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REPORT

BUILDING BATTERIES BETTER:
DOING THE BEST WITH LESS


Assembly workers installing a battery in a plug-in hybrid vehicle at a Ford plant in Wayne, Michigan.

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EXECUTIVE SUMMARY

Meeting our climate goals and reducing harmful air pollution that especially burdens environmental justice communities will require a dramatic shift away from fossil fuel–powered vehicles and toward more plug-in electric cars, trucks, and buses.[1] In fact, we are already seeing increasing demand for electric vehicles (EVs) and expect this demand to accelerate this year and over the coming years. This is good news.[2]

EVs require large rechargeable batteries, and those batteries contain minerals that must be mined—specifically lithium, nickel, cobalt, manganese, and graphite.[3] Unfortunately, mineral mines can contaminate surrounding waters and ecosystems, jeopardize the health and safety of local communities and workers, and run roughshod over sacred Indigenous lands.[4] But EV batteries did not create this problem and are far from the only products that require mined materials. Minerals are in countless items we use every day including laptops, cell phones, home appliances, and even the goalposts and cones used in sports and the buttons and zippers on pants and jackets.

Now that EVs and other clean energy technologies designed to reduce environmental impacts rely on the poorly managed mining industry, calls to clean up centuries of harm from the mining industry are getting louder. EVs could serve as a catalyst to clean up the dirty mining industry's act.

Moreover, EVs will always be a more environmentally friendly choice than fossil fuel–powered cars simply because they do not rely on continuous fossil fuel extraction, which has destroyed aquifers, polluted the air, and harmed the health of so many people over the past century.[5] In 2021 alone, the U.S. transportation sector used 4.86 billion barrels of oil—that's enough barrels to cover more than 300,000 football fields, an area 25 percent larger than the entire city of Los Angeles.[6] Once this oil is burned, it is gone forever. Conversely, an old EV battery is essentially a small mineral reserve filled with extremely concentrated and high-quality materials like lithium and nickel that can be reused again and again.[7] Transitioning to EVs creates an opportunity to reduce long-term reliance on extractive industries that will never be an option for fossil fuel vehicles.

To successfully transition away from fossil fuels, we need to mine minerals for EVs, but we need to do it right. Without appropriate protections in place, EV mineral extraction could end up mimicking the harms of dirty fossil fuel extraction. As we ramp up the production and processing of minerals to meet clean energy needs over the coming years, regulators and industry will need to implement new strategies and policies, such as improved waste management, cleaner extraction technologies, and community engagement and consent for siting that will reduce the impacts of mining as much as possible.[8]

This paper focuses on the most effective strategy to limit the harms from battery supply chains: reducing the type and amount minerals needed. While there are many actions that will reduce the harmful impacts of extracting minerals, these harms cannot be fully mitigated because extraction inherently requires some level of energy, land, and chemical use.[9] Therefore, reducing the amount of mining needed is key to reducing harms. Given the rapid increase in EV production and sales, increasing material efficiency though improvements in battery technology, second-life applications for vehicle batteries, and better recycling will pay dividends over the coming years and decades. These are long-term policies that will not eliminate the need for mining of battery materials. However, they will reduce the amount of new mining we will need in the future and put us on the road to a truly clean and just economy.

The federal government has recently taken steps toward strategically building environmentally responsible EV battery supply chains in the United States through the Bipartisan Infrastructure Law (BIL or Infrastructure Law) and the Inflation Reduction Act (IRA or Climate Law).[10] However, not enough of the funding in this legislation—or strategic planning—is currently going toward reducing the amount of minerals we need.

Building a low-impact and more circular battery supply chain can be achieved by:

I. Decreasing reliance on difficult-to-access critical minerals through technological improvements. For example, the U.S. Department of Energy's (DOE's) Advanced Materials and Manufacturing Technologies Office should direct funding toward improving material efficiency in EV battery manufacturing; the Environmental Protection Agency (EPA) should make batteries a specific category in prize programs such as its Green Chemistry Challenge and in the ecolabel certifications it funds, like the Electronic Product Environmental Assessment Tool (EPEAT); and DOE should continue to award grants through BIL to commercial scaling of improved battery chemistries and ensure that research and development of novel chemistries is also supported.

II. Extending electric vehicle battery life spans through second-life applications. For example, EPA and the U.S. Department of Transportation should create a separate category for used lithium-ion EV batteries within their hazardous waste regulations to reduce unnecessary barriers and costs to reuse (and recycling), EPA should enforce national battery labeling requirements based on the Global Battery Alliance's Battery Passport through the Resource Conservation and Recovery Act, and DOE's Vehicle Technology Office should explore opportunities to expand funding for battery health testing and second-use research and commercial scaling beyond the $73.9 million for R&D available through BIL.

III. Closing the loop: recycling, end-of-life, and recycled materials markets. For example, DOE should expand funding for the ReCell Center's research on battery recycling methods that minimize impacts and maximize recovery rate; the State Department, if possible, should include batteries as one of the next sectors of focus for the First Movers Coalition to encourage public–private collaboration on battery supply chain issues; EPA should set recovery rate targets for battery recycling like those in the E.U. Sustainable Batteries law and require that all EV batteries be recycled; and DOE should prioritize high recovery efficiencies in its selection criteria for BIL grants.

Beyond the technology itself, public policies should provide people with the variety of cleaner transportation options and encourage the use of more efficient vehicles so that fewer minerals are needed in the first place. All of these actions that support more efficient use of minerals and decrease the need for mining must occur in parallel with much-needed mining reform.

The task before us is to produce the minerals we need for a cleaner economy in the best way possible so that we can, once and for all, put the harms from fossil fuels in the rearview mirror.

TRANSITIONING TO ELECTRIC VEHICLES IS CRUCIAL FOR REDUCING GREENHOUSE GAS EMISSIONS AND TOXIC SMOG—BUT WE MUST LIMIT HARMFUL IMPACTS OF BATTERY SUPPLY CHAINS

The U.S. transportation system is responsible for more than 31 percent of our nation's greenhouse gas emissions, the largest share of any sector. That's 1.82 billion metric tons of carbon dioxide equivalent per year—more than the transportation emissions from Russia, India, and China combined.[11] Beyond carbon, transportation is also a leading source of pollutants like particulate matter and carbon monoxide that directly impact public health, especially in environmental justice (EJ) communities (i.e., communities where discrimination based on characteristics such as socioeconomic status and race has caused increased exposure to environmental harm and lack of access to benefits and decision making processes, also referred to as frontline communities or overburdened communities).[12] Moreover, oil extraction to provide fuel for gas-powered transit has led to the obliteration of entire forests, spills that contaminate drinking water and jeopardize entire freshwater and ocean ecosystems, and carcinogenic emissions from wells that have harmed millions of people in the United States alone.[13]

For decades, EJ communities living near freight transportation hubs have been leading the movement for cleaner operations in the transportation sector, including transitioning to zero-emission operations.[14] To answer these demands and to address the massive impact of the U.S. transportation system on public health and climate change, U.S. decision makers must prioritize the replacement of internal combustion engine vehicles with zero-emission vehicles. The majority of these zero-emission vehicles will likely be plug-in electric vehicles (EVs) powered by batteries.[15]

The electrification of our transportation sector will substantially reduce or may even eliminate many of the climate and health impacts associated with fossil fuel supply chains and vehicle emissions.[16] For example, over their life span, the average electric sedan and pickup truck are currently responsible for less than half the greenhouse gas emissions of their gasoline-powered equivalents (including emissions from mineral production and battery manufacturing)—and the emissions reductions and air quality benefits from EVs will continue to improve as more and more of the electricity that charges them comes from renewable resources.[17]

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An oil pumpjack near a playground in Weld County, Colorado.

Although the transition to EVs reduces impacts from the fossil fuel industry, it can increase impacts from other industries. Shifting to EVs is increasing demand for large batteries that present their own supply chain impacts and challenges associated with mineral extraction, material processing, and manufacturing, such as geographic concentration of materials and supply chain activities, environmental contamination, and human rights and labor concerns.[18]

Shifting away from a transportation system dependent on massive oil fields and continuous pushes to drill in new communities and in wild places will provide enormous environmental and public health benefits. But decision makers must not allow transportation electrification to simply shift the impacts of the transportation sector from one community to another. Instead of further burdening communities historically overburdened by transportation pollution and mineral and fuel extraction, decarbonization should benefit these communities, including through improved mobility choices and accessibility for all. To ensure that the transition to EVs does not cause undue harm, it is vital that meaningful community engagement occur early and often in any project, policy, or program development.

This brief focuses on how to make the necessary transition to EVs more sustainable by reducing the need for newly mined materials for EV batteries, in tandem with mitigating the impacts of mining.

THE COMPLEXITY AND MINERAL REQUIREMENTS OF ELECTRIC VEHICLE BATTERY SUPPLY CHAINS MUST BE UNDERSTOOD IN ORDER TO MEET DEMAND WHILE MINIMIZING IMPACTS

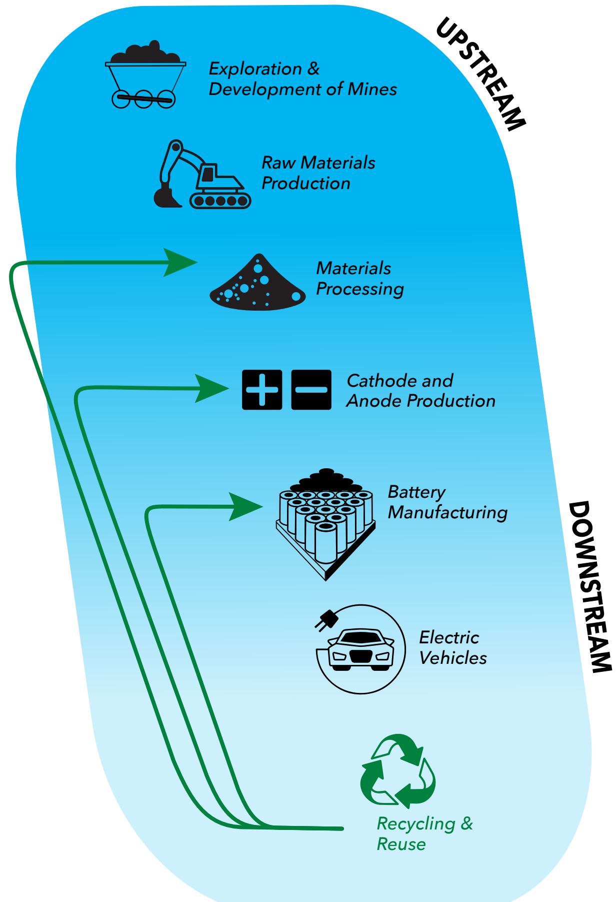
Electric vehicle batteries contain many materials and components that are sourced from around the globe. This makes their supply chains complex, creating challenges in meeting demand as well as opportunities for inefficiency and harm. Understanding that complexity is necessary to implement holistic solutions that overcome challenges in meeting demand while minimizing inefficiencies and harms.

Battery packs are made up of housing and wiring materials like aluminum that connect many small battery cells containing minerals, many of which are designated "critical minerals."[19] The designation refers to a specific list of minerals that are defined by the Department of Interior based on their constrained supply, distribution concentration risk, and ties to economic or national security.[20] The designation of the materials on the list, routinely updated by the Department of the Interior, is subjective.

Currently, there are 50 minerals considered critical.[21] Current clean energy technologies rely on high volumes of 11 of these, resulting in increased demand for minerals with already constrained supply.[22] Five of the 11—lithium, cobalt, nickel, manganese, and graphite—are commonly used in today's leading lithium-ion battery technologies.[23] Many minerals that are on the official critical minerals list are necessary for technologies unrelated to the clean energy transition, and some rare earth elements and other metals, like copper, that are necessary for clean energy transition technologies, including batteries, do not currently meet the definition of "critical." Therefore, terms like "battery minerals" and "transition minerals" better encompass the mineral needs for electric vehicle batteries and other clean energy technologies.[24] However, current laws, regulations, and executive orders use the term "critical minerals" when referring to minerals used in EV batteries and other clean energy technologies, which may allow minerals unrelated to the energy transition to benefit from clean energy policies and funding.

