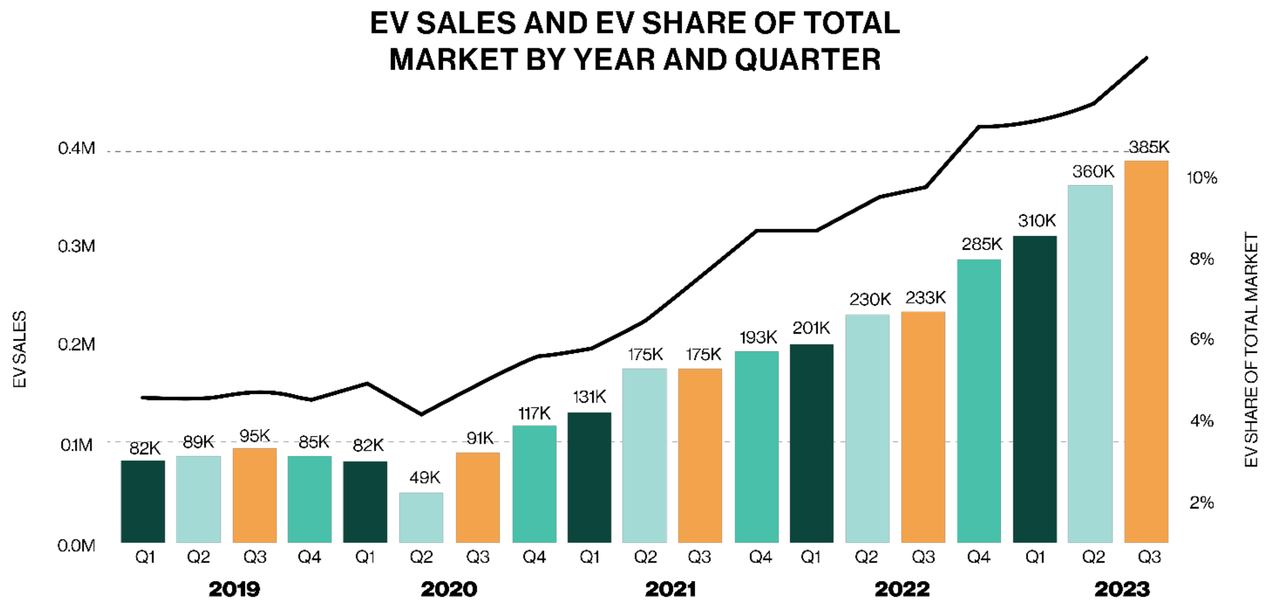

Figure 4. *EV sales and EV share of total market 2019-2023.*[17]

With these policies, 239 million EVs are expected to be on the road by 2050, making three of every four vehicles electric.[18] This is a significant increase to the current amount of EVs, considering there were only just over two million EVs on the road in 2021.[19] This rapid acceleration of EV adoption increases demand for the critical minerals that are used in lithium-ion batteries and creates new opportunities for recycled materials. While still a new industry, recycling could help EV battery manufacturers keep up with increasing demands while reducing the impacts of mineral extraction and mining. Recycling can relieve battery supply chain pressures while also mitigating environmental and social mining stresses.

Retired EVs

The EV market is still in its relative infancy. As a result, there has yet to be a large influx of retired EVs. For internal combustion engine (ICE) vehicles, many regulations are already in place concerning vehicle batteries. These policies outline where to take vehicle batteries at the end-of-life, guidelines on disposal, and clear recycling standards.[20] For EVs, however, an analogous policy ecosystem does not yet exist. While the body of an EV may be similar to an ICE vehicle, its lithium-ion core is not regulated under federal law like ICE batteries, creating confusion about their proper disposal.

Considering that EV adoption has only really begun to accelerate in the U.S. since 2018 and the average life of an EV is 8-12 years, the number of EV batteries being recycled will be relatively modest for the next few years. However, in the late 2020s the quantity of EV batteries reaching end-of-life will

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[17] Light Duty Electric Drive Vehicles Monthly Sales Updates, Argonne National Laboratory, https://www.anl.gov/esia/light-duty-electric-drive-vehicles-monthly-sales-updates.

[18] "Nationwide Impacts of California's Advanced Clean Cars II Rule," Energy Innovation, 2023, https://energyinnovation.org/wp-content/uploads/2023/04/Nationwide-Impacts-Of-Californias-Advanced-Clean-Cars-II-Rule-1.pdf.

[19] "The United States surpassed two million on-road light-duty electric vehicles in 2021," U.S. Energy Information Administration, 2023, https://www.eia.gov/todayinenergy/detail.php?id=60422.

[20] Lead-Acid Battery Recycling, https://www.batteryrecyclersofamerica.com/lead-acid-battery-recycling.

begin growing significantly.[21] In California alone, an estimated 165,000 EVs will be retired by 2030, and up to 1.6 million will be retired by 2050.[22] Regarding the batteries, as much as 12 million tons of EV batteries will be retired globally in the next decade.[23]

As the upcoming influx of retired EVs nears, it is crucial to create policies that encourage an industry that is prepared to handle them. Developing a circular battery economy composed of second-life applications is the way forward.

SECOND-LIFE PATHS FOR EV BATTERIES

Regulations requiring EV batteries to be evaluated for second-life usage ensure that minerals extracted for batteries are reused in some manner and not discarded. While some manufacturers and governments have already begun work on increasing second-life applications for these batteries,[24] this is still an emerging area of regulation. Without proper management and appropriate policy direction, some batteries may end up in landfills, creating waste that not only leaches toxins into the ground but can also cause dangerous fires.[25] EVs are already significantly more economically and environmentally beneficial to society than ICEs,[26] and ensuring proper end-of-life treatment of their batteries will further improve the environmental friendliness of this new technology.

Instead of being improperly disposed of, creating a circular economy will ensure that EV batteries are used in second-life applications. General steps in the reuse, repurposing, or recycling of a battery may look something like Figure 5 in a circular economy.

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[21] "Direct recycling of spent Li-ion batteries: Challenges and opportunities toward practical applications," *iScience*, 2023, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10480636.

[22] "Why Do We Need EV Battery Recycling Policy?," Union of Concerned Scientists, 2023, https://blog.ucsusa.org/jessica-dunn/why-do-we-need-ev-battery-recycling-policy.

[23] "Greenpeace report troubleshoots China's electric vehicles boom, highlights critical supply risks for lithium-ion batteries," Greenpeace, 2020, https://www.greenpeace.org/eastasia/press/6175/greenpeace-report-troubleshoots-chinas-electric-vehicles-boom-highlights-critical-supply-risks-for-lithium-ion-batteries.

[24] "Toyota, Redwood Materials expand deal to source recycled battery materials," Manufacturing Dive, 2023, https://www.manufacturingdive.com/news/Toyota-Redwood-Materials-expand-recycled-battery-materials-agreement/700463; "Green Deal: EU agrees new law on more sustainable and circular batteries to support EU's energy transition and competitive industry," European Commission, 2022, https://ec.europa.eu/commission/presscorner/detail/en/IP_22_7588.

[25] "Environmental Impacts of Lithium-Ion Batteries," Institute for Energy Research, 2023, https://www.instituteforenergyresearch.org/renewable/environmental-impacts-of-lithium-ion-batteries.

[26] Electric Vehicle Myths, https://www.epa.gov/greenvehicles/electric-vehicle-myths.

EV BATTERY PATHWAYS

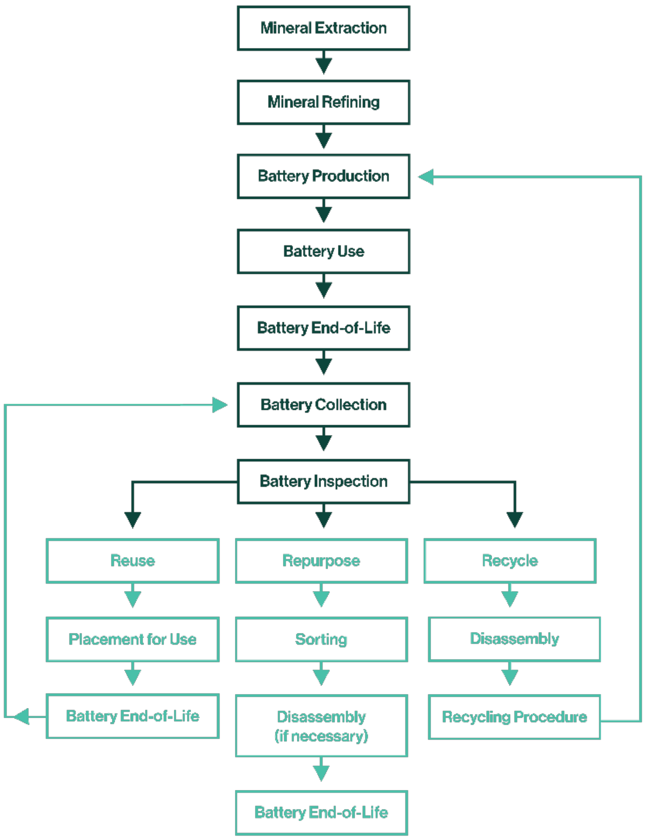

***Figure 5**. Stages of an EV battery pathway in a circular economy.*

Battery Collection

Once an EV battery reaches its end-of-life, the battery needs to be collected. In the absence of standards clearly defining who is responsible for this collection, batteries can become stranded or improperly disposed of. Policies assigning responsibility to an entity for battery collection are crucial to a functional circular economy.