Because EV batteries contain so many elements that must be individually mined and processed before being brought together for manufacturing, electric vehicle battery supply chains include many participants across the globe. The stages of the supply chain progress from upstream extraction to downstream battery manufacturing to recycling (Figure 1).

Figure 1: Electric Vehicle Battery Supply Chain



Infographic by Jessica Russo. Source images by the U.S. Department of Energy and C. Bickel/Science.[25]

The mining industry is responsible for the upstream portion of battery supply chains including identifying and exploring mineral reserves, which can take several years and require drilling for samples to see where minerals exist in quantities economical to mine.[26] After an economically and technologically feasible area for mining has been found, mining begins as ores—sediments mixed with valuable minerals—are extracted from these resources.[27] These ores are then transported to a facility where they are processed to remove extraneous materials and refined to a quality suitable for batteries.[28] Once refined, electrode manufacturers use these materials to make cathodes and anodes—the "positive" and "negative" sides of the battery, respectively—and send the electrodes to downstream processing or facilities that make battery cells (Figure 2).[29] Finally, the battery cells are sent to yet another manufacturing process or facility where they are assembled into large packs that can then be used in electric vehicles.[30] At the end of the downstream portion of this supply chain, batteries can be reused or recycled so that their materials can be recovered and used in new batteries.[31]

Coordination between these streams can be complicated due to challenges related to national industrial capacity and security, enforcement of standards and best practices, and information monitoring and sharing.

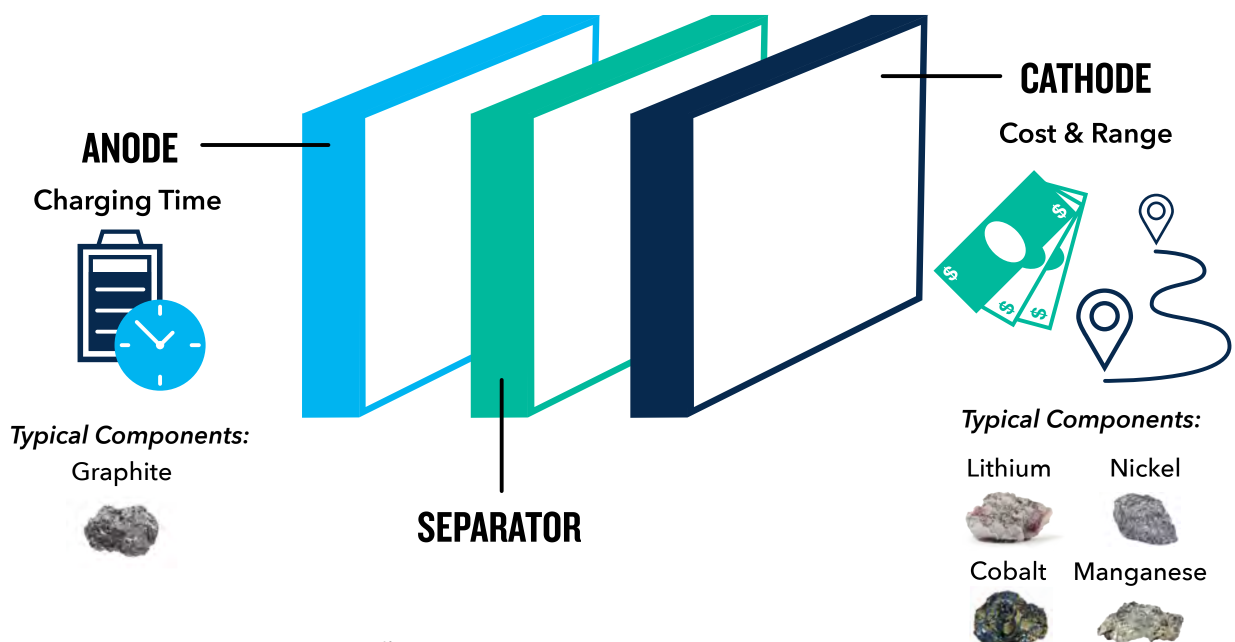
Geographic Concentration of Critical Mineral Stocks and Supply Chain Activities Creates Bottlenecks and Vulnerabilities

Coordination between stages of battery supply chains is made simultaneously more important and more difficult by the natural concentration of many minerals needed for EV batteries in a handful of countries. More than 50 percent of lithium and cobalt reserves (i.e., located and economically accessible stocks) are in Chile and the Democratic Republic of the Congo (DRC), respectively; manganese reserves are concentrated in South Africa, Ukraine, Brazil; graphite is concentrated in Russia, China, and Brazil; and nickel is concentrated in Indonesia, Australia, and Brazil.[32] Regarding ongoing extraction activities, Argentina, Chile, Australia, and China combined make up 90 percent of current global lithium production, and 60 percent of current cobalt extraction takes place in the DRC.[33] In 2021, U.S. manufacturing relied on imports for 100 percent of its graphite and manganese, more than 75 percent of its cobalt, about 50 of the nickel it used, and more than 25 percent of lithium.[34]

This geographical concentration extends beyond upstream mineral extraction to midstream supply chain activities. According to an International Energy Agency (IEA) analysis, China alone accounts for over half of all cobalt, graphite, lithium, and manganese processing, 70 percent of cathode and 86 percent of anode production, and more than 75 percent of lithium-ion battery cell manufacturing.[35] Much of the remaining cathode production and cell manufacturing is located in nearby Japan and South Korea.[36]

The geographic concentration of mineral reserves and midstream supply chain activities in countries with weak governance structures and political conflict leaves supply chains vulnerable to bottlenecks and price volatility. For example, Russia's invasion of Ukraine has caused prices of transition minerals like nickel to soar and fluctuate amid concerns over supply from Russia, a leading global source of nickel.[37] Supply chain activities that occur after extraction, like mineral processing and cathode and anode production, can be more quickly ramped up in other locations since, unlike extraction, they are not directly tied to natural resource distribution.

Figure 2: Electric Vehicle Battery Components



Infographic by Jessica Russo. Source image by Volkswagen.[38]

Rapidly Increasing Demand for Minerals and Underdeveloped Recycled Materials Markets Are Putting Unprecedented Growth Pressure on Global Mineral Supply

Mineral supply streams cannot be expanded instantaneously to meet demand. Exploration of new resources and construction of mine sites take several years.[39] Recycling can help alleviate long-term demand pressure by keeping materials in circulation once they have been extracted.[40]

The clean energy sector is already a significant driver of economy-wide demand growth for some minerals. For example, electric vehicle and grid storage batteries are the largest consumers of lithium.[41] Additionally, clean energy is set to become the sector with the fastest demand growth for many transition minerals; a recent analysis by IEA under a "Sustainable Development Scenario" predicts that clean energy technologies will represent 60–70 percent of global demand for nickel and cobalt and almost 90 percent of demand for lithium by 2040.[42] Batteries alone are expected to account for nearly half of the growth in global minerals demand from the clean energy sector in 2040, assuming rapid decarbonization to meet global and U.S. climate goals.[43] Of the energy storage–related growth over this period, electric vehicles account for 90 percent of that growth, with grid energy storage accounting for the rest.[44] Therefore, the impact of EV batteries on the relationship between supply and demand in global mineral markets is significant, and they will play an even more influential role over the next two decades.

However, increasing demand for EV batteries will have a greater impact on some mineral markets than on others. A World Bank Group report concluded that mineral markets serving multiple sectors or multiple clean energy technologies may be better positioned to keep up with demand than minerals used primarily or exclusively in batteries.[45] For example, EV batteries make up a significant portion of the overall market demand for lithium and graphite, and there are few clean energy technologies other than EV batteries that require these minerals.[46] To keep up with rapidly increasing demand from these technologies, IEA predicts that production levels of lithium and graphite in 2050 will need to increase by nearly 500 percent relative to today's production in order to meet demand under a two-degree warming scenario.[47] On the other hand, aluminum is used in many sectors besides clean energy technologies. As a result, growing demand from clean energy technologies will account for only 9 percent of overall global production levels by 2050 under the two-degree warming scenario.[48] Therefore, aluminum supply will more easily keep pace with increased demand from EV batteries with less price volatility than will metals like lithium and graphite.

The U.S. Department of Energy (DOE) has begun to gather information through public comment periods and research to identify challenges and opportunities and begin strategizing on how to meet critical mineral demand.[49] U.S. government agencies and labs must work together now to determine what gaps may inhibit the United States' ability to meet future capacity needs by analyzing resource requirements and considering strategies like recycling and new battery technologies that reduce the gap between supply and demand by improving material efficiency rather than focusing only on increasing supply.

While the forecast increase in mineral demand can seem daunting, it is important to keep in mind that even though renewable energy and energy storage (i.e., batteries) require more minerals than their fossil fuel counterparts, this comparison is for manufacturing only.[50] During their use, clean energy technologies typically require very few material inputs compared with fossil fuel power plants and vehicles, which, over their entire useful life span, require constant input of mined fuels that cannot be reused.[51] Additionally, because EVs do not need consistent oil inputs throughout their lives, EV owners are much better protected from supply risks and price volatility than owners of gas-powered vehicles.[52]

By acting as a source of the materials needed to produce new batteries, recycled batteries can further alleviate demand pressure for new materials and limit reliance on mining for raw materials and related impacts. Recycling is a crucial part of creating circular economic systems—systems that reduce environmental and public health harms by eliminating waste and pollution and reusing materials.[53] Today's technologies permit 95 percent of critical minerals to be recovered, on average, from lithium-ion batteries during commercial-scale recycling.[54] A University of California, Davis, study concluded that "under idealized conditions, retired batteries could supply 60 percent of cobalt, 53 percent of lithium, 57 percent of manganese, and 53 percent of nickel globally in 2040."[55]

However, the lack of battery labeling requirements, the limited scale of collection and processing infrastructure, the absence of recycled content standards for new batteries, and nuanced waste regulation all contribute to underdeveloped infrastructure for battery recycling and market demand for recycled materials. Further, some countries in Europe still have some pyrometallurgic recycling—a method that recovers little to no lithium and requires additional processing to recover cobalt and nickel.[56] This recycling method will likely be phased out in Europe due to the European Union's enforcement of recycled content standards mandating that certain percentages of materials—including lithium—used in new products must have previously been recycled from old products.[57] Implementation of policies like these is necessary to ensure that recycling can reach its full demand-reduction potential.

BATTERIES RELY ON THE HISTORICALLY HARMFUL MINING INDUSTRY

So many objects we use every day have their own mineral supply chains. EV and consumer electronics battery supply chains present unique challenges compared with many of these other supply chains because of the natural geographic concentration of battery mineral reserves and the unprecedented demand growth for such batteries. Yet all mineral supply chains, EV batteries included, have aspects in common. Mineral extraction has contaminated the environment, harmed human health, and used Indigenous and public lands without proper engagement or compensation since long before EVs became a new demand source for minerals.[58] Now that EVs, a key part of the pathway to a net-zero economy, are reliant on this historically harmful activity and demand for vehicles is skyrocketing, the calls to clean up the mining industry's act are finally gaining well-deserved attention.

Among Other Environmental Harms, Mining Can Contaminate or Deplete Water Supplies

Of the many ways mining harms the environment, its impact on water is of particular concern. Many mineral reserves are in arid climates, and mines can contaminate or deplete water sources that are often integral, culturally significant, or sacred to Indigenous People.[59] Hard-rock waste piles known as tailings, deposited and stored around mining sites, can contaminate the surrounding land and watersheds, and dams meant to contain them have entirely collapsed, causing waste to flow directly into surface water.[60] The particularly horrific failure of the Brumadinho tailings dam in Brazil in 2019 killed 270 people.[61] Toxic waste can also enter watersheds during the mining process, for example through acid mine drainage.[62]

A satellite view of salt ponds at the Albemarle Corporation Lithium Operation in Esmeralda County, Nevada.