Battery Inspection

Once a battery is collected, it must be inspected to determine its current capacity and material composition, which will help to identify the appropriate treatment of the battery. Currently, battery inspection can be difficult due to lack of accessible information. There are no federal regulations in the U.S. that require battery labeling,[27] nor any regulations that require state-of-health information to be available. Battery labeling would help to identify material composition, whereas state-of-health information would help identify the battery's remaining capacity for use.

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[27] No federal regulations require battery labeling, but some state regulations do. States that have adopted California's ACCII regulation agree to battery labeling requirements; these will take effect in the next few years as the law is phased in. Final Regulation Order, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/2acciifro1962.6.pdf.

State-of-health information on a battery can be difficult to determine once an EV reaches its end-of-life. If the EV is still functioning, this information can be accessed, but only through proprietary technology used by certified mechanics. If the vehicle can no longer be turned on or the battery is removed, an estimate for state of health can only be determined by a proprietary connector which can only be used by the original auto manufacturer.[28] As a result, it is very difficult to perform third-party battery inspection. Once an inspection is performed, the appropriate next steps for a particular battery can be determined, depending on inspection results indicating it can be reused, repurposed, or recycled. In each case, it is preferable to reuse first, repurpose second, and then recycle once no other path can be taken.

Reuse Path:

Battery Placement

If the battery is determined to be suitable for direct reuse, it can be placed for use in another vehicle. The next time the battery is removed, the process will repeat at the collection step.

Repurpose Path:

Sorting

After inspection, if the battery cannot be reused but can be repurposed, sorting will determine how it can be repurposed. Repurposing applications include streetlamps, EV charging stations, or electricity grid energy storage.[29] For instance, Volkswagen now uses second-life EV batteries in EV charging stations,[30] and the California-based company, B2U Storage Solutions, uses batteries to store energy from its onsite solar farm.[31] Even automakers are getting into the repurposing space, with Nissan partnering with Relyion Energy to repurpose EV batteries for energy storage.[32]

Disassembly (if required)

In some cases, a battery pack may need to be disassembled before it can be repurposed. Many battery repurposing applications require a consistent, steady energy supply. However, older battery packs can vary greatly in capacity and capabilities.[33] While the state of health for individual batteries can be identified during the inspection phase, certain applications may require further disassembly to ensure a cohesive unit of batteries exists within the application. More information on the disassembly process can be found in the recycling section below.

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[28] "Battery State of Health – What is It? Why is It Important?," Union of Concerned Scientists, 2022, https://blog.ucsusa.org/jessica-dunn/battery-state-of-health-what-is-it-why-is-it-important.

[29] "Scaling up reuse and recycling of electric vehicle batteries: Assessing challenges and policy approaches," The International Council on Clean Transportation, 2023, https://theicct.org/wp-content/uploads/2023/02/recycling-electric-vehicle-batteries-feb-23.pdf.

[30] "Powering the future of transportation: Creating an ethical, sustainable battery supply chain," Plug in America, 2023, https://pluginamerica.org/wp-content/uploads/2023/08/Creating-Ethical-Sustainable-Battery-Supply-Chain-for-EVs.pdf.

[31] B2U Storage Solutions, https://www.b2uco.com.

[32] "Nissan has a plan for used Leaf batteries: Powering buildings," Business Insider, 2023, https://www.businessinsider.com/eletric-car-battery-recycling-nissan-plan-leaf-grid-repurposing-2023-1.

[33] "A review on the key issues for lithium-ion battery management in electric vehicles," *Journal of Power Sources*, 2013, https://www.sciencedirect.com/science/article/abs/pii/S0378775312016163.

Battery Placement

The final step for repurposed batteries is to place them in their new application. Depending on the application the battery is used in, the placement can extend a battery's lifespan by 6-30 years.[34] In applications such as EV fast chargers, an EV battery's life can extend more than 30 years. In applications such as energy storage for individual buildings, battery lifespans can be extended by nearly 12 years. Table 1 outlines a few examples of repurposed applications,[35] along with the timeline in which a battery's lifespan can be extended.

Application	Description	Extended Battery Lifespan
EV Fast Charger	Batteries are repurposed for energy storage use within an EV fast charger	30 years
Self-Consumption	Batteries are repurposed for energy storage for a singular building	11.6 years
Area Regulation	Batteries are repurposed for energy storage and for grid stability services	5.7 years
Transmission Deferral	Batteries are repurposed to provide power support to a neighborhood grid transformer by storing energy during off-peak hours and delivering it when needed	12 years

***Table 1**. Battery lifespans when repurposed in various applications.*

Once the battery can no longer be used in its new application, it should be sent back to the battery collection step. After this, its subsequent path would likely be recycling. However, inspection is still required to determine whether it can be repurposed again within another application.

Recycling Path:

Disassembly

To be recycled, battery packs must be disassembled. Each pack contains several modules, which hold numerous cells.[36] In these cells are the actual battery components, or the valuable minerals recovered during recycling. Therefore, to be recycled, the packs must be disassembled to reach the cells inside.

Recycling Procedure

After disassembly, the battery packs can be recycled. There are several recycling processes, including pyrometallurgical recycling, conventional hydrometallurgical recycling, and direct recycling. These

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[34] "Second life batteries lifespan: Rest of useful life and environmental analysis," *Journal of Environmental Management*, 2019, https://www.sciencedirect.com/science/article/pii/S0301479718313124.

[35] The applications listed below give a timeline of how batteries' lives can be extended by being repurposed. However, these are not the only applications available for repurposing. As outlined in other sections of the report, batteries can be repurposed in numerous other ways, such as for streetlamps or in large grid storage applications.

[36] "Anatomy of an EV Battery," KPA, 2022, https://kpa.io/blog/anatomy-of-an-ev-battery.

different recycling processes vary in terms of which materials they can extract and how effectively materials can be recovered. Two of these processes, pyrometallurgical recycling and conventional hydrometallurgical recycling, are used on a commercial scale. The third process, direct recycling, is still developing and becoming more widely available.[37]

Pyrometallurgical recycling recovers high amounts of cobalt, copper, and nickel, but cannot recover lithium and aluminum. It is attractive due to its straightforward technique that makes adoption of the process easier.[38] However, conventional hydrometallurgical recycling is often preferred as it can recover high amounts of all central minerals – up to 99% of aluminum, cobalt, copper, nickel, lithium, and manganese.[39] It is also a less energy-intensive process.[40] New methods and technologies continue to be developed on a commercial scale.

Direct recycling is a newer process that has not been deployed as widely, but it has the potential to recover materials without breaking down the chemical structure of the cell, meaning the materials recovered from this process could be directly reused in batteries.[41] The ability to recover materials while maintaining original battery components would allow for lower-cost reconstructed material, which can help reduce EV battery costs and incentivize recycling.[42]

Additionally, Ascend Elements, a lithium-ion battery recycling facility in Massachusetts, uses a unique hydro-to-cathode recycling process.[43] This is a specific and newly developed type of hydrometallurgical recycling. Studies have found that batteries made from this recycling process can have a faster charge and last longer than new batteries due to the manipulation of porous composition of minerals during the recycling process.[44] Until more facilities can upgrade their recycling technology, hydrometallurgical recycling remains the most effective and energy-efficient method for recycling lithium-ion EV batteries.

Recycling is the last stage for all batteries in a circular economy. After this, the battery's materials can be directly integrated into production of new batteries, significantly decreasing the need for additional mineral extraction.

Transportation as a Recurring Barrier to Battery Second-Life Applications

The transport of batteries will be a recurring challenge for making battery second-life paths economically viable. Batteries need to be physically moved in collection, likely between collection and inspection, and again after inspection. This can be difficult for a few reasons. First, battery staging and transport can be cost-prohibitive. It is more cost-effective to transport many batteries at once rather than just a few, so batteries must be held in a safe location while awaiting transport to a new facility. These storage facilities must be up to code with hazardous waste holding standards, which can be

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[37] ReCell Center: Advanced Battery Recycling, https://recellcenter.org.

[38] "Energy and environmental aspects in recycling lithium-ion batteries: Concept of Battery Identity Global Passport," U.S. Department of Energy Office of Scientific and Technical Information, 2020, https://www.osti.gov/biblio/1694390.

[39] "How are EV batteries (actually) recycled?," Union of Concerned Scientists, 2023, https://blog.ucsusa.org/jessica-dunn/how-are-ev-batteries-actually-recycled.