The metals mining industry is the United States' single largest source of toxic waste releases.[63] Many former mines are classified as brownfields—sites contaminated by hazardous substances or pollutants and sometimes eligible for support and funding from EPA for cleanup and reuse.[64] According to a Bureau of Land Management inventory of abandoned mines on U.S. public lands, there are more than 50,000 of these sites, 80 percent of which still require further investigation and/or remediation.[65]

Besides contaminating water, many mining methods require high water usage, which can deplete aquifers.[66] The impacts of water usage can be exacerbated by the ecosystems in which mines are often located. For example, a major portion of current global lithium mining takes place in the Puna de Atacama desert region of northern Chile and Argentina.[67] The brine evaporation method for lithium extraction, which is commonly used in Chile (a top exporter of lithium to the United States), requires 18 months of evaporation and water dumping in an already dry ecosystem, with little to no environmental impact monitoring.[68]

Water contamination and depletion plus the physical destruction of mining also endanger wildlife and threatens biodiversity, especially in desert wetlands. In Chile, these wetlands overlap with much of the desired land for mining; moreover, agricultural and pastoral practices of several Indigenous groups in the Puna de Atacama region take place in these areas. So when this land is used for mining, the impacts are widely experienced.[69]

In addition to contributing to groundwater depletion and ecosystem threats, mining projects themselves are at risk of events caused by climate change.[70] For example, climate change is contributing to more frequent droughts which can impact the water supply used at mine sites.[71] Best practices for waste management and new technologies for waste treatment and extraction can help reduce water use and contamination and increase safety around mine sites.

Those living near mines in the United States will tend to bear the localized environmental impacts from mining, such as contaminated water and destruction of natural and cultural resources. These impacts are especially felt by Indigenous communities in this country, as 97 percent of nickel, 89 percent of copper, 79 percent of lithium, and 68 percent of cobalt reserves lie within 35 miles of Native American reservations.[72]

Human Rights Violations and Harmful Labor Conditions Related to Mining Are Documented Globally

Labor and human rights abuses toward Indigenous groups and local communities related to mining are a major concern for some mines and are especially concentrated in a handful of countries outside the United States.[73] For example, in the DRC, which produces 71 percent of global cobalt supply, 20 percent of all production is from small-scale or "artisanal" mines, which have little oversight for health and safety compliance.[74] The Business & Human Rights Resource Centre's Transition Minerals Tracker found that a majority of reported violations in Africa in 2021 were connected to copper and/or cobalt mining in the DRC and Zambia, and violations in South America were mostly tied to three copper mines in Peru.[75] Recent federal administrative action also cited concerns that child labor has been used in Congolese cobalt mining.[76] Although some efforts, such as amendments to the Congolese mining code in 2018, are attempting to regulate the mining sector in the DRC, individuals fear that implementation of these amendments will be weakened as a result of pushback from mining companies and government corruption.[77]

The United States has ratified the International Labor Organization's standards abolishing forced labor and the worst forms of child labor within the United States, and there are very few rights violations reported in the United States according to the Transition Minerals Tracker.[78] But the United States still relies on battery minerals from other countries, and there is still much room for improvement in U.S. labor policies and community engagement on projects.[79] The United States can use its influence as a major purchaser of minerals for batteries to incentivize improved labor practices and human rights protections in other countries. Workforce transition planning and programs are still needed throughout EV battery supply chains to ensure the creation of well-paying and stable jobs and to ensure that those jobs are accessible to local communities where facilities are being sited.

LIMITING THE IMPACTS OF BATTERY SUPPLY CHAINS REQUIRES LIMITING DEMAND FOR NEW MINERALS

Although minerals for electric vehicle batteries come from all around the world, the United States can support programs that incentivize improved practices outside its borders. It can also implement strategies—including better waste management methods, new extraction technologies, and community engagement and consent for siting—to reduce environmental, public health, and human rights issues in domestic mining for battery materials. However, some level of impact is unavoidable for extractive activities.

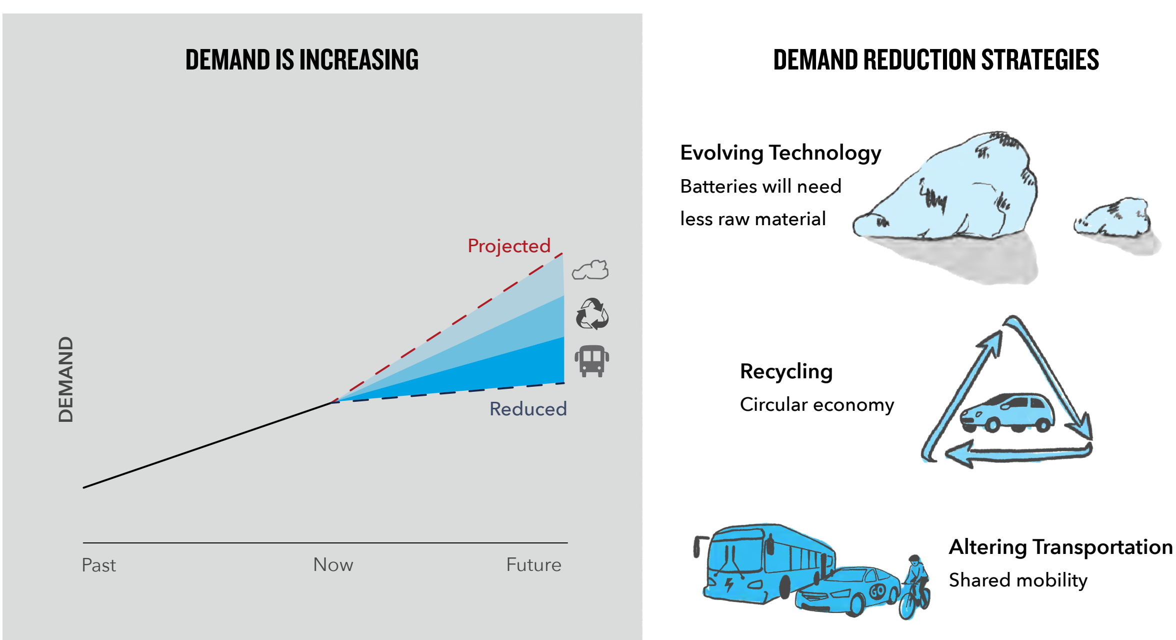
To illustrate, hard-rock mining—a common form of mining authorized at over 700 sites on U.S. public lands today—is inherently harmful due to the excavation of land to get the ores that contain mineral resources.[80] Over time, the chemicals used to extract minerals from these ores and trace amounts of metals leach into lands and waters and impact communities and ecosystems. These impacts have been exacerbated over the past 40 years as resource quality for many mineral commodities has halved, such that extracting the same volume of minerals results in double the amount of waste that was previously generated.[81] For example, extracting one metric ton of a mineral that typically comes from a low-grade ore like copper or nickel required 700 metric tons of resulting waste rock and tailings in 2017, 30 percent more than what was required just seven years prior, in 2010.[82]

The least wasteful and polluting mine is a mine that is never built. Decision makers must prioritize strategies and policies that reduce downstream demand for mineral extraction. Key strategies, illustrated in Figure 3, include secondary uses for EV batteries, efficient recycling, innovative battery chemistries and manufacturing technologies, reducing per-vehicle energy use, and reducing vehicle demand by diversifying mobility choices.

The next five sections of this brief examine recommended strategies and actions for building low-impact and circular EV battery supply chains in the United States, including identifying relevant regulatory agencies, legislation, and potential policies that would help further each specific strategy. The suggested actions are not an exhaustive list but rather demonstrate the range of opportunities to improve EV battery supply chains.

However, it will not be possible to avoid new mining entirely or stop all current mining. Therefore, in parallel to reducing demand for new minerals, mining practices must be reformed to minimize harmful impacts from current and future mining operations.

Figure 3: Strategies That Reduce the Amount of Minerals Needed to Meet Battery Demand



Infographic by Jessica Russo.

Topic 1: Decrease reliance on high-risk and hazardous minerals through technological improvements

Topic 1 Top-Line Actors and Recommendations:

Using different chemical makeups and improving manufacturing of EV batteries can reduce reliance on mineral supply chains linked to human rights concerns or geopolitical conflict.

- Manufacturers can improve battery energy density, design, and manufacturing processes.
- DOE can incentivize manufacturing processes that reduce waste, chemical use, and energy use, and EPA can incentivize innovative battery chemistries.
- The Climate and Infrastructure Laws (IRA and BIL) are existing potential platforms and funding sources for these incentives, and DOE should explore options to expand funding for existing programs.
- Existing ecolabel certifications for IT products, like EPEAT and TCO, can be expanded to include EV batteries to encourage manufacturers to improve battery chemistries, design, and material sourcing.[83]
- Ecolabel certification guidelines can be used as foundations for policies that require all EV battery manufacturers to adhere to best practices for material use and manufacturing.

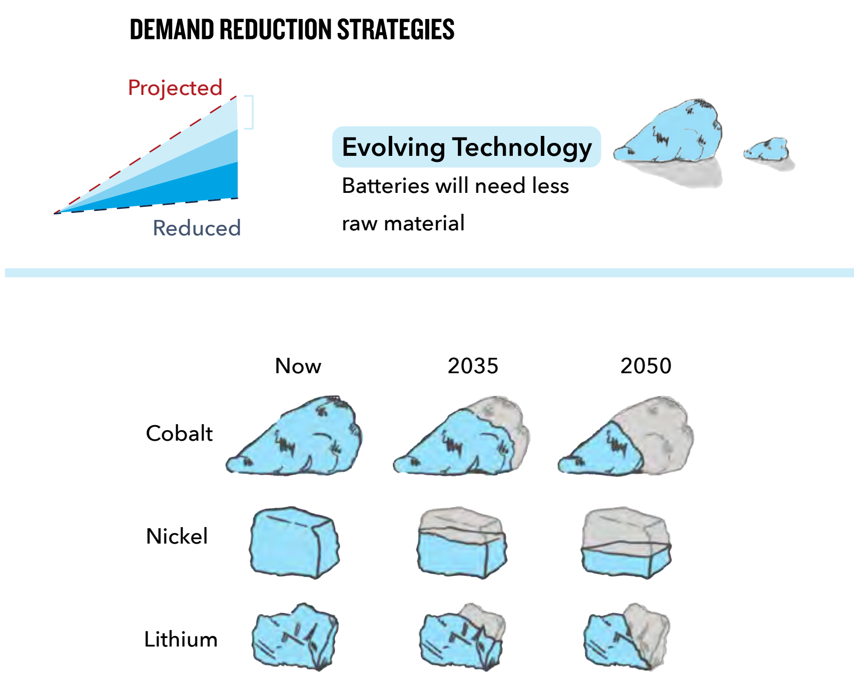
While the current mineral demand forecasts for clean energy technologies seem daunting, it's important to recognize that these forecasts often do not consider the full potential of energy density improvements through new technologies.[84]

Battery energy density refers to the amount of energy a battery can store per unit of its weight (watt-hours per kilogram).[85] Improving battery energy density (Figure 4) increases the amount of energy that can be stored using the same amount of materials. Increasing energy density is important not only for reducing demand for battery minerals but also for improving the range of electric vehicles—how far vehicles can travel on a single charge—through two design options. Since vehicle range is impacted by the weight of the vehicle, which includes the weight of the battery, greater range can be achieved with an improved energy density either by maintaining the weight of the battery pack while increasing its energy storage capacity, or by maintaining the energy storage capacity of the battery pack while reducing its weight.[86]

There are many opportunities for manufacturers to store more energy per kilogram of battery materials, including making improvements in current lithium-ion chemistries or developing entirely new chemistries. Different chemistries can also reduce or even eliminate reliance on the five critical minerals commonly used in today's EV batteries, as supported by analysis from BloombergNEF's *Electric Vehicle Outlook*.[87]

Additionally, improving efficiencies and waste recovery in battery manufacturing processes can reduce the amount of new mineral inputs needed to create the final product.[88] Through strategies like these, batteries can deliver the same amount of energy storage with less mineral extraction, which will reduce costs as well as environmental and frontline community impacts. Essentially, we need to make better batteries *and* make those batteries better.

Figure 4: Evolving Battery Technologies Will Require Less Mineral Content per Battery



Infographic by Jessica Russo.

Issue Area 1.1: Incentivize innovative battery materials, chemistries, and design

TYPES OF LITHIUM-ION BATTERIES

Lithium-ion batteries are a type of rechargeable battery now popular for a variety of technologies including cell phones, computers, and electric vehicles.[89] Within the lithium-ion category, there are many types of batteries that have different chemical makeups. All rechargeable lithium-ion battery chemistries allow lithium ions to travel from the cathode to the anode, where chemical reactions generate an electrical current (i.e., discharge of the battery), and back from the anode to the cathode (i.e., recharge of the battery).[90] Rechargeable lithium-ion batteries use different combinations of minerals in the cathode, and sometimes in the anode as well.[91] Lithium-ion battery chemistries are generally classified by the active materials used in the cathode.[92] As shown in Figure 2, graphite is commonly used in the anode, and some combination of lithium, nickel, cobalt, and manganese (like nickel-manganese-cobalt for NMC batteries or nickel-cobalt-aluminum oxide for NCA batteries) is used in the cathode.[93] Lithium-iron phosphate (LFP) batteries require no cobalt or nickel and use lithium-iron phosphate as the cathode material instead.[94]

New battery chemistries—both in lithium-ion batteries and in new battery types like "solid-state"—will allow batteries to deliver more energy storage with less material need.[95] This reduction in materials can come from 1) improvements in design, management systems, and charging methods that allow a battery to maintain the same general chemistry but use a lesser amount of critical minerals, 2) new ratios of minerals within the same battery chemistry type that shift demand away from specific minerals that have more supply chain risks, such as cobalt, and 3) new chemistry categories that entirely eliminate certain rare and high-risk minerals and/or unlock a new ceiling of energy density potential.[96]

In addition to reducing material use overall, developing new chemistries is an opportunity to reduce toxicity.[97] Research, competitions, and awards are all useful tools for incentivizing new technologies that reduce reliance on critical minerals and toxic chemicals.

Strategy: Improve lithium-ion chemistries

Improving current lithium-ion battery technology by changing the chemical composition of the battery—including more efficiently using current materials and substituting new materials—could help meet the forecast growth in demand for critical minerals.[98] Already since 2010, improvements in lithium-ion chemistries have tripled the energy density of lithium-ion batteries, which has contributed to an 89 percent drop in the price of a battery pack over the same period (on a per energy capacity, or kWh, basis).[99] Further, emerging lithium-ion improvements could again double energy density by 2025.[100] For example, replacing the graphite anodes typically found in lithium-ion batteries with silicon anodes

A mechanical engineering researcher tests novel recycling methods to reduce cost and reduce waste of lithium ion batteries at the National Renewable Energy Laboratory.

could increase lithium-ion energy density.[101] Group14, a company working to improve battery anodes, blends silicon, carbon, and void space to create a material that has been proven as a displacement for graphite anodes and provides a 50 percent increase in energy density and reduced capacity loss over time during use.[102] Material substitutions like these can allow lithium-ion batteries to deliver improved performance at a smaller size.

Additionally, investing in and improving lithium-ion batteries with different chemical makeups can reduce the need for specific metals that are especially constrained by supply chain concentration issues linked to human rights concerns (e.g., cobalt from small-scale mines in the DRC) or geopolitical conflict (e.g., nickel from Russian mines).[103] For example, lithium iron phosphate (LFP) batteries use iron instead of cobalt or nickel, which is a much more abundant material.[104] Even though LFP batteries have a lower energy density than lithium-cobalt, they alleviate reliance on more critical minerals associated with high supply chain risks.[105] Plus, LFP energy density has been improved by recent innovation, such as cell-to-pack technology that reduces overall EV battery weight by eliminating the need to use additional materials to house battery cells in a pack.[106]

Companies like Tesla are using LFP batteries in their standard-range EVs today.[107] In fact, in its 2022 *EV Outlook* analysis, BloombergNEF reported that even with the predicted increases in EV adoption, forecast cobalt demand in 2030 was reduced by about 50 percent relative to the value predicted in its 2019 outlook.[108] This lower-than-expected demand increase is due to shifts toward LFP batteries as well as cathodes with higher ratios of nickel to manganese and cobalt (e.g., from the 1-to-1-to-1 ratio of NMC 111 batteries to the 8-to-1-to-1 of NMC 811).[109] Substitutes for the five main battery minerals can reduce risks and mining impacts. For instance, although the iron used in LFP batteries has fewer supply chain risks than cobalt and nickel, extraction of iron (and other substitutes) still has impacts, which is why improving mining practices is an essential part of the energy transition.

Strategy: Support novel battery chemistry development

Supporting research and development (R&D) of novel (i.e., non-lithium-ion) battery chemistries that—like improved lithium-ion chemistries—can unlock higher energy densities or use non-critical minerals can help reduce reliance on geographically concentrated supply chains.

Researchers are currently developing novel battery chemistries entirely different from lithium-ion batteries that could be used in EVs. Potential new approaches include eliminating cobalt from the cathode and graphite from the anode through technologies like zinc-air and silicon anodes; and reducing price, energy, toxicity, flammability, and metal inputs through technologies like lithium-metal batteries. Research into sodium-ion batteries also shows that they could be a sustainable alternative for short-range EV batteries with carbon anodes and cobalt-free cathodes.[110] Companies like Ionic Materials are developing solid polymer (nonaqueous) electrolytes—the material that ions flow through to pass between the anode and the cathode during charging and discharging—which improve safety and chemical stability of batteries, thus allowing the use of more volatile chemistries such as lithium-metal anodes used in solid-state batteries.[111] Solid-state batteries are also much smaller, and therefore can have higher maximum energy densities than lithium-ion batteries, since smaller volumes of solid materials like ceramics can be used rather than greater volumes of liquid electrolytes.[112] A diverse mix of chemistries can be helpful to minimize demand for any one mineral and for specific high-risk minerals, but this diversity can present challenges to commercial-scale dismantling and recycling at the end of life.

Strategy: Develop battery ecolabel certifications for verifying material use, due diligence, and circularity

Many products have ecolabel certifications to inform customers of certified achievement of environmental priorities and/or energy performance, such as the EPA's EnergyStar® certification, which informs customers of the energy efficiency of household appliances, and the U.S. Green Buildings Council's Leadership in Energy and Environmental Design (LEED) program, which certifies buildings on the basis of their energy efficiency, material toxicity, and indoor air quality.[113] Some certifications may also extend to cover the entire life cycle of a product including labor practices, end-of-life management, and user health and safety.[114] Participation in these certifications is voluntary for manufacturers, but they have an incentive to comply so that their products meet customer preferences or company sustainability commitments.

However, there is no existing certification for electric vehicle batteries. Battery labeling guidelines do exist, but these are separate from ecolabels and do not require that batteries meet any standards; they focus on access to information on the types of minerals, design, and state-of-health metrics of the battery (see Strategy: Require battery labeling).[115] Having some form of certification for EV batteries could help drive uptake for materials with less impactful supply chains.[116]

Fortunately, an EV battery ecolabel certification system would not need to start from square one. There are a few existing certifications that have some components of what an EV-specific certification should include or that could potentially be expanded to include EV batteries using existing monitoring parties. For instance, the Global Electronics Council's (GEC) Electronic Product Environmental Assessment Tool (EPEAT) is a Type I ecolabel (i.e., it requires third-party certification) that has a tiered (i.e., gold/silver/bronze) ranking system.[117] The tiered ecolabeling encourages manufacturers to participate and improve their products to achieve a higher tier. EPEAT covers a wide variety of products determined by the GEC business case analysis and selection process.[118] EPEAT's performance categories will include many items especially relevant to sustainable battery supply chains in the near future since the GEC is working to expand EPEAT evaluation criteria to include attributes like circularity (e.g., recycled content), responsible minerals sourcing, and reduction in hazardous chemicals.[119] Current products covered under EPEAT include mobile phones, servers, and solar panels (photovoltaic modules), so adding electric vehicle batteries may not be a stretch. Plus, the Federal Acquisition Regulation requires that 95 percent of electronic products purchased by federal agencies be EPEAT-registered.[120] Given that the Federal Sustainability Plan established by President Biden calls for 100 percent of new federal light-duty vehicles to be zero-emission by 2027, there is incentive for the GEC to incorporate EV batteries into the EPEAT certification system and/or for EPA to financially support this addition since it provided the initial grant for development.[121]

Another good example of a quality Type I ecolabel is the Swedish Confederation of Professional Employees (TCO) certification system for information technology (IT) products. Although this certification focuses on consumer electronics and server network technologies, it prioritizes responsible mineral sourcing, hazardous substance elimination, and circularity—all of which are major keys to addressing battery supply chain challenges.[122] While the TCO certification does not have a tiered ranking system, the organization does update its criteria every three years to ensure that TCO-certified products address the most pressing sustainability concerns.[123] This regular update process encourages gradual improvements for certified products. Between relevant certification criteria and consistent updates that could incorporate new issues and technologies, the TCO certification could be a useful model for an EV battery certification.

Strategy: Reduce use of toxic materials

R&D for battery technologies should also prioritize reducing the use of toxic chemicals, such as cobalt. Cobalt is found on many toxic chemical inventories in the United States and internationally due to its potential to cause harms to human health including cancer and cardiovascular issues if, for example, workers are exposed to cobalt dust without suitable protections.[124]

Regulating toxic chemicals is a challenging and piecemeal process. In the United States, any contamination from battery manufacturing, recycling, and processing facilities is or could be regulated through the Clean Air Act or the Clean Water Act.[125] But in terms of types and volumes of materials used to make products (i.e., battery chemistries), these would fall under the Toxic Substances Control Act, a federal law that regulates nearly all commercial, industrial, and consumer chemicals.[126] Further, the Resource Conservation and Recovery Act (RCRA) (which will be discussed later as a tool for EPA regulation of recycling) regulates a specific list of chemicals as hazardous waste, but adding a new substance to the list requires a complex administrative process, and even if added, substances can slip through the cracks.[127] As a general example outside EV battery supply chains, EPA's definition of per- and polyfluoroalkyl substances (PFAS) chemicals is much more narrow than the definition widely accepted by the scientific community and international organizations, and as a result, 87 percent of the reported releases of these harmful chemicals in the United States are not regulated as PFAS.[128]

Even though comprehensive toxic chemical regulation can take a long time, it is ultimately the best way to ensure reduced use. In the interim, other tools can help incentivize voluntary toxic chemical reduction in EV batteries. Similar to the ecolabel certification discussed above, there are already many existing certifications, strategies, and awards that support reduction of toxic material use. Batteries—including EV batteries—could be incorporated into these existing green chemistry systems.

For example, EPA hosts the annual Green Chemistry Challenge, which for the past 26 years has recognized labs and companies for their green chemistry successes.[129] Two of the awards over the past decade have been dedicated to battery-related projects.[130] The EPA could further encourage green battery efforts, perhaps by designating a specific vehicle battery category within the competition.

In terms of certification options, the Cradle to Cradle certification is an internationally recognized certification for safety, circularity, and responsibility of materials managed by an independent nonprofit.[131] The certification is based on circular economy principles, has tiered compliance levels, and is endorsed by many major consumer brands, organizations, and sustainability standards.[132] Within the Cradle to Cradle certification are five categories: material health, product circularity, clean air and climate protection, water and soil stewardship, and social fairness.[133] Additionally, a stand-alone Material Health certificate is offered with the goal of ensuring that a product avoids the use of well-known toxic chemicals.[134] There are a couple of products containing consumer batteries that have received the Cradle to Cradle certification, demonstrating that it can apply to batteries.[135] More engagement and collaboration between the Cradle to Cradle organization and electric vehicle and battery manufacturers, as well as federal and private labs developing battery technologies, could help generate interest in developing certifiable batteries.