[40] "The difference between hydrometallurgy and pyrometallurgy," TES, 2023, https://www.tes-amm.com/news/the-difference-between-hydrometallurgy-and-pyrometallurgy.

[41] "New advances in recycling of lithium-ion batteries," CAS, 2023, https://www.cas.org/resources/cas-insights/sustainability/new-advances-recycling-lithium-ion-batteries.

[42] ReCell Center, https://recellcenter.org.

[43] Ascend Elements, https://ascendelements.com.

[44] "Recycled lithium-ion batteries can perform better than new ones," *Scientific American*, 2022, https://www.scientificamerican.com/article/recycled-lithium-ion-batteries-can-perform-better-than-new-ones.

difficult.[45] Second, once the batteries are ready to be transported, this must be done in a particular manner. LIBs are currently classified as hazardous waste, meaning they must be transported according to specific guidelines outlined by the Department of Energy that require strict packaging standards. While the U.S. Environmental Protection Agency (EPA) is in the process of reclassifying batteries as universal waste,[46] the current guidelines increase transportation costs. Today, nearly 30% of the cost of recycling batteries is attributed to transportation.[47]

Smart policy design can reduce costs, thereby alleviating this barrier to second-life battery applications. For more detail, see the Policies to Promote EV Battery Second-Life Applications section on page 21.

The Current State of EV Battery Second-Life Policy

Effectively crafting policy to expand EV battery second-life applications requires identifying what should be done with EV batteries at their end-of-life and who should be responsible for taking these actions. In defining what should be done with end-of-life EV batteries, it's important to maximize the usefulness of a battery by prioritizing reuse, then repurposing, then recycling in that order. In this section we will outline the policies that jurisdictions interested in second-life applications are pursuing and then discuss how policy development is progressing internationally and domestically.

Today, there are two primary regulatory models:

- **Extended Producer Responsibility (EPR)**: This approach makes the battery producer responsible for handling the battery when it reaches end-of-life. This is usually the vehicle manufacturer, although it may change after a battery is repurposed or reused. This policy extends the manufacturer's responsibility beyond the battery's end-of-life, ensuring that the battery will be reused, repurposed, or recycled. This policy clearly defines responsibility and is relatively easy to integrate into the current EV infrastructure.
- **Core Exchange Program with Vehicle Backstop**: This approach creates incentives for consumers to return the battery for reuse or further processing. Core exchange programs work by requiring the consumer to pay a deposit on the battery at the time of purchase, which is then refunded back to the consumer once the battery is returned. This policy approach also ensures that producers become responsible for ensuring proper end-of-life management if the core exchange program fails, and a battery becomes stranded. While this policy is often preferred by auto manufacturers, it is more complex and difficult to implement than EPR.[48]

Both core exchange and EPR programs address the critically important question of who is responsible for EV batteries when vehicles reach end-of-life. Regardless of which approach is selected, it is crucial that any policy mandates the reuse, repurposing, and recycling of LIBs. While the alternatives above focus on LIB responsibility, it's also critical to clearly identify what the responsible parties should do with

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[45] For more information on hazardous waste, refer to the Current State of EV Battery Second-Life Policy section.

[46] Lithium-Ion Battery Recycling, https://www.epa.gov/hw/lithium-ion-battery-recycling.

[47] "Why Do We Need EV Battery Recycling Policy?," Union of Concerned Scientists, 2023, https://blog.ucsusa.org/jessica-dunn/why-do-we-need-ev-battery-recycling-policy.

[48] See core exchange program within the Policies to Promote EV Battery Second-Life Applications section for a more thorough explanation of why core exchange can be confusing and burdensome.

LIBs. Ideally, policy approaches create clear requirements to ensure batteries are being assessed for second-life application which will maximize the efficacy of that battery. Second-life applications will be prioritized in this order: reuse, repurpose, and finally, recycle. Whether a core exchange or EPR policy is selected, the policy should seek to prioritize the second-life application that will maximize the value of a retired EV battery.

In addition to specific policies that assign responsibility and maximize efficient use of batteries at their end-of-life, there are other complementary policies which can support a circular economy for EV batteries:

- **Recycling standards**: Recycling standards are included in EV second-life policies that exist today, and the European Union (EU) is a global leader in developing stringent and enforceable recycling standards[49] Mandated standards can ensure that facilities are retrieving the highest amount of material possible while producing the least amount of waste.
- **Incentive programs**: Incentives to support various components of the EV battery circular economy can help to develop the second-life EV battery market quicker and increase profit in the industry.[50]
- **Access to state of health**: Increasing access to state of health on EV batteries can be extremely beneficial for the second-life supply chain. This would allow interested parties to instantly assess how much life is left in an EV battery, which is not currently commonplace. By requiring transparency around the state of health, batteries can be inspected more quickly and easily.
- **Global battery passport**: Implementation of a global battery passport can provide further transparency regarding EV batteries. A global battery passport can help identify important information such as where the battery was produced and its carbon footprint.[51]
- **Updating hazardous waste rules**: In the United States, LIBs are designated as hazardous waste, which makes them difficult to transport and store. Moving LIBs into a more broadly defined universal waste category can reduce logistics and transportation costs associated with second-life applications.[52]

The policy landscape for promoting second-life applications is still very new, but quickly advancing. While the EU and China have led policy development to date, progress at the federal and state level in the U.S. indicate this matter is gaining traction, with state government emerging as an important focal point for regulation.

National Landscape

In the United States, progress toward creating a circular economy for EV batteries has relied mostly on grants and incentives at the federal level. The federal government has taken multiple actions

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[49] "Proposal for a regulation of the European Parliament and of the Council concerning batteries and waste batteries," European Commission, 2020, eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020PC0798&rid=1.

[50] The IRA has already put some incentives in place; if manufacturers use recycled materials in their batteries, they can become eligible for the $7,500 tax rebate – IRA Section 13401 – Clean Vehicle Credit, https://iratracker.org/programs/ira-section-13401-clean-vehicle-credit.

[51] "Guest blog: Circulor's Guide to the EU Battery Regulation and its Battery Passport Requirement," TechUK, 2023, https://www.techuk.org/resource/guest-blog-circulor-s-guide-to-the-eu-battery-regulation-and-its-battery-passport-requirement.html.

[52] "Lithium-ion Car Battery Recycling Advisory Group Final Report," California Environmental Protection Agency, 2022, https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-Recycling-Advisory-Goup-Final-Report.pdf.

surrounding the second life of EV batteries, including supporting research, investing in the creation of new facilities, and incentivizing recycling.

The Bipartisan Infrastructure Law was one of the first major federal actions regarding EV batteries. The BIL included $7 billion of funding[53] to support a domestic battery supply chain.[54] While much of this support was for developing new mining and processing facilities for critical materials, a portion was allocated toward recycling and research on battery second-life applications. A funding opportunity within the BIL[55] allocated $37 million toward the "research, development, and demonstration of" second-life uses for EV batteries and innovative and updated recycling processes.[56] Ten projects have received a combined $74 million from the bill to create new recycling facilities and advance novel projects.[57]

Congress made additional investments in battery recycling through the Inflation Reduction Act. The IRA revised the requirements for vehicles to qualify for the federal EV tax credit, indirectly incentivizing battery recycling. Beginning in 2023, a vehicle can only qualify for half of the credit if at least 40% of the minerals in the battery were mined or processed within the U.S. or a country that has a free trade agreement with the U.S. That percentage will continue to increase every year up to 80% in 2027.[58] These requirements can be satisfied through use of minerals that have come from recycling facilities located in North America, incentivizing increased recycling.

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[53] "FACT SHEET: Biden-Harris Administration Proposes New Standards for National Electric Vehicle Charging Network," The White House, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/09/fact-sheet-biden-harris-administration-proposes-new-standards-for-national-electric-vehicle-charging-network.

[54] For states looking to investigate the companies and facilities in their area, the National Renewable Energy Lab has created an extensive Lithium-Ion Battery Supply Chain Database. This database is updated consistently and can quickly and publicly be accessed through Excel. You can find the downloadable database at https://www.nrel.gov/transportation/li-ion-battery-supply-chain-database-download.html.

[55] Bipartisan Infrastructure Law Electric Drive Vehicle Battery Recycling, Transport, and Design, https://www.highergov.com/grant-opportunity/bipartisan-infrastructure-law-electric-drive-vehicle-battery-recycling-transpor-349963.

[56] "DOE intends to award up to $37M to advance EV battery recycling, transportation and design," Green Car Congress, 2023, https://www.greencarcongress.com/2023/08/20230824-doebil.html.

[57] "Bipartisan Infrastructure Law: Battery Recycling and Second Life Applications Selections," Office of Energy Efficiency & Renewable Energy, 2022, https://www.energy.gov/eere/vehicles/articles/bipartisan-infrastructure-law-battery-recycling-and-second-life-applications.

[58] "Treasury Releases Proposed Guidance on New Clean Vehicle Credit," U.S. Department of the Treasury, 2023, https://home.treasury.gov/news/press-releases/jy1379.

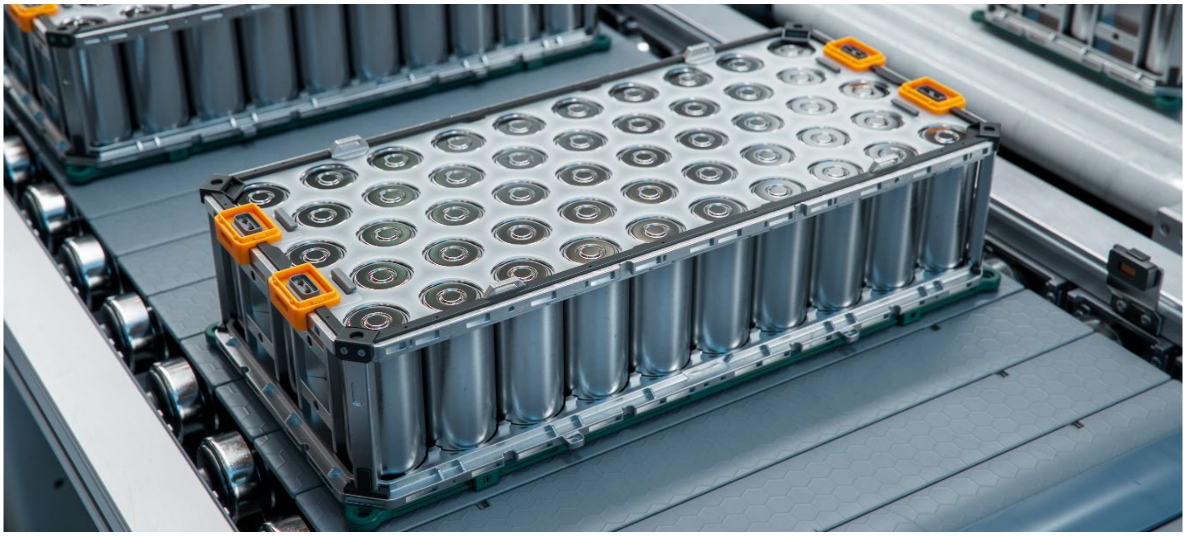

***Figure 6**. Lithium-ion high-voltage battery.*

While grants and incentives have boosted battery recycling domestically and supported elements of an emerging circular economy, more policy is still required for a comprehensive regulatory landscape. Currently, there are no federal standards regulating EV batteries' end-of-life management, nor any requirements for battery recycling. Lithium-ion batteries are currently designated as hazardous waste, creating strict requirements around logistics and transportation. However, recycling is only encouraged, not mandatory.[59] Changing the waste designations for EV batteries could better support universal recycling. For example, since lead-acid batteries are defined under specific universal waste regulations by the EPA, these batteries are recycled in every state.[60] The EPA is currently drafting a proposal to move LIBs into a specific universal waste category as well,[61] but for now LIBs are not regulated as such. A universal waste category would prohibit EV batteries from being disposed of in a landfill, but it would still not lead to a fully built-out ecosystem promoting optimal use of end-of-life EV batteries. To do that, an EPR or core exchange policy which assigns responsibility for EV batteries at end-of-life is necessary – as well as more regulation and guidance on how to handle EV batteries and prioritize the most effective second-life applications. Policies to create a comprehensive framework for EV battery second-life applications do not appear to be imminently forthcoming at the federal level, although there are some encouraging developments at the state level.

State-level policy addressing end-of-life EV batteries is in its infancy, but some leadership states are starting to support the emerging circular economy for EV batteries. Since 2021, the District of Columbia, California, Washington, and New Jersey have all passed laws requiring EV batteries to be evaluated for second-life usage and/or recycling, while also making it illegal to dispose of these batteries in landfills.[62]

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[59] Learn the Basics of Hazardous Waste, https://www.epa.gov/hw/learn-basics-hazardous-waste.

[60] Recycling Laws by State, https://www.call2recycle.org/recycling-laws-by-state.

[61] Improving Recycling and Management of Renewable Energy Wastes: Universal Waste Regulations for Solar Panels and Lithium Batteries, https://www.call2recycle.org/recycling-laws-by-state.

[62] "New Jersey has made it illegal to discard EV batteries in landfills," GreenBiz, 2024, https://www.greenbiz.com/article/new-jersey-has-made-it-illegal-discard-ev-batteries-landfills.

The Lithium-Ion Battery Recycling Advisory Group is a leader in this area, shaping much of the domestic discourse for how to develop policies to promote battery reuse, repurposing, and recycling. The group began its work in 2019 exploring effective pathways to ensure that EV batteries were not being disposed of, but rather sent upstream for second-life uses. They concluded with an intensive report of the best policies for second-life applications.[63] The advisory group included stakeholders from different sectors such as government entities, NGOs, auto manufacturers, and other related businesses like recycling companies. During deliberations, which were carried out for approximately three years, the group heard from experts on various technical and policy issues, formed subcommittees focused on specific elements of forming a cohesive EV battery second-life ecosystem, and debated the merits of proposed policy approaches.[64] Ultimately, all members of the committee voted on a suite of recommended policies. Many other states have built on the progress of the Lithium-Ion Battery Recycling Advisory Group, either by directly implementing policies discussed in that report[65] or by developing their own working group to explore which policies may work for their state.

While state-level policies and federal grants have created some early momentum for more recycling in the U.S., the nation still lacks a comprehensive policy framework to create a truly cohesive ecosystem for second-life applications throughout the entirety of the country. Internationally, however, many countries are making more significant strides toward promoting a circular economy for EV batteries.

International Landscape

EUROPEAN UNION

Recently, the EU has turned its attention to creating a more circular economy for LIBs. In 2020, the EU unveiled the European Green New Deal, outlining a path to net-zero emissions by 2050.[66] Much of the plan focuses on increasing clean energy and decoupling economic growth from resource use, and it has led to advancements in regulation of EV batteries.

Most notable is the EU Battery Regulation, which was proposed in 2020 and approved in 2023. This regulation entered into force in August 2023 and is being gradually phased in starting in 2024.[67] For EVs, the regulation's first requirements will have to be met in 2025.[68] The extensive ruling focuses on identifying responsibilities for batteries, mandating collection and percentage of key materials that need to be recovered through recycling processes, and increasing access to EV battery information.

The EU has opted for an extended producer responsibility approach. The EU has used EPR policies in the past, such as for lead-acid batteries in a 2006 directive, and intends to continue this approach with

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[63] "Lithium-ion Car Battery Recycling Advisory Group Final Report," California Environmental Protection Agency, 2022, https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-Recycling-Advisory-Goup-Final-Report.pdf.

[64] *Id.*

[65] In 2023, Washington and New Jersey passed legislation to implement an extended producer responsibility program modeled off the "Producer Take Back" policy discussed in the Lithium-Ion Battery Recycling Advisory Group report which assigns end-of-life responsibility for EV batteries. They also adopted recommendations from the report regarding various battery labeling requirements.

[66] Timeline - European Green Deal and Fit for 55, https://www.consilium.europa.eu/en/policies/green-deal/timeline-european-green-deal-and-fit-for-55.

[67] "Green Deal: EU agrees new law on more sustainable and circular batteries to support EU's energy transition and competitive industry," European Commission, 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7588.

[68] "EU Battery Regulation and Carbon Footprint Requirements," Minviro, 2023, https://www.minviro.com/resources/blogs/eu-battery-regulation-carbon-footprint-requirements.

LIBs.[69] A more comprehensive regulatory framework for EPR will apply by mid-2025, phasing in higher requirements for recycling efficiency[70] and collection rates.[71] Requirements for collection rates will increase over time, ranging from 51%-73%, depending on battery type and date. For recycling, lithium-ion batteries must obtain a minimum 65% recycling efficiency by 2025.[72] Recycling efficiency rate requirements for specific minerals also become more stringent. In 2027, recovery rates must be at least 50% for lithium and 90% for nickel, cobalt, and copper. By 2031, the lithium recovery rate increases to 80% while nickel, cobalt, and copper increase to 95%.[73] To track this, the EU is in the process of developing verification procedures to ensure recycling efficiency rates are met.

***Figure 7**. Lithium battery pack and wiring connections.*

Additionally, the new regulation mandates improved access to EV battery information. First, the regulation creates new labeling standards, thereby facilitating the emerging circular economy for second-life batteries. Dismantlers and recycling facilities will be able to identify the batteries' mineral composition more quickly. These enhanced labeling standards go into effect in 2026. The regulation applies labeling to the overall device rather than directly on the battery to increase visibility for entities working with the battery.[74]

The new regulation also creates a battery passport framework to track information such as carbon footprint,[75] proof of responsible sourcing, battery composition, recycled content, state of health, and

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[69] "New EU regulatory framework for batteries," Minviro, 2023, https://www.minviro.com/resources/blogs/eu-battery-regulation-carbon-footprint-requirements.