EUROPEAN UNION'S CHEMICALS STRATEGY FOR SUSTAINABILITY TOWARDS A TOXIC-FREE ENVIRONMENT

The European Union has initiated a comprehensive chemical safety and regulation strategy that focuses on sustainability and was developed as part of its commitment to zero pollution through its Green New Deal.[136] The Chemicals Strategy for Sustainability Towards a Toxic-Free Environment employs many holistic concepts to protect consumers, workers, and the environment from harmful substances.[137] One of these concepts is "safe and sustainable-by-design"—a pre-market approach to reducing toxic chemicals in products.[138] Part of this design approach focuses on "nontoxic material cycles"—limiting toxic materials throughout the life cycle of a product, including its disposal, in order to ensure the safety of recycling processes and the secondary materials they produce, which are key to securing sustainable battery supply chains.[139]

Government agencies can incentivize safe and sustainable-by-design and nontoxic material cycles in industry practices by developing and implementing improved materials policies based on these concepts. For example, part of the E.U. Chemicals Strategy includes the E.U. Commission formulating safe and sustainable-by-design criteria for chemicals, ensuring development and commercialization of safer chemicals, and promoting use of safer chemicals through industrial pollution legislation.[140] The Commission is also tasked with ensuring that safety is maintained throughout products' and materials' life cycles by developing risk assessments for chemicals, supporting expansion of safe recycling facilities, and introducing information requirements to track the presence of chemicals throughout products' life spans.[141]

It would be beneficial for the United States to adopt a similarly holistic strategy for toxic substance regulation to improve on the current piecemeal regulation and limit harms in supply chains across products—thus addressing the root of the problem rather than coming at the issue product by product or chemical by chemical. However, even though such major reform is unlikely in the United States in the near term, decision makers should integrate safe and sustainable-by-design and nontoxic materials cycles into programs for battery supply chains while they are rapidly developing and expanding. For example, recent federal programs like the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA) could use Requests for Information or general comments to gather recommendations on how to incentivize and support nontoxic material cycles through funding allocation.[142]

Issue Area 1.2: Improve efficiency in waste recovery from manufacturing processes

Inefficiencies in manufacturing processes lead to wasted materials. More efficient manufacturing design and processes can reduce the volume of raw materials and mining needed to produce a new battery.

Strategy: Improve material efficiency in manufacturing

Improving today's manufacturing processes so that they produce the same batteries and materials but do so more efficiently, with less waste and scrap, can reduce demand for new materials in the short term. Any chemical or physical process—such as cathode or anode manufacturing—generates some amount of waste or by-products, but these can be minimized by making improvements to each stage of the process. DOE's Advanced Manufacturing Office already manages programs to support the development of improved manufacturing processes.[143] This office should expand and allocate additional funding to any existing programs that already include battery technologies, and new programs and grants should be developed to support specific types of manufacturing improvements for batteries. The Inflation Reduction Act (IRA) is one new source of funding for advancing battery manufacturing processes. The IRA 48C credit provides up to a 30 percent tax credit for "qualifying advanced energy projects," which include production of technology, materials, and components of electric vehicles.[144] The grant programs that DOE is administering as part of IIJA funding for battery supply chains have also already awarded funding to 21 projects, several of which focus on high-efficiency manufacturing; these include the ENTEK U.S. Lithium Separator Manufacturing Project, which eliminates chemicals and improves material efficiency and recycling during manufacturing of separator materials.[145] Therefore, DOE has plenty of pathways to continue incentivizing the least wasteful manufacturing methods for batteries.

Topic 2: Extend electric vehicle battery life spans through second-life applications

Topic 2 Top-Line Actors and Recommendations:

Second-life batteries can extend a product's usable life, reduce greenhouse gas emissions, and provide an option that's cheaper than new batteries. Access to information about a battery's materials and chemistry as well as real-time state-of-health data is crucial for determining battery malfunctions and repairs, evaluating potential second-life uses, and assigning appropriate transportation and waste protocols. This information access is also crucial for recycling at the end of a battery's first or second life.

- EPA and the U.S. Department of Transportation (DOT) both regulate retired lithium-ion batteries through hazardous waste regulations, and both agencies should collaborate to structure alternative waste classifications and handling protocols for EV batteries.[146] An EV-battery-specific waste classification would have to be created at the federal level first before state environmental agencies could adopt it.[147]

Used electric vehicle batteries at ReJoule in Signal Hill, California.

- California's Advanced Clean Cars II (ACC II) regulation requires automakers to adhere to labeling requirements based on the European Union's Sustainable Battery Law.[148] Other states can adopt this regulation under Section 177 of the Clean Air Act, and/or EPA could set a national labeling standard through its authority under the RCRA.[149] Congress has already allocated $15 million to EPA through the Bipartisan Infrastructure Law (BIL) to develop battery labeling guidelines by September 2026.[150] EPA should accelerate this timeline and model labeling guidelines after existing frameworks like the Global Battery Alliance's Battery Passport and the European Union's Sustainable Batteries Law.
- ACC II also requires vehicle manufacturers to make real-time battery state-of-health information accessible via a common vehicle connector and scan tool.[151] Additional standards will be needed to ensure that dismantlers, repurposers, and recyclers will still have access to this information after a battery is removed from its original vehicle.[152] Requiring universal diagnostic systems for batteries is one option to enable information access, and the national Society of Automotive Engineers (SAE) J1634 procedure—the basis for all current EV testing required by EPA—could be a starting point for national battery testing and data access standards.[153]
- Stakeholders, government agencies, and standard bodies will also need to agree on second-life performance, safety, and liability. Standards could be modeled after the European Union's Sustainable Batteries Law, which specifies a transfer in responsibility from the original manufacturer of the battery to the repurposer.[154]

Second-life applications for EV batteries—uses for batteries after a vehicle is retired or the capacity drops below an acceptable range for EV users—allow batteries that have already been manufactured to stay in use longer. Previously used batteries are often still in perfectly good shape for uses outside personal or commercial fleet EV applications, where high ranges are needed and valued.[155] EV batteries are typically retired when their capacity drops to 70–80 percent of the original (typically after around 15 years), but 80 percent capacity of a large battery with high energy density can still meet the needs of many other battery applications.[156] Depending on many factors such as the second-use case and the health of the battery, a second-life battery could provide energy storage for up to an additional 5 to 15 years.[157]

Second-life applications fall into two categories. The first is *reusing*, which refers to a second-life EV battery being used in another EV application. These used batteries could be incorporated into EVs that do not need high ranges, such as forklifts, golf carts, or vehicles making short trips around ports and rail yards.[158] The second category is *repurposing*, which refers to using an old EV battery in another energy storage application. Repurposing includes decentralized energy storage such as fast charging stations, where batteries can be used to provide additional power, as well as solar energy storage for rooftop or microgrid systems.[159] For example, RePurpose Energy has piloted commercial-scale energy storage products from used EV lithium-ion batteries. The company has its own battery testing and management software to determine the health of the batteries it receives and to monitor and manage those batteries during their second-use phases in energy storage systems.[160]

Batteries can also be repurposed into large, centralized grid operations to combat challenges like storing excess solar energy during the day and releasing it at night, or managing differences in energy demand on both a daily basis (due to typical increased energy use in evenings) and an annual basis (due to extreme weather). A study from the National Renewable Energy Laboratory (NREL) identifies peak-load shaving—charging batteries while grid demand is low and drawing power from those batteries when demand is high—as the most promising application for second-life EV batteries, and many utilities and companies are already piloting projects that put peak-load shaving to the test.[161]

Extending battery life spans through second-life applications has several benefits. First, the emissions from using an EV battery are relatively low compared with manufacturing the battery.[162] Therefore, the longer a battery stays in operation, the lower its life cycle emissions on a per-kWh of storage basis or a per-kilometer-driven basis. For example, the International Council on Clean Transportation found that second-life grid applications can extend a battery's usable life by 72 percent, thus resulting in a 42 percent reduction of greenhouse gas emissions attributable to the EV battery on a per-kilometer basis.[163] Second, using second-life batteries in other applications can be much cheaper than purchasing a new battery. For storage applications, second life batteries have a 30–70 percent cost advantage over new.[164] Also, the supply of batteries for second-life applications will likely outpace demand since EV markets are growing faster than energy storage markets.[165]

It is important to keep in mind that a battery cannot be taken out of a vehicle and put straight into a new application. Its current health must first be determined by gathering information such as its power capability, energy storage capacity, and potential cell failure(s) based on the battery's management system.[166] Then the battery may need to be remanufactured or reassembled in order to fix minor issues, replace faulty cells, and ensure that the battery has all of the characteristics needed for its second life.[167] These processes will require data sharing and cooperation among industry stakeholders. Not all batteries will be suitable for reuse or repurposing.

Governments and industry should work together to figure out strategies and policies that allow EV batteries to be reused and repurposed safely before being recycled. They should also work together to educate consumers, new and used auto dealers, and scrapyards about recycling options, incentives, and logistics including how to deliver or ship used batteries and obtain replacements. Many of these actions are also crucial to end-of-life recycling of EV batteries, regardless of whether they are given a second life before recycling.

Issue Area 2.1: Standardize definitions; set labeling requirements; and restructure waste classification, safety, and logistics

Legal definitions, waste classifications, and labeling requirements are key to unlocking second-life uses and end-of-life recycling. Getting a battery out of an EV and into a new vehicle or storage application requires communication among many stakeholders concerning both transportation and logistics as well as information about the battery's chemistry, design, and current health. Streamlining this process will require standardized definitions of terms—including those related to waste and second-life characteristics—and updated labeling requirements. This will ensure that different actors can effectively communicate and that EV waste is handled and recycled appropriately.

Strategy: Create standard definitions for battery sector terminology

All stakeholders and regulatory agencies involved need to agree on definitions of waste, reuse, remanufacturing, etc., so that information from one entity can be easily interpreted by another. Also, there should be standardized definitions for what constitutes first-, second-, and end-of-life batteries that could be based on battery health factors like the amount (percentage) of the original battery capacity remaining. These definitions should have some built-in flexibility to ensure that they don't inhibit reuse or recycling options while still providing clear guidelines. These definitions should then be incorporated into policies and regulations that also clearly define different stages of EV batteries' life cycles and how they should be labeled, transported, handled, and evaluated during each stage.

Strategy: Support unique hazardous waste categorizations and rules for EV batteries

EPA regulates hazardous waste during treatment, storage, disposal, and some transportation-related activities through RCRA.[168] An item is categorized as "universal hazardous waste" on the basis of thresholds for four characteristics: ignitability, corrosivity, toxicity, and reactivity.[169] Lithium-ion EV batteries fall into this category since they can exhibit one or more of these characteristics depending on the type of materials used and the state of charge when disposed of.[170] Hazardous waste management rules are intended to prevent contamination from waste starting at the time of creation and through transportation, storage, and recycling and disposal.[171] However, with just a few exceptions, these rules mandate that all waste must meet the same compliance requirements and do not take into account how hazards and risks vary among waste (or battery) types or what the intended final destination is (e.g., recycling versus reuse versus landfill). Because these rules attempt to apply a one-size-fits-all solution to waste management regulation, they can end up creating barriers to more sustainable end-of-life options like certain types of recycling and reuse; this may reduce investment in battery recovery and motivation to recycle and recover materials.[172]

However, the EPA can create more flexible alternative regulations designed for a specific type of waste, such as lithium-ion EV batteries.[173] For example, lead-acid batteries have their own regulations that prioritize their recovery for recycling purposes.[174] Under this unique categorization, lead-acid batteries are still regulated as a hazardous waste, but they have their own set of rules that take into account risks and hazards related to how they are typically used, collected, or disposed of.[175] This separate categorization implements specific requirements related to transportation, logistics, and storage of these batteries where adherence to all of the general requirements for "universal hazardous waste" would otherwise present unnecessary barriers to collection for recycling.[176] A similar alternative categorization for lithium-ion EV batteries that accounts for their unique hazards and life cycle would ease logistics, costs, and liability associated with reusing, repurposing, remanufacturing, and recycling EV batteries.

LESSONS LEARNED FROM LEAD-ACID BATTERIES

The physical process of recycling lead-acid batteries has contaminated ecosystems and communities, and these harms must not be repeated. However, the process of collecting lead-acid batteries for recycling is wildly successful; nearly all lead-acid batteries are collected for recycling in the United States rather than being chucked into landfills. The reform of waste regulations that allowed for this collection success should serve as a model for other types of batteries.

DOT also regulates lithium-ion batteries during transport through the Pipeline and Hazardous Materials Safety Administration (PHMSA) and hazardous materials regulations that classify lithium-ion batteries as a Class 9 hazardous material.[177] This presents an opportunity for federal waste regulations to help guide states, align cross-jurisdictional requirements, and clarify licensing and compliance for all stakeholders involved. Returning to the example of lead-acid batteries, DOT has shown an ability to adapt regulations based on the circumstances of transport and risks of the item. Used lead-acid batteries are not subject to certain DOT requirements if a specific set of safety standards are met during shipping.[178] Similarly, lead-acid batteries traveling by highway or rail are allowed some exemptions from rules that apply to air and vessel transport.[179] Agencies should similarly collaborate to structure waste classifications and handling protocols for EV batteries and related materials throughout the end-of-life process including evaluation, remanufacturing, dismantling, recycling, and transportation involved in each phase.

EPA must first take action to create EV-battery-specific hazardous waste regulations before states can adopt and implement these rules. All U.S. states and territories can administer their own hazardous waste program under RCRA, except for a few that do not have approved hazardous waste programs like Iowa, Alaska, and Puerto Rico.[180] However, these regulations must be at least as stringent as the federal regulations, which act as minimum standards.[181] Therefore, any changes to universal hazardous waste classifications would have to be made by EPA before state agencies could implement the new rules. To illustrate, the California Lithium-Ion Car Battery Advisory Group suggested that the California Department of Toxic Substances Control (DTSC) consider EV batteries as universal hazardous waste "only after it has been demonstrated they do not have sufficient remaining capacity for reuse or repurposing."[182] But the group's recommendation acknowledged that the United States EPA must first make this status change before DTSC can consider adoption.[183]

Strategy: Require battery labeling

Battery labeling is a crucial early step in battery regulations because labels ensure that actors throughout the battery supply chain—from manufacturing to EV maintenance to reuse and recycling—can access the information they need. Battery labels are separate from ecolabel certifications; they convey information about a battery's materials, chemistry, design, and operational capabilities and health for stakeholders like vehicle mechanics and recycling facilities, while ecolabels verify that a battery meets specific criteria such as responsible materials sourcing.

Without systematic data sharing through standardized labels, it will be difficult to implement and enforce many of the suggested potential solutions to supply chain challenges. Every battery should have a physical label on it that allows third parties beyond the original equipment manufacturer (OEM) to access information like materials and chemistry, lifetime, charging capacity, separate collection requirements, hazardous substances, and safety risks. This label should be accessible while the battery is still sealed (i.e., completely intact) and could exist as a QR code that could be scanned by anyone handling the battery, as is recommended by the Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries (the E.U. Sustainable Batteries Law).[184]

It is possible that OEMs may want to incorporate some sort of log-in or information request through the code or develop a separate information-sharing system for any proprietary information. If this is the case, there should be a streamlined process to ensure that information is still easily accessible. For example, a dismantler that regularly handles EV batteries should not have to go through an approval process for every single battery it receives.

The EPA could enforce these labeling requirements through the RCRA.[185] The Infrastructure Law requires that EPA at least develop battery labeling guidelines by September of 2026 and allocates $15 million for this project.[186] Relatedly, EPA should work with policymakers and industry coalitions to agree on and set clear requirements for what information about a battery should be accessible to anyone, available to specific types of supply chain actors, or available only through one-off requests or contractual relationships with the OEM that produced the battery. The agency should then accelerate the timeline for producing labeling guidelines as much as possible and use existing frameworks like the Global Battery Alliance's Battery Passport and the E.U. Sustainable Batteries Law.

While federal regulations are useful for consistency and guidance, state regulations provide another avenue for battery labeling regulation in the United States, allowing forward-thinking states to move quickly and set regulatory precedent for other early adopters to follow. A current example of state regulations are the battery labeling requirements in the Advanced Clean Cars II (ACC II) regulation adopted by the California Air Resources Board (CARB).[187] These requirements, influenced by the E.U. Sustainable Batteries Law (also referred to as the E.U. Directive), place the responsibility of labeling on vehicle manufacturers and demand both a physical label and a digital identifier linked to a repository of battery information.[188] The physical label must include the battery's chemistry, manufacturer, voltage, and capacity as well as the digital identifier.[189] The identifier must provide access to a virtual information repository that includes the same information as the physical label plus product safety or recall information, safe disposal instructions and considerations, and any hazardous or heavy-metal materials.[190] This repository is also where manufacturers could include additional types of information, such tracking, safety, or disassembly, either voluntary or if required through future legislation. However, ACC II does not require state-of-health data (e.g., remaining capacity) to be accessible via the physical label; this presents hurdles to end-of-life processing.[191]

CARB adopted these labeling requirements in order to boost consumer confidence in EVs and enable second-life applications and recycling.[192] Other states interested in doing the same can also adopt ACC II standards under Section 177 of the Clean Air Act.[193] This is allowed because of a waiver under Section 177 that allows California to adopt its own standards that exceed federal Clean Air Act standards and permits other states to adopt any standards that California adopts.[194] Now that California has finalized the ACC II rule, nine other states have already adopted or committed to adopting this updated rule, thereby laying a foundation for battery labeling in the United States.[195]

GLOBAL BATTERY ALLIANCE'S BATTERY PASSPORT

The Global Battery Alliance (GBA) is a group that includes businesses, industry actors, and nongovernmental organizations and works in partnership with governments to collaborate on initiatives and advocate for responsible and sustainable battery supply chains.[196] GBA prioritizes establishing a circular battery supply chain, lowering greenhouse gas emissions, improving access to high-quality jobs, and protecting human rights.[197] In alignment with these goals, GBA developed a Battery Passport—a digital identifier for each EV battery that holds all life cycle information in one place including state-of-health, material procurement due diligence, and recycling procedures.[198] The Battery Passport is included as a method for battery labeling in the E.U. Sustainable Batteries Law and is recognized in California's Lithium-Ion Car Battery Recycling Group's final recommendations to the state.[199]

Issue Area 2.2: Improve battery management systems access, testing, and remanufacturing

While the labeling requirements mentioned above will allow access to information about a battery's design and material content, access to additional information concerning the battery's real-time condition is also crucial. Acquiring this state-of-health data from batteries, including charging capacity of the battery pack, charging speed, and cell degradation or failure, requires access to the battery's management system. Many stakeholders will need this data, as well as access to management systems, in order to run tests on batteries to diagnose malfunctions, determine repairs, evaluate potential second-life uses, and assign and carry out appropriate transportation and logistics protocol after a battery's first life. Currently there are no regulations in the United States requiring battery manufacturers to ensure that state-of-health data can be accessed through a battery's management system.[200]

To ensure that the process from battery state-of-health determination and testing to its final destination in a second life or at a recycler is as efficient as possible, infrastructure for collecting and testing batteries at the end of their first lives should be built out and co-located with battery recycling and remanufacturing facilities. While the BIL Electric Drive Vehicle Battery Recycling and Second Life Applications Funding Awards administered by DOE's Vehicle Technology Office will deliver $73.9 million in funding for battery health testing and second-use research, larger pots of public funds should be allocated to scaling battery testing and remanufacturing facilities to commercial output level and supporting companies that provide logistics and safety, similar to the funding streams currently available to battery manufacturing facilities.[201] For example, Cirba Solutions was recently awarded funding to expand a recycling facility in Ohio through the BIL Battery Materials Processing and Battery Manufacturing & Recycling Funding Opportunity.[202] The company also provides battery testing and repair, collection, transportation, logistics, and storage services throughout different phases of the battery life cycle, and these activities should have a mechanism of funding support as well.[203]

Strategy: Promote third-party access to battery management systems

As mentioned, many people will need to access information about a battery from its management system. For example, EV owners and prospective used EV buyers should know a car battery's current health relative to when it was new, which could simply be integrated into the vehicle's dashboard display. Repair technicians, especially those who work independently from a car manufacturer or dealership, will need to be able to access more-detailed data than are typically included in state-of-health information, including manufacturer-specific diagnostic and repair information that require automotive service tools.[204]

In addition to the battery labeling requirements outlined above, CARB's ACC II regulation sets data access requirements that will be phased in for vehicle manufacturers over two years for model years 2026 and 2027 and will make additional information like battery voltage, current needed for battery testing, historical use data, and fault codes accessible to EV users and repair technicians via a common vehicle connector and scan tool.[205] CARB based the metrics reporting on the SAE J1634 procedure, which is currently the basis for all EV testing required by EPA and CARB.[206] Since the SAE J1634 testing procedure is already the national standard for lab testing of EV battery capacity and range before being placed in on-road vehicles, it would be a good starting point for national battery testing and data accessibility standards, and it may need to be accompanied by additional data accessibility requirements so that more-detailed information could be required in cases of repair and reuse.

However, the ACC II regulation's state-of-health data standardization requirements have a key shortcoming—there are no requirements for access once a battery is removed from its original vehicle.[207] Typically, battery repurposers or recyclers receive batteries after they have been removed from vehicles, so a complementary policy is needed to ensure that third parties can access the information they need to appropriately determine the next steps for end-of-life batteries destined for recycling or reuse.[208] Recognizing the issue, a majority of California's Lithium-Ion Car Battery Recycling Advisory Group voted in favor of a universal diagnostic system that could be installed on batteries to enable information access after removal from vehicles.[209]

Strategy: Set liability, performance, and safety standards

Another prominent barrier to EV battery second-life applications is the lack of clarity surrounding performance and safety liability for batteries. For example, OEMs may be hesitant to allow their batteries to be used in second-life applications that are entirely managed by another party if they could be held liable for any battery performance and safety issues even if they are not overseeing the battery's use.[210] Or utilities may hesitate to incorporate used batteries into their grid systems since they often do not have stringent performance standards.[211] Stricter battery standards are needed for quality, safety, and performance, as is as a regulatory body that reviews and refines these standards and reports on cost and operating benchmarks to create customer certainty and decrease utility concerns.

To ensure the success of large-scale grid storage second-life applications for EV batteries, battery OEMs will need to collaborate with utility operators and any other owners or operators of grid assets on creating clear liability frameworks and determining how batteries can (and cannot) be used for grid storage. Stakeholders, government agencies, and standard bodies will also need to agree on second-life performance and safety responsibilities and standards.[212] The E.U. Sustainable Batteries Law specifies that when there is a change in ownership status for repairing or repurposing a battery, responsibility for the battery should be transferred to the economic actor that places the battery on the market or puts it into service for its second use.[213] California's Lithium-Ion Car Battery Recycling Group makes a similar recommendation that responsibility should be transferred from OEMs to repurposers, which may include a label change or transfer of responsibility for end-of-life management.[214] However, it may be beneficial for OEMs to maintain liability during second-life uses in the case of producer responsibility and take-back standards for end-of-life batteries, or so that they can retain the value from recycled materials.[215] Potential solutions should be considered through stakeholder engagement.

Topic 3: Close the loop: recycling, end-of-life, and recycled materials markets

Topic 3 Top-Line Actors and Recommendations:

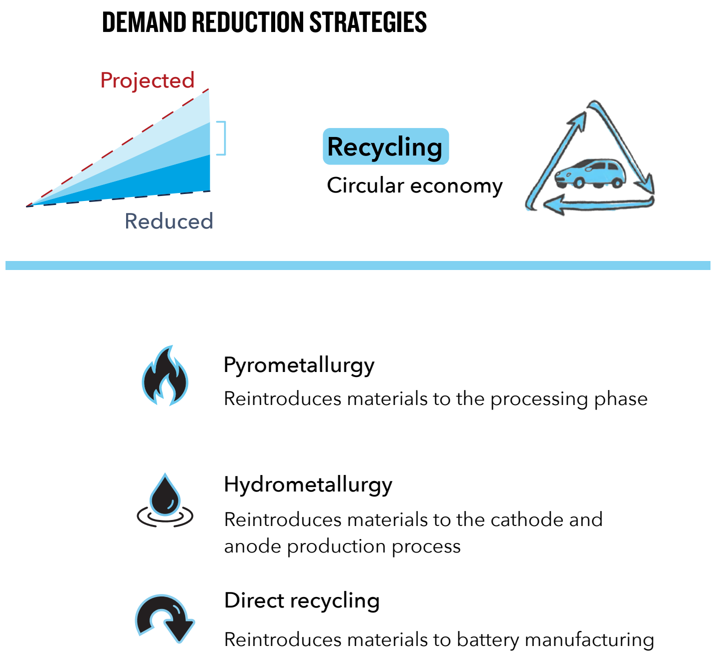
Recycling old batteries provides a source of materials for new batteries without new mining, reduces the life cycle emissions associated with battery production, and moves toward a circular economy that requires less and less new material inputs. There are many additional strategies that, in combination with those recommended in Topic II on battery reuse, will ensure as many batteries as possible are recycled as efficiently as possible.