[70] Washington's SB-5144 defines recycling efficiency rate as "the ratio of the weight of recovered battery components and materials recycled by a program operated from recovered batteries to the weight of those recovered batteries collected by a program offer."

[71] A "collection rate" means the ratio by weight of collected used EV battery components versus the expected amount of battery weight which should be reaching end-of-life in a given year. 3R Policy Indicator Fact Sheet: Recycling Rate and Target, Institute for Global Environmental Strategies, https://www.iges.or.jp/en/publication_documents/pub/issue/en/3318/3R_02.pdf.

[72] "Proposal for a Regulation of the European Parliament and of the Council concerning batteries and waste batteries," European Commission, 2020, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020PC0798&rid=1.

[73] "Guest blog: Circulor's Guide to the EU Battery Regulation and its Battery Passport Requirement," TechUK, 2023, https://www.techuk.org/resource/guest-blog-circulor-s-guide-to-the-eu-battery-regulation-and-its-battery-passport-requirement.html.

[74] "New EU Batteries Regulation: Introducing enhanced sustainability, recycling and safety requirements," White & Case, 2023, https://www.whitecase.com/insight-alert/new-eu-batteries-regulation-introducing-enhanced-sustainability-recycling-and-safety.

[75] The carbon footprint tracked through the battery footprint will aim to calculate the embedded emissions of an EV battery from mine to manufacturer, during its first life, second-life application, all the way to being recycled. The methodology for calculation and verification of the carbon footprint is still being determined but will ultimately be available to the public. For more, see: https://thebatterypass.eu/assets/images/content-guidance/pdf/2023_Battery_Passport_Content_Guidance_Executive_Summary.pdf.

durability to be identified through a single QR code. Battery passport regulations will go into effect in February of 2027.[76]

Due to its comprehensiveness, the EU Battery Regulation could become a template for other countries looking to strengthen second-life EV battery regulations. The EU Battery Regulation is a model framework for increasing battery transparency, setting mandatory rates for recycling and collection, and ensuring proper management over second-life EV batteries.

CHINA

China introduced its EV battery second-life policy in 2012 with the New Energy Automotive Industry Development Plan. This was meant to motivate battery makers to recycle more and expand the number of specialized recycling facilities.[77] In 2017, China took even more steps by implementing EPR policies in the battery landscape. The following year, the country went on to implement two additional significant policies. The first, the Battery Traceability Management Platform, requires manufacturers to use unique IDs to trace batteries, which would ease second life and recycling facility processes. The second, the Interim Measure for the Management of Recycling and Utilization of Power Batteries of New Energy Vehicles, requires manufacturers to collaborate with recycling companies in designing batteries that would be easier to recycle. Pilot programs were also set up across 17 cities to advance and monitor EV batteries' reuse, repurposing, and recycling.[78]

Throughout this time, China also set voluntary recovery rate standards for specific minerals. The voluntary recovery rate was 85% for lithium and a 98% recovery rate was set for nickel, cobalt, and manganese.[79] Companies meeting this voluntary standard can earn a certification, although it is unclear how many companies have pursued this voluntary certification. In 2021, China set up new pilot programs across 20 cities aimed at promoting a green battery supply chain and ensuring direct battery tracking.

China has significantly advanced its second-life EV battery policy to promote a circular economy. While not as comprehensive as the EU Battery Regulation, China's framework addresses many of the same issues. Standards for battery management, information transparency, and recycling rates are reflected in both China's and the EU's approaches on governing second-life EV batteries.

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[76] "Guest blog: Circulor's Guide to the EU Battery Regulation and its Battery Passport Requirement," TechUK, 2023, https://www.techuk.org/resource/guest-blog-circulor-s-guide-to-the-eu-battery-regulation-and-its-battery-passport-requirement.html.

[77] "A Review on Battery Market Trends, Second-Life Reuse, and Recycling," *Sustainable Chemistry*, 2021, https://www.mdpi.com/2673-4079/2/1/11.

[78] "Lithium-ion Car Battery Recycling Advisory Group Final Report," California Environmental Protection Agency, 2022, https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-Recycling-Advisory-Goup-Final-Report.pdf.

[79] "Scaling up reuse and recycling of electric vehicle batteries: Assessing challenges and policy approaches," The International Council on Clean Transportation, 2023, https://theicct.org/wp-content/uploads/2023/02/recycling-electric-vehicle-batteries-feb-23.pdf.

Policies to Promote EV Battery Second-Life Applications

State governments are increasingly taking action to put regulatory frameworks in play to ensure a circular economy for EV batteries. The federal government can make important contributions by investing in battery recycling facilities and changing waste designations, but states are likely to be at the forefront of the push for holistic regulatory environments that will maximize EV battery second-life applications. In this section, the specific policies that states can implement to promote EV battery second-life applications are explored in greater detail.

As states grapple with the best way to create an EV battery circular economy, it is important they identify what should be done with EV batteries at their end-of-life and who should be responsible for taking these actions. Policies that states should explore include:

- Extended producer responsibility;
- Core exchange with vehicle backstop;
- Mandatory reuse, repurposing, and recycling of LIBs;
- Recycling efficiency standards;
- Incentive programs;
- Improving access to battery state-of-health information; and
- Global battery passports.

Extended Producer Responsibility

Extended producer responsibility refers to extending the responsibility for a product beyond its distribution; the responsibility extends past the product's end-of-life to ensure proper disposal. In this context, an EPR policy would make producers responsible for the collection, transport, and eventual distribution of batteries to second-life application facilities. In an EPR policy, the "producer" first refers directly to the auto manufacturers themselves, although once an EV battery is repurposed for a second-life application, the term "producer" is used to refer to the entity that repurposed that battery. Sometimes EPR policies also include an oversight agency to regulate producers and ensure proper management of end-of-life batteries.

For example, California's EPR program requires producers to create a stewardship program reviewed and revised by an oversight agency. This oversight agency will routinely inspect and audit the producer to ensure compliance with statutes and regulations outlined by the program.[80] Recently passed legislation in New Jersey and Washington would create a similar dynamic in those states, where a state agency regulates the EPR model. The EPR model is not unique to EV batteries, as it has already been widely used for other products, such as paint, mattresses, and carpets.[81] This policy is an extremely popular option for EV battery management. It is frequently proposed by organizations studying LIB circular economies, and it will be the central policy for LIB management in the EU and China.

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[80] Extended Producer Responsibility, CalRecycle, 2024, https://calrecycle.ca.gov/epr.

[81] *Id.*

This policy would avoid stranded batteries, and ensure sustainable battery disposal, thereby promoting a circular economy. It also presents additional benefits, such as incentivizing auto manufacturers to cost-effectively design batteries for better reuse, repurposing, and recycling. And it has the benefit of clarity; other policy approaches with multiple responsible parties can create confusion and hinder effective implementation. In contrast, under EPR, auto manufacturers maintain battery responsibility until they are transferred to another second-life facility (repurposing or recycling facility).

States should be aware that EPR policy is often not supported by auto manufacturers, as it increases their regulatory responsibilities. In California's Lithium-Ion Battery Recycling Advisory Group, auto manufacturers had mixed support for EPR. The traditional auto manufacturers present – represented by Honda, Ford, and members of the Alliance for Automotive Innovation – opposed this policy. The all-electric manufacturer present in the working group, Tesla, supported an EPR policy. Despite opposition from some auto manufacturers, EPR is the best option for establishing clear responsibility for EV batteries throughout their second-life applications. The EPR approach clearly defines responsibility, is easily understandable, and doesn't put additional direct costs on consumers or dismantlers.

Core Exchange with Vehicle Backstop

Another option is the core exchange program, paired with vehicle backstops. A core exchange program for EV batteries works by requiring customers to pay a deposit on their battery at the time of purchase. That deposit is then refunded when the customer returns the battery to an appropriate disposal facility. Core exchange programs exist in other sectors, such as for lead-acid batteries. These policies incentivize consumers to return the battery to the proper disposal facility instead of placing the compliance obligation on producers, which is what occurs under an EPR framework. However, the core exchange framework poses significant challenges.

For instance, determining responsibility under a core exchange approach is challenging when there are multiple owners of the vehicle. It is unclear how the core exchange program would work after the vehicle is traded or sold from its first purchaser and becomes a used vehicle. This is crucial to address as EVs with a lithium-ion battery are likely to become increasingly circulated in the used car market over the next few decades. One potential solution to this challenge could be requiring transfer of the core deposit from the original owner to the new owner of the EV at the point of resale. The purchase price of the used vehicle would include the core deposit cost within the sale from the original owner. Then, once the car is sold, the core deposit becomes part of the sale and transfers to the new owner. However, this type of framework has not yet been established for used EVs. Any such approach would need to include clear communication to subsequent owners of the used vehicle about their obligations under the core exchange program. Given the potential chains of ownership, enforcement would likely pose significant challenges. More research is needed to identify how a core exchange program would work with used EVs in practice.