- EPA could set recovery rate targets through RCRA for recycling facilities similar to the E.U. Sustainable Batteries Law to maximize materials recovery and prevent downcycling.[216]
- Recycled content declarations and standards would also help prevent downcycling by ensuring that recycled materials are reused in new batteries; these standards could be piloted through existing federal procurement policies like the Defense Production Act for the U.S. Department of Defense and implemented through state and/or federal legislation.[217]
- States can implement extended producer responsibility (EPR) and/or core exchange plus backstop policies that clarify who is responsible for collecting end-of-life EV batteries, incentivize collection, and guide collection facility siting and transport requirements.[218]
- Existing sustainable material procurement policies and programs for other sectors, such as those put in place by the federal Buy Clean Task Force, California's Buy Clean Act, and the First Movers Coalition, could be expanded to include EV batteries or used as a model for new battery programs.
- The "smart from the start" approach employed for low-impact siting of solar projects piloted through collaboration with DOE, the Department of Interior, and the Bureau of Land Management can be used as a model to identify sites for recycling facilities.[219]
- DOE has already funded research on efficient and low-impact recycling methods through national labs and the Infrastructure Law, but the agency should expand funding where possible and incorporate disassembly design criteria, Principles of Green Chemistry, and e-Stewards Standards into selection criteria for funding opportunities to incentivize better design for recycling and chemical use.[220]

Even with technologies and strategies that extend EV battery life spans and allow them to be used in other applications after their retirement from vehicles, batteries will eventually reach a point of reduced capacity at which they are no longer effective and will need to be retired. An EV battery is essentially a small mineral reserve filled with extremely concentrated and high-quality materials. Advanced recycling procedures that allow critical minerals and other materials to be recovered from batteries at the end of their lives and incorporated into new batteries will reduce waste as well as the need for raw material mining and refining. Moreover, using recycled materials in new batteries can reduce the life cycle emissions associated with battery production by 7–17 percent due to the energy saved by avoiding upstream raw material mining and processing.[221]

Currently less than 10,000 metric tons' worth of EV batteries are reaching the end of their first lives each year.[222] Because the number of end-of-life EV batteries is so small, many of

Figure 5: Reusing Minerals From Recycled Batteries to Manufacture New Batteries Will Reduce Demand for Primary Minerals



Infographic by Jessica Russo.

them are used in second-life storage pilot projects or being recycled in small quantities at battery recycling facilities that mostly handle consumer electronics products.[223] However, the number of EV batteries that will be retired per year will continue to increase exponentially in the coming decades, which will make reuse and recycling on a case-by-case basis a nonviable waste management option.[224] If governments work with industry actors to clear barriers, develop technologies, and build out infrastructure for safe and circular end-of-life EV battery handling, good policies and programs can be developed from the start of EV retirement and unnecessary waste and hazards can be avoided. Fully closing the loop for EV batteries and ensuring that materials are recovered and reused requires coordination, transparency, and data sharing among many different stakeholders. Definitions, labeling requirements, and waste classifications for enabling second-life uses are also key to streamlining end-of-life logistics and recycling and enhancing access to information needed throughout these processes.

Policy development must focus on keeping materials from end-of-life EV batteries within U.S. battery supply chains through regulations ensuring that (1) materials are recovered from end-of-life batteries, (2) the United States has the infrastructure and workforce necessary to recycle batteries and refine recovered materials, and (3) requirements and incentives encourage reuse of recycled minerals in domestic battery manufacturing.[225]

Issue Area 3.1: Advance efficient recovery technologies and design for recovery

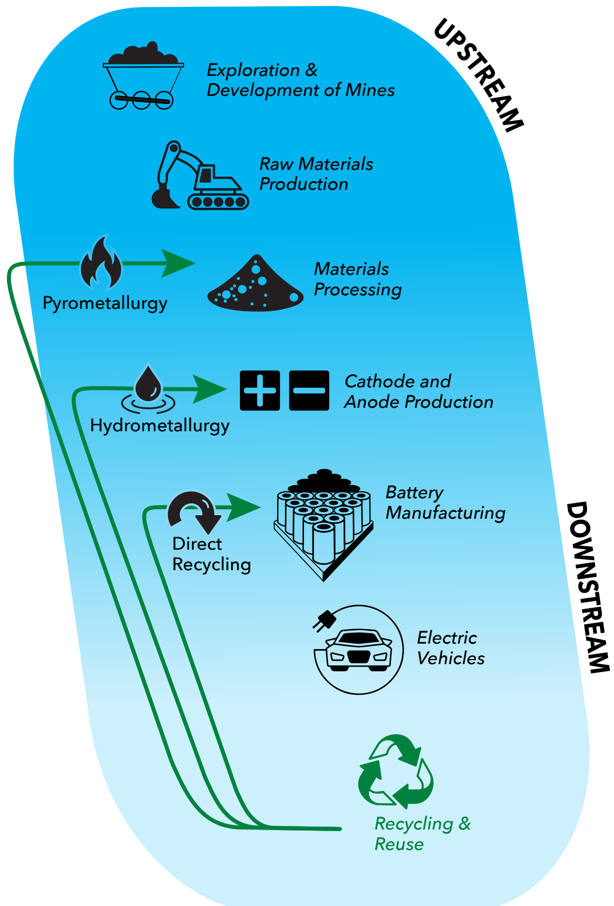
TYPES OF RECYCLING PROCESSES

In the past, pyrometallurgical processing was a common recycling process to recover metals from electronics. This process requires sorting, crushing, and heating and produces a copper-nickel-cobalt-iron alloy of recovered minerals; the other battery materials, like lithium, remain in a slag waste product and are typically not recovered.[226] After the pyrometallurgical process, the resulting alloy can then go through hydrometallurgical processing to further separate the materials.[227] However, this method results in low recovery rates of minerals, and on its own, pyrometallurgical recycling recovers no manganese or lithium.[228] Further, if the materials that are recovered are not refined to a quality suitable for batteries, they may be downcycled from use in batteries into uses that require lower-quality alloys.[229]

Like pyrometallurgical recycling, hydrometallurgical recycling begins with mechanical sorting and crushing but then recovers the minerals by using acids to produce solvents containing the materials.[230] The minerals, including lithium, are then recovered from the solution at rates of 95 percent on average.[231]

A third method of recycling, known as direct recycling, is a recently developed method that has yet to reach commercial scale. Direct recycling begins with dismantling similar to hydrometallurgical processing. Then the battery goes through a series of steps that ultimately recovers the cathode mostly intact to be used in a new battery.[232] The benefits of direct recycling include lower costs, lower energy and water consumption, and lower associated emissions than pyro- and hydrometallurgical recycling.[233] However, there is a trade-off. Because of certain processes inherit to direct recycling, lithium is lost during recycling, resulting in a 40 percent recovery rate—less than half the rate achieved through hydrometallurgical recycling.[234] Because of lithium loss, the recovered cathode must go through relithiation (lithium restoration) before reuse in a new battery.[235]

Figure 6: Outputs from Different Recycling Processes Are Circulated Back Into Different Stages of Battery Supply Chains



Infographic by Jessica Russo. Source images by the U.S. Department of Energy and C. Bickel/Science.236

Three recycling processes (Figure 5 and Figure 6) are common for lithium-ion batteries—pyrometallurgical (smelting—superheating materials), hydrometallurgical (leaching—dissolving with acids and extracting materials from solution), and direct recycling (cathode recycling—recovery of cathode materials without breaking down their chemical structure).[237] Recycling methods, especially direct recycling, can benefit from continued research and support toward scaling commercial facilities. Currently, Argonne National Laboratory, Oak Ridge National Laboratory, and NREL are working to further develop new recycling methods that improve material recovery efficiencies, cost effectiveness, and scalability.[238] The ReCell Center, funded by DOE, allows these labs to collaborate with industry and academia on this research.[239] For example, ReCell is currently researching how cathodes recovered in direct recycling could be upcycled to an improved chemistry—say, from NMC 111 (1-to-1-to-1 ratio of nickel-to-manganese-to-cobalt) to a higher nickel chemistry like NMC 622, which has a higher energy density.[240]

Workers disassembling an electric vehicle battery at Redwood Materials in Carson City, Nevada.

DOE can also allocate grant funding for battery supply chain projects through the BIL.[241] These initiatives should consider prioritizing support for manufacturing and recycling processes that limit toxic chemical use. Even with highly efficient processes, safeguards, and monitoring, no loop can be 100 percent closed; some waste will inevitably enter the environment. Ensuring that recycling processes and the materials involved are not extremely harmful to humans and ecosystems is an essential part of limiting impacts.

Strategy: Support research and development of efficient, scalable, and cost-effective recovery technologies

While IIJA will make $7 billion available for battery supply chain projects within the next few years, only $74 million—just over 1 percent of total funding—was awarded for research and development of recovery technologies.[242] The Federal government should explore ways to allocate more funding to these programs and leverage the existing ReCell program with national labs to help boost research and development capacity for recycling technologies.

Targets and monitoring of the amount of materials recovered through recycling processes can help reduce wasted material. There are two useful metrics for these targets: (1) recycling efficiency, which is the portion of an entire battery that is recovered during recycling, and (2) material recovery, which is the portion of a particular material within a battery that is recovered during recycling. Material recovery rates need to be set for each specific material, but only one recycling efficiency rate is needed.

Setting recovery rates for government-funded research projects early on will ensure development of technologies that have high recovery rates, thus making it feasible to expand these efficiency requirements to all recycling facilities. Once highly efficient technologies can be demonstrated at small and commercial scales, these targets should be required for new facilities and ramped up for any existing facilities. For example, the E.U. Sustainable Batteries Law sets a 65 percent recycling efficiency target for EV lithium-ion batteries in 2025 that ramps up to 70 percent in 2030. Material recovery targets ramp up from 90 percent to 95 percent from 2027 to 2031 for minerals like cobalt and nickel and 50 percent to 80 percent for lithium.[243] These lower rates for lithium may be to accommodate direct recycling, which has approximately 40 percent recovery rates for lithium while hydrometallurgical recycling recovers up to 90 percent.[244] (With rising demand and improving technologies, these rates were raised from their original values at 35 percent and 70 percent over the same period as a result of advocacy from many NGOs.)[245] EPA or state environmental agencies should set and enforce similar ramping rates and consider having different requirements for different recycling methods. Additionally, grant allocators like DOE could incorporate recycling efficiency targets into their selection criteria for funding awards available through the Infrastructure Law and other programs.

Strategy: Design low-impact disassembly and recovery processes

Recycling processes can be energy intensive and can create risk of exposure to toxic materials that are either contained in the battery being recycled or used in the recycling process.[246] Designing and manufacturing batteries for easy disassembly can help limit the challenges of end-of-life recycling by, for example, reducing the amount of energy or chemicals needed for processing. Every battery manufacturer will and should have its own design that allows its batteries to meet its performance metrics. Regardless of differences, each design should be required to consider end-of-life disassembly to make it easier for materials to be recovered and reused in new batteries. Policymakers should work with industry leaders, nongovernmental organizations, and subject matter experts to develop and support disassembly design criteria that enable disassembly plants and recycling facilities to use similar procedures for all battery modules and cells regardless of which manufacturer they originated from.