Figure 8. *Electric car charging.*

Another complexity with the core exchange approach occurs where vehicles are still in service but require new batteries. If the vehicle is still under warranty, the producer would likely bear responsibility for providing a new battery and properly managing the old one. For vehicles out of warranty, consumers would still be incentivized to return the battery through the core exchange program because then they would recover the money put down for their battery deposit. Upon returning the battery, the responsibility for battery management would shift from the consumer to the entity running the inspection facility, who would then determine if the battery could be reused, repurposed, or recycled. The only exception to this pathway is if a vehicle battery becomes abandoned, in which case the original auto manufacturer must take responsibility for the battery management. This is called the vehicle backstop, meant to ensure a battery does not become stranded.

The core exchange with vehicle backstop policy essentially pushes end-of-life management responsibility away from the auto manufacturers and onto a set of other stakeholders. This is problematic because auto manufacturers are much better positioned to maintain responsibility throughout a battery's lifespan and ensure it reaches an appropriate second life. Auto manufacturers have superior access to information about batteries. They also have a better understanding of the battery's material composition, a particularly important consideration since EV battery labeling is not mandatory. Additionally, the only way to access state-of-health information for a removed battery is through a proprietary connector owned by the original auto manufacturer.[82] Since auto manufacturers have exclusive access to state-of-health information, they are best positioned to responsibly assess and properly dispose of the battery. If it becomes commonplace for auto manufacturers to be required to take responsibility for EV batteries at the end of a vehicle's life, they are more likely to design batteries in a manner where second-life application provides maximum benefit. This could lead to

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[82] "Battery State of Health – What is It? Why is It Important?," Union of Concerned Scientists, 2022, https://blog.ucsusa.org/jessica-dunn/battery-state-of-health-what-is-it-why-is-it-important.

batteries being manufactured with increased longevity, which would be more successful in second-life applications. For all these reasons, the core exchange program is likely to be more complicated and less efficient than extended producer responsibility.

Unlike the EPR policy framework that is being implemented in the EU, China, and several U.S. states, the core exchange with vehicle backstop policy is more complicated and less tested in the real world. There are several components of the policy framework which are still not entirely resolved. However, it is important to understand this policy, as it is the favored way of assigning battery management responsibility by the major automakers – who are, by far, the most significant producers of EV batteries in the world. Nonetheless, for all the reasons mentioned above, EPR is likely to remain the most effective policy in creating an EV battery circular economy.

Mandatory Reuse, Repurposing, and Recycling of LIBs

While it is crucial to identify who will be responsible for EV batteries, it is also necessary to outline what will be done with the batteries and the order in which these steps should occur. The best practice is first to identify the state of the battery. Once the state of the battery is identified, the appropriate next step in the circular economy can be determined. Where possible, priority should be given to reusing the battery. At times a retired EV battery may require refurbishment, superficial work such as replacing components or individual cell modules before it can be reused. If refurbishment and reuse are not possible, the next best alternative is repurposing the battery for use in another application. Finally, if no other options are appropriate, the battery should be sent for recycling.

To ensure policy frameworks are definitive and actionable, states must clearly define these steps and the priority ranking. For example, the state of Washington recently passed legislation that proposes a "battery management hierarchy" to prioritize certain end-of-life processes.

Washington's SB 5144[83] states that:

> "(2) 'Battery management hierarchy' means a management system of covered batteries prioritized in descending order as follows:
>
> (a) Waste prevention and reduction
>
> (b) Reuse, when reuse is appropriate
>
> (c) Recycling"

And the bill further clarifies how different applications are prioritized within battery stewardship programs:

> "Batteries collected by the program must be managed consistent with the battery management hierarchy. Lower priority end-of-life battery management options on the battery management hierarchy may be used by a program only when a battery stewardship organization documents to the department that all higher priority management options on the battery management hierarchy are not technologically feasible or economically practical."

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[83] Washington Senate Bill 5144, 2023, https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/Senate%20Passed%20Legislature/5144-S2.PL.pdf?q=20240226084227.

It is also vital to create standard definitions within this process. For example, New Jersey bill S3723 provides definitions for many key terms, such as remanufacture (synonymous with “refurbish”), repurpose, and recycle.[84]

Recycling Efficiency Standards

Recycling efficiency standards minimize material waste. Recycling can be completed at high recovery levels. For example, Redwood Materials averages recovery of about 95% of the raw materials recycled at its facility in Nevada.[85] Certain policies, such as ones in the EU, will phase in recycling content standards to allow time for all facilities to meet these high-level targets. Recently, Washington state required a recycling efficiency rate of at least 60% for rechargeable batteries.[86] Enforcing recycling efficiency rates of all batteries that operate within the state is challenging, as many EV batteries may ultimately cross state boundaries to be reused, repurposed, or recycled. However, this could be a boon for more recycling in some instances.

Take for example Nevada, which has some of the largest battery recycling facilities in the country. If Nevada implements stringent battery recycling efficiency standards, those will pertain to all the batteries entering the state to be recycled from other jurisdictions. States should also monitor actions by the federal government, which could potentially set their own minimum threshold for EV battery recycling. While there are certainly complexities with potential federal regulation and the fact that EV batteries may cross borders, Washington has demonstrated that states can take action to set their own recycling efficiency standards, and other states pursuing second-life EV battery policies should follow suit.

Incentive Programs

Incentives for businesses to invest in EV battery second-life applications help encourage a circular economy. EV battery recycling is in the early stages of market development. Incentives and other industry support will help EV battery recycling scale. Currently, the federal government provides incentives for research on EV batteries, mainly through the Department of Energy. Additionally, clauses within the IRA indirectly incentivize recycling EV batteries; materials from recycled LIBs can help batteries qualify as U.S. made for tax rebates.[87] Incentives should be expanded to include other second-life applications, such as incentives for reuse and repurposing.

While many incentives occur on the federal level, states can and should explore opportunities to support EV battery second-life applications. Grants that help fund research on EV batteries and the formation of second-life application facilities can rapidly speed up the timeframe for the emerging market to become profitable.

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[84] New Jersey S3723, "Electric and Hybrid Vehicle Battery Management Act," 2023, https://www.njleg.state.nj.us/bill-search/2022/S3723.
[85] Redwood Materials, https://www.redwoodmaterials.com/solutions.
[86] Washington Senate Bill 5144, 2023, https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/Senate%20Passed%20Legislature/5144-S2.PL.pdf?q=20240226084227.
[87] IRA Section 13401 – Clean Vehicle Credit, https://iratracker.org/programs/ira-section-13401-clean-vehicle-credit.

Access to State of Health

It is crucial to increase the amount of available information about EV batteries, as this will benefit assessment of batteries for appropriate second-life use and dismantlement. Currently, to obtain necessary information about a specific battery, one must conduct complex tests to determine what can be done with the battery. One area where increased information access is particularly critical is around the state of health of EV batteries. No current laws require manufacturers to identify the state of health of an EV battery. This information is crucial for dismantlers who obtain the battery at its end-of-life to understand the next steps. Battery state-of-health information is essential to determine whether a battery can be reused or repurposed, or whether it has been degraded to the point that it needs to be recycled. Without this information, entities removing the battery must conduct costly and lengthy tests. In the next several years, when many EV batteries are reaching the end of their first life, ubiquitous access to battery state-of-health information would allow dismantlers to process batteries more rapidly and more cheaply, bringing down the cost and time required to process EV batteries into second-life applications or be recycled.

There are some battery labeling requirements, but even these are not enforced nationwide. States that adopt the Advanced Clean Cars II standards agree to battery labeling requirements, and these will take effect in the next few years as the law is phased in.[88] However, it is yet to be seen whether manufacturers will label their batteries nationwide or only label those destined for the states adopting ACCII. Even with these labeling requirements, immediate access to state-of-health information is not available, although labeling does make it easier for battery dismantlers to identify key battery characteristics. More needs to be done to enable instantaneous access to battery state of health, and states should continue to explore innovative ways to provide this information, in addition to adopting policies like ACCII which lead to better battery labeling practices. Other comprehensive policies, like the global battery passport concept, could also address this important issue.

Implement a Global Battery Passport

Implementing a global battery passport would increase the available information on individual EV batteries. While other policies increase the information necessary for the safety and proper use of these batteries, this approach evaluates the complete life cycle of EV batteries. A global battery passport would provide information – through a QR code – such as where the original materials were sourced, where the battery was assembled, battery state of health, and things like the life cycle carbon impact and footprint of the battery.[89] This would increase transparency around social and environmental concerns with batteries and facilitate a circular economy. Additionally, it would be useful for demonstrating compliance when U.S. regulations regarding a battery's sourced location come into effect with the IRA.[90]

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[88] Final Regulation Order, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/2acciifro1962.6.pdf.

[89] "Guest blog: Circulor's Guide to the EU Battery Regulation and its Battery Passport Requirement," TechUK, 2023, https://www.techuk.org/resource/guest-blog-circulor-s-guide-to-the-eu-battery-regulation-and-its-battery-passport-requirement.html.

[90] To qualify for the federal EV tax credit purchase beginning in 2023, a vehicle can only be eligible for the credit if at least 40% of the minerals within the battery were mined or processed in the U.S., including recycled materials. Implementing a global battery passport could track if minerals within batteries were mined, processed, or recycled in the U.S.

The organization behind the global battery passport – the Global Battery Alliance – has already conducted several pilot programs for the project.[91] These passports are also a part of the EU's battery law and will be implemented in 2027.[92] The EU was the first jurisdiction to implement a requirement for a global battery passport, and it is not clear if this policy could be implemented at the state level in the U.S. However, given the passport's ability to simplify many key processes needed for a true EV battery circular economy, state leaders should explore if it is possible to require this in any new EV battery second-life policies.

***Figure 9**. Used lithium-ion battery undergoing repair.*

Benefits of EV Battery Policy

As discussed throughout this report, significant progress is needed to create a circular economy for EV batteries. However, in recent years, policymakers across the globe have begun to recognize that there are also significant benefits to promoting EV battery second-life applications and are implementing policies to create an ecosystem in which EV battery reuse, remanufacturing, and recycling is technically feasible and economically beneficial. State governments are emerging as key actors for advancing EV battery policies and are demonstrating that they can establish regulatory frameworks faster than the federal government.

Economic Benefits

A circular economy for EV batteries can yield significant economic benefits. These can be broken down into specific reuse, repurposing, and recycling benefits.

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[91] Battery Passport Pilot, https://www.globalbattery.org/action-platforms-menu/pilot-test.

[92] "Guest blog: Circulor's Guide to the EU Battery Regulation and its Battery Passport Requirement," TechUK, 2023, https://www.techuk.org/resource/guest-blog-circulor-s-guide-to-the-eu-battery-regulation-and-its-battery-passport-requirement.html.

Historically, reused batteries can be less expensive than new batteries; past studies have found that the cost for reused batteries can be as low as $20 per kWh, with most falling in the range of $44 to $180 per kWh.[93] In comparison, a new battery during the same period cost around $198 per kWh.[94] As costs of new LIBs are declining, reused batteries and new batteries are becoming more cost-comparable. Investments in the battery supply chain have allowed new lithium-ion batteries to fall to a record low of $139 per kWh.[95] Prices of reused batteries remain variable, with prices ranging from $20 to $300 per kWh. However, as the supply of used batteries increases, it is likely their prices will drop to the lower end of this range. Considering that a battery accounts for 40% of an EV's price, any reduction in price can be significant to the overall cost.[96]

Repurposing an EV battery can provide economic benefits in larger-scale applications. An increasingly popular application entails using retired EV batteries to store energy, which can then be sold back to the electricity grid at peak hours. LIBs are particularly useful for storing energy due to their "low maintenance, longer lifespan, high specific power and energy, low internal resistance, fast charging capabilities, and low self-discharge."[97] Companies like B2U are already using retired EV batteries as onsite grid storage,[98] and are demonstrating that this is a profitable use case.[99]

Finally, recycling EV batteries' component parts also has potential to be profitable. Recycling for smaller-scale batteries is already profitable, and it's expected that this will be true for EV batteries within the next few years.[100] Once the recycling market expands, potential profits on the batteries might approach $22 per kWh.[101] For a Tesla Model Y, by far the most popular EV globally[102] and in the U.S.,[103] this represents a potential profit of nearly $1,500 per recycled battery.[104] Manufacturers and battery producers are already recognizing the potential profitability of this emerging market by making investments in the recycling industry. As shown in Table 2, partnerships between producers and recycling facilities started in 2021 and have continued in 2023.

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[93] "Identifying and Overcoming Critical Barriers to Widespread Second Use of PEV Batteries," National Renewable Energy Laboratory, 2015, https://www.nrel.gov/docs/fy15osti/63332.pdf.

[94] *Id.*

[95] "Lithium-ion battery prices hit record low, drop 14% from 2022: BloombergNEF," Utility Dive, 2023, https://www.utilitydive.com/news/lithium-ion-battery-prices-record-low-production-bnef/700825.

[96] "Focus: The battery test race to work out what used EVs are really worth," Utility Dive, 2023, https://www.utilitydive.com/news/lithium-ion-battery-prices-record-low-production-bnef/700825.

[97] "Potential of lithium-ion batteries in renewable energy," 2015, *Renewable Energy*, https://www.sciencedirect.com/science/article/abs/pii/S0960148114007885.

[98] B2U Storage Solutions, https://www.b2uco.com.

[99] "B2U Repurposes Used EV Batteries," Los Angeles Business Journal, 2023, https://labusinessjournal.com/featured/b2u-repurposes-used-ev-batteries.

[100] "One Year Update: Redwood's California EV Battery Recycling Program," Redwood Materials, 2023, https://www.redwoodmaterials.com/news/update-california-ev-battery-recycling-program.

[101] "Financial viability of electric vehicle lithium-ion battery recycling," *iScience*, 2021, https://www.sciencedirect.com/science/article/pii/S2589004221007550?via%3Dihub.

[102] "Ranked: Electric Vehicle Sales by Model in 2023," Visual Capitalist, 2023, https://www.visualcapitalist.com/electric-vehicle-sales-by-model-2023.

[103] "The Most Popular EVs of 2023," Energy Sage, 2023, https://www.energysage.com/electric-vehicles/most-popular-evs.

[104] A Tesla Model Y battery is 67 kWh. At a profit of $21.91 per kWh battery recycled, this represents a potential profit of $1,468 per battery.

Producer	Recycling Facility	Date Announced
Panasonic	Redwood Materials	November, 2022[105]
Ford Motor Company	Redwood Materials	September, 2021[106]
Volkswagen Group of America	Redwood Materials	July, 2022*[107]
Toyota Motor North America	Redwood Materials	June, 2022*[108]
General Motors	Li-Cycle	May, 2021*[109]
Honda Motor Company	Ascend Elements	February, 2023[110]

Table 2. *Partnerships announced between producers and recycling facilities within the last few years. Asterisks indicate that the partnership has been expanded after the original announcement date.*

Each component of the EV battery circular economy leads to investments in local economies and the creation of clean energy jobs. One study found that "for every 1,000 tons of end-of-life LIBs as waste, 15 jobs are created for the collection, dismantling and recycling of said batteries." [111] A U.S.-based circular economy will also ensure an increase in jobs in the production sector that has been historically outsourced to other countries. Investment into this circular economy has already begun; $74 million was recently invested into building out recycling and reuse products in the United States.[112] These investments cover a wide variety of the second-life products, with funding given to separation and processing facilities like the American Battery Technology Company in Nevada and EV battery energy storage unit facilities like Element Energy in California.[113] The map below shows a few spots in the West where second-life application facilities are already in use.

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[105] "Panasonic and Redwood Materials strike multibillion-dollar battery component deal for U.S. production," CNBC, 2022, https://www.cnbc.com/2022/11/15/panasonic-redwood-materials-strike-battery-component-deal.html.

[106] "Redwood Materials and Ford Motor Company announce strategic relationship," Redwood Materials, 2021, https://www.redwoodmaterials.com/news/redwood-materials-and-ford-motor-company-announce-strategic-relationship.

[107] "Redwood Materials and Volkswagen Group of America announce partnership," Redwood Materials, 2022, https://www.redwoodmaterials.com/news/redwood-and-volkswagen-partnership; "Volkswagen Expands Redwood Materials Collaboration with Consumer Battery Recycling Program," Batteries News, 2023, https://batteriesnews.com/volkswagen-expands-redwood-materials-collaboration-consumer-battery-recycling-program.

[108] "Redwood Materials and Toyota collaborate on electric vehicle battery collection, remanufacturing, recycling, and battery materials supply," Redwood Materials, 2022, https://www.redwoodmaterials.com/news/redwood-materials-and-toyota-collaboration; "Toyota, Redwood Materials expand deal to source recycled battery materials," Manufacturing Dive, 2023, https://www.manufacturingdive.com/news/Toyota-Redwood-Materials-expand-recycled-battery-materials-agreement/700463.

[109] "Ultium Cells LLC and Li-Cycle Collaborate to Expand Recycling in North America," GM, https://news.gm.com/newsroom.detail.html/Pages/news/us/en/2021/may/0511-ultium.html; "Li-Cycle Expands Partnership with Ultium Cells LLC: Li-Cycle to Operate New Lithium-Ion Battery Recycling Facility Co-Located with Ultium Cells LLC's Battery Cell Manufacturing Plant in Ohio," Li-Cycle, 2022, https://investors.li-cycle.com/news/news-details/2022/Li-Cycle-Expands-Partnership-with-Ultium-Cells-LLC-Li-Cycle-to-Operate-New-Lithium-Ion-Battery-Recycling-Facility-Co-Located-with-Ultium-Cells-LLCs-Battery-Cell-Manufacturing-Plant-in-Ohio/default.aspx.

[110] "Honda and Ascend Elements Reach Basic Agreement to Collaborate Toward Stable Procurement of Recycled Lithium-ion Battery Resources in North America," Honda, 2023, https://global.honda/en/newsroom/news/2023/c230227aeng.html.

[111] "EV Battery Recycling and Its Impact on Society," IEOM Society International, 2020, https://www.ieomsociety.org/detroit2020/papers/731.pdf.

[112] "Biden-Harris Administration Announces Nearly $74 Million to Advance Domestic Battery Recycling and Reuse, Strengthen Nation's Battery Supply Chain," U.S. Department of Energy, 2022, https://www.energy.gov/articles/biden-harris-administration-announces-nearly-74-million-advance-domestic-battery-recycling.

[113] Bipartisan Infrastructure Law: Electric Drive Vehicle Battery Recycling and Second Life Applications Funding Opportunity Announcement, U.S. Department of Energy, 2022, https://www.energy.gov/sites/default/files/2022-11/Recycling%20and%20Second-Use%20Selections%20Factsheets%2011-16.pdf.

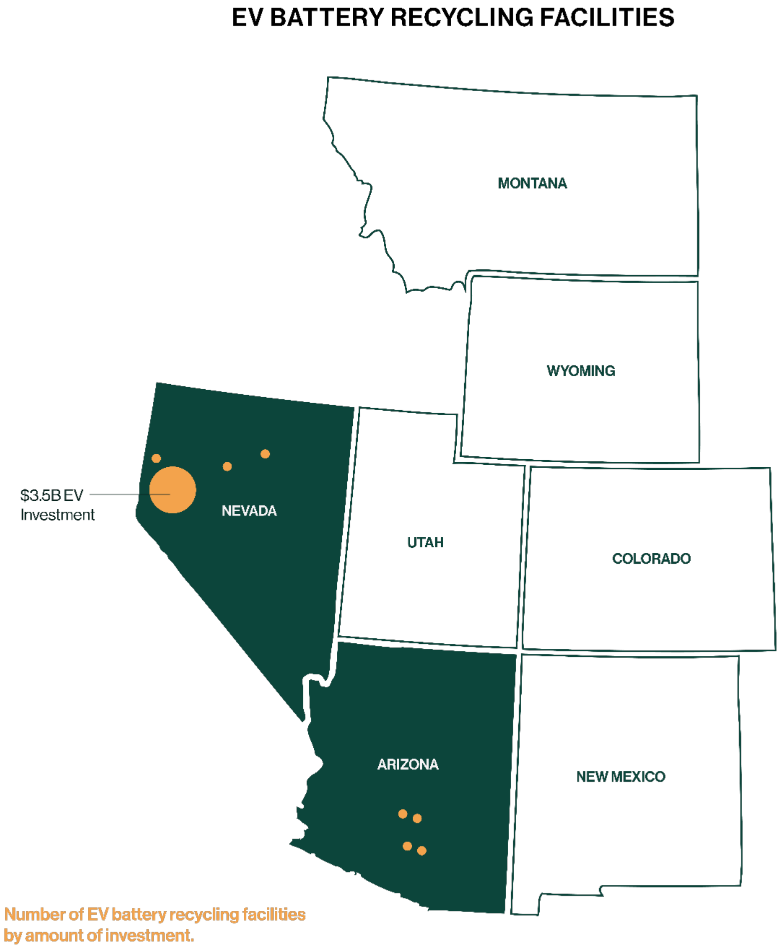

***Figure 10**. Locations of second-life application facilities in the West, updated as of 12/19/2023.*[114]

Environmental Benefits

Beyond the economic benefits, there are also significant environmental advantages associated with a circular economy for EV batteries. One of the most prominent benefits is the reduced need for mining. Reusing and repurposing batteries will reduce the pressure on mining to produce new batteries, and recycling will allow for reused materials instead of raw ones. According to one study, if all lithium-ion EV batteries were recycled, the demand for raw minerals could be reduced by up to 64% by 2050.[115]

Reusing and repurposing batteries also dramatically extends a battery's lifespan, which, in turn, can reduce its carbon footprint. For instance, the carbon footprint of a single lithium-ion EV battery can be reduced by 17% when it is reused or repurposed before being recycled.[116] This also applies to the applications EV batteries can be repurposed in; using an old EV battery to meet energy storage needs

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[114] EV Jobs Hub, BlueGreen Alliance Foundation, https://evjobs.bgafoundation.org.

[115] "Creating a circular EV battery value chain: End-of-life strategies and future perspective," *Resources, Conservation & Recycling*, 2022, https://www.sciencedirect.com/science/article/pii/S0921344922003275.

[116] "Second life and recycling: Energy and environmental sustainability perspectives for high-performance lithium-ion batteries," *Science Advances*, 2021, https://www.science.org/doi/10.1126/sciadv.abi7633.

rather than developing a brand-new energy storage unit will further improve the life cycle emissions benefits of energy storage. Additionally, energy storage supported by retired EV batteries allows commercial or residential customers to sell energy to the electricity grid during peak hours. These systems can then reduce the load on the grid during peak hours and could even reduce the need for carbon-intensive peaker plants.[117]

National Security Benefits

A circular economy in the United States can provide national security benefits. The U.S. has a limited domestic supply of most minerals used in LIBs, due to low deposits and lack of infrastructure. As a result, the U.S. is dependent on foreign supplies of critical minerals. Currently, the U.S. is attempting to bolster the domestic supply chain through mineral requirements for EV batteries from the Inflation Reduction Act, which incentivizes battery manufacturers to use recycled batteries.[118]

Reliance on other countries for these minerals could decrease U.S. security and leave the country vulnerable to global market shifts. The need for any material from another country puts the domestic market at a higher risk. Events of war, natural disasters, supply chain disruption, or economic instability in other countries can cause disruption in the U.S. if we rely too heavily on these nations. Increasing the availability of EV batteries domestically through a circular economy will allow the EV market to remain more durable in times of global instability.[119]

Conclusion

The U.S. transition from internal combustion engines to electric vehicles is well underway. In the coming decades, these electric vehicles will begin to retire by the thousands. As these vehicles retire, a significant supply of lithium-ion batteries, full of valuable materials, will become available.

While there is still time before most of these vehicles reach their end-of-life, we need policies in place to ensure a robust EV battery second-life industry. By developing smart regulations and policies, we can create a more sustainable circular economy for EV batteries. A circular economy for lithium-ion EV batteries will not only help solve the issue of battery production and waste but will also bring economic, environmental, and national security benefits.

Some necessary action toward a circular economy lies within federal jurisdiction, but states are also uniquely positioned to implement policies for EV battery second-life applications. States should consider implementing policies that determine what should be done with retired batteries, such as mandating the reuse, repurposing, and recycling of lithium-ion batteries. States should also ensure that responsibility for lithium-ion EV batteries is clearly defined – ideally by implementing an extended producer responsibility program, as leading markets have already done. Beyond this, states should watch for policies at the federal level that may impact all EV second-life policy. Recycling standards, increased access to information, and updated waste rules for LIBs can greatly impact the management and use of these batteries in their second life.

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[117] "Sustainability Assessment of Second Life Application of Automotive Batteries (SASLAB)," JRC Exploratory Research (2016-2017), Final Technical Report, 2018, https://core.ac.uk/reader/162256840.

[118] For more information on these requirements within the IRA, refer to page 15 of this report in The Current State of EV Battery Policy section.

[119] "Executive Summary: National Blueprint for Lithium Batteries, 2021-2030," Federal Consortium for Advanced Batteries, 2021, https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf.

Appendix

A: Critical Minerals

There are five critical minerals within lithium-ion batteries. For more information on each individual mineral, please refer to the following resources:

- **Lithium:** https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-lithium.pdf
- **Cobalt:** https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-cobalt.pdf
- **Manganese:** https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-manganese.pdf
- **Nickel:** https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-nickel.pdf
- **Graphite:** https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-graphite.pdf

B: Mining Practices

While outside the scope of this paper, increased mining for the use of lithium-ion EV batteries should be carefully studied. Below are some resources for those interested in learning more about mining practices in the U.S.:

- **About mining and minerals:** https://www.blm.gov/programs/energy-and-minerals/mining-and-minerals
- **Clean Energy Minerals Reform Act:** https://democrats-naturalresources.house.gov/imo/media/doc/clean_energy_mineracts_reform_act_of_2023.pdf
- **Initiative for Responsible Mining Assurance:** https://responsiblemining.net
- **FPIC policies:** https://www.ihrb.org/explainers/what-is-free-prior-and-informed-consent-fpic
- **Mining and Environmental Health Disparities in Native American Communities:** https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5429369