Additionally, government-funded research programs should incentivize reducing toxic chemicals and processes during recycling. Choosing processes and chemicals with low toxicity concern will lower the risk of harmful chemical exposure for people working in battery recycling; it will also lower the risk for people, land, and water near recycling facilities in the event of an accident or waste releases from the facility. Recycling processes should follow the Principles of Green Chemistry and adhere to e-Stewards Standards, which provide best practices for e-waste management and monitoring of downstream toxic waste for recycling facilities.[247] Adherence to these principles could be considered in grant allocations discussed throughout this section.[248]

Issue Area 3.2: Ensure market certainty for secondary materials

To incentivize investments in recycling infrastructure and in scaling up, there needs to be a market for the secondary materials that are recovered after end-of-life battery processing. Policies that incentivize recirculation of these materials back into new batteries specifically, rather than other technologies, are crucial to ensuring that battery supply chains are circular rather than linear. If these materials are purchased by a sector that exports materials or has less stringent recycling requirements than domestic battery supply chains will ideally have in the near future, then supply chain circularity could be compromised, which would reduce the supply of secondary materials for new batteries and increase the need to mine new materials.

Researchers at the University of California, Davis, modeled costs for different recycling methods for lithium-ion EV batteries. Recycling in the United States in 2020 became profitable at or above approximately 8,000 metric tons per year for hydrometallurgical, 7,000 for direct, and 20,000 for pyrometallurgical recycling.[249] Including transport by train in the analysis slightly increases profitability compared with using only trucking transportation.[250] The total value of recovered materials for LFP batteries decreased much more over time than did materials for nickel and cobalt based chemistries because nickel and cobalt are the two most valuable metals recovered from EV batteries and are not present in LFP batteries.[251] To put these cost parity values into perspective, EV battery retirements in 2020 totaled somewhere between 3,000 and 10,000 metric tons.[252] This volume of retirement is too small for any one facility to reach cost parity by recycling only EV batteries, but retirement numbers are predicted to increase rapidly: Up to 73,000 metric tons of EV batteries could be retired in 2025, and by 2030 this volume could hit more than 400,000 metric tons.[253]

Strategy: Create government requirements and voluntary industry standards for recycled material procurement

The price of recycled materials will continue to decrease, aided by economies of scale as recycling facilities expand (i.e., processing around 10,000 metric tons of old EV batteries each year).[254] However, getting to that point will require initial investments in facility build-out. One way to drive investment in recycling is by ensuring demand for those materials. Government clean procurement requirements for contract awards and voluntary industry recycled procurement and content standards will ensure that major buyers will purchase only recycled materials or even pay a premium for those materials.

As a start, the Buy Clean Task Force established through President Biden’s executive order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability will provide recommendations for data collection; pilot programs; and grants, loans, and technical assistance that will be needed or could be provided by the federal government to establish clean supply chains and procurement requirements.[255]

Similar programs are also being undertaken at the state level. California has already implemented similar state legislation through the California Buy Clean Act, and New York's governor recently signed the Low Embodied Carbon Concrete Leadership Act.[256] These programs are focused on construction materials but could be used as a model for battery materials.

Similarly, the First Movers Coalition is a partnership between companies and government entities managed by the U.S. State Department and the World Economic Forum.[257] Its mission is to define purchasing commitments for clean energy technologies needed for net-zero energy goals, secure commitments from supply chain actors, and implement those commitments.[258] This coalition is made up of more than 60 companies representing more than 10 percent of global Fortune 2000 market value and continues to grow.[259] So far the coalition has announced its focus on seven sectors—aluminum, aviation, carbon dioxide removal, cement and concrete, trucking, shipping, and steel—three of which were added in 2022.[260] Given the category's rapid growth and focus, battery materials would be a fitting addition to the First Movers Coalition sectors.

The Biden administration's recent Presidential Determination (No. 2022-11) that exercised the Defense Production Act to secure a domestic supply chain for critical minerals includes the creation of a strategic reserve of minerals similar to the current Strategic Petroleum Reserve.[261] Given this priority, the administration should use the aforementioned programs as models to create market certainty for secondary materials with its mineral buying power. The State Department, if possible, should include batteries as one of the next sectors of focus for the First Movers Coalition to encourage public–private collaboration on issues like market certainty.

Another way to guarantee purchasing of battery-quality secondary materials is for agencies to implement recycled content standards (RCSs)—minimum percentages of materials contained in newly made batteries that must have been previously recycled—and to specify that the recycled content must originate from battery supply chains. These RCSs would (1) ensure that at least some battery manufacturers' material procurement is reserved for recycled materials, (2) incentivize battery manufacturers to take back batteries, since they would have even more of an interest in maintaining a consistent supply of recycled materials sources, and (3) prevent downcycling of battery materials. In the context of EV batteries, downcycling refers to materials being recovered from recycling old batteries but not refined to a quality high enough for use in new batteries; the resulting secondary material may instead be used in other sectors that may not have similar recycling requirements, and therefore may ultimately end up in landfills.

RCS minimums may need to start low and slowly ramp up. The minimums could begin by being coupled with economic incentives or as part of the labeling requirements for recycled content inclusion. For example, the E.U. Sustainable Batteries Law requires recycled content declaration for new batteries starting in 2027, with mandatory recycled minimums set for 2030 and 2035—cobalt ramping from 12 percent to 20 percent, lithium going from 4 percent to 10 percent, and nickel rising from 4 percent to 12 percent.[262] Researchers at University of California, Davis, concluded that battery manufacturers in the United States could feasibly meet RCSs of 11–12 percent for cobalt, 7–8 percent for lithium, and 10–12 percent for nickel in 2030, with increases to 15–18 percent for cobalt, 9–11 percent for lithium, and 15–17 percent for nickel in 2035.[263] The United States could require recycled content declarations and RCSs through a variety of pathways including mandates for the U.S. Department of Defense's procurement policies through President Biden's Presidential Determination Pursuant to the Defense Production Act or through requirements tied to federal funding like Infrastructure Law grant programs or tax credit eligibility for battery manufacturing and EV purchasing.[264]

PATHWAY FOR ADVOCACY: STATE-LEVEL CONVENINGS AND POLICY RECOMMENDATIONS

While federal guidance is important to steer, standardize, and coordinate strategies and policies throughout the United States, eager states, especially those with more rapidly growing EV markets, could get a head start on recycling regulations. For example, through 2018 legislation California tasked three state organizations—the California Environmental Protection Agency, the Department of Toxic Substances Control, and the Department of Resources Recycling and Recovery—with leading the Lithium-Ion Car Battery Recycling Advisory Group to recommend policies to the state legislature that enable recycling.[265] The law required inclusion of representatives from specific categories of stakeholders like environmental organizations, auto dismantlers, and public and private organizations involved in manufacturing, collection, processing, and recycling.[266] These stakeholders collaborated on a final report of policy recommendations that was published and delivered to California state legislators in May 2022.[267] Lawmakers are expected to introduce legislation in 2023 based on two primary recommendations from the report that define responsibility for end-of-life batteries and recycling—"core exchange with a vehicle backstop," and "producer take-back."[268] This is an example of how state governments can play an important role as a convener of stakeholders and take action on recycling policies developed through collaboration.

A worker unpacking electric vehicle batteries from a delivery truck at ReJoule in Signal Hill, California.

Issue Area 3.3: Build recycling infrastructure

Nearly a million new EVs hit the road in the United States in 2022 alone.[269] This number is expected to rapidly increase over the next decade—with an added boost from the IRA—reaching more than 50 percent of total new passenger vehicle sales by 2030.[270] The infrastructure needed for dismantling, recycling, and refining must be scaled to meet needs before the significant numbers of EVs produced today reach the end of their first lives. To plan for expansion now, governments and universities can host pre-competitive convenings—when several companies in the same industry or supply chain come together to solve a shared problem that does not directly impact competitiveness—to (1) encourage collaboration among industry competitors, (2) avoid antitrust concerns and work duplication, and (3) identify geographical areas or existing manufacturing plants that are prime sites for new or retooled battery collection, recycling, and processing facilities.[271]

Transportation and logistics for recycling an end-of-life battery account for 40–60 percent of the total recycling cost.[272] Co-locating recycling infrastructure with battery manufacturing and remanufacturing plants can ease transportation logistics, communication, and accountability—as well as overall cost. Governments should also work with industry to develop permitting processes and staff up responsible agencies to get infrastructure built out in a timely manner while ensuring that contamination is monitored and prevented and project siting does not place an undue burden on any populations, especially environmental justice communities or inhabitants of Indigenous lands.

Strategy: Plan ahead for new recycling infrastructure

Currently, recycling processes are governed on a state-by-state basis in the United States, but EPA has the authority to set guiding federal standards that act as minimums. For example, all batteries as covered under EPA's Universal Waste Rule legally must be disposed of at a facility permitted through the RCRA, but some recycling facilities may be subject to different requirements that are designed specifically for recycling facilities instead.[273] Siting and approval for these facilities require many activities including community engagement and environmental impact assessments. Uniform national standards and enforcement specific to battery recycling facilities, potentially issued by EPA under the RCRA, would guide states toward new standards and resources needed for successful recycling. A clear process designed specifically for battery recycling facilities rather than universal disposal facilities will allow facilities needed for battery recycling, including storage, dismantling, and processing facilities, to be built effectively and efficiently with community input included from the start.

In terms of siting and land use, NRDC and other organizations have effectively led the way in promoting a "smart from the start" approach to low-impact renewable energy and transmission siting, as evidenced by improvements like fast permitting in Solar Energy Zones on Bureau of Land Management lands in Nevada.[274] Planning ahead for facility siting and using lands that have already been disturbed in some way through previous contamination, invasive species, etc., can lessen impacts while reducing the time needed to complete construction and get the site up and running. DOE in collaboration with NREL identified many of these lands as appropriate for renewables through its Solar Futures Study.[275] A similar evaluation for recycling infrastructure siting potential could be useful in minimizing impacts of the facility on surrounding ecosystems and communities and ensuring that there are enough recycling facilities to process the increasing number of end-of-life EV batteries. However, planning ahead for facilities does not mean that proper environmental and community protections can be disregarded at any point in the planning, construction, or operation of a new facility.

Issue Area 3.4: Guarantee collection for end-of-life batteries

There are many logistical challenges involved in getting an end-of-life battery out of a vehicle or grid storage application and to a dismantling and recycling facility. Legal frameworks are needed to make clear what parties are responsible for end-of-life batteries and guide collection facility siting and needs. Collection sites need to be locally accessible and connected with regional networks of storage and recycling facilities to ensure that batteries can be easily dropped off and stored before being reused or recycled in a timely manner.

Strategy: Mandate extended producer responsibility and/or core exchange plus backstop

Extended producer responsibility, or EPR, refers to the extension of a producer's responsibility beyond manufacturing a product to the entire life cycle of the product, including end-of-life management. [276] EPRs will typically be required for a type of consumer product, such as leftover paints, mercury thermometers, and mattresses.[277] Because EPRs are established product by product, manufacturers of a type of product usually come together to manage end-of-life responsibilities. A producer responsibility organization (PRO) is a common approach to EPR management and entails industry actors managing and funding takeback and recycling requirements. However, the current systems provide too many exemptions for PROs and not enough oversight, so PRO-managed producer responsibility schemes can lead to subpar results and monopolies over recycling systems.[278] Therefore, an alternate model for enforcement when it comes to batteries, such as a government-managed program that industry actors pay into, could help EPR programs achieve targets.

There are other approaches to making sure end-of-life batteries are safely collected. One of these is a core exchange program, a centralized system commonly used for tracking end-of-life disposal of many types of auto parts. A "core," often a monetary deposit, is used to incentivize customers to return a part like a vehicle battery. Core exchange can be combined with a vehicle backstop policy so that manufacturers become responsible for the handling of a battery in the event that the core incentive does not work as planned and no other third party, such as a dismantler or repurposer, has purchased the end-of-life battery and assumed responsibility. California's Lithium-Ion Car Battery Recycling Group voted in favor of a core exchange and vehicle backstop policy in addition to producer take-back policies for EV batteries.[279] However, the California group's recommendations do not specifically say that the "core" for the proposed exchange and backstop policy must be a monetary deposit.[280] This core exchange plus vehicle backstop model is useful for encouraging and specifying responsibility during reuse and repurposing or third-party dismantling but could potentially lead to hazards in practice. For instance, in scenarios where dismantlers are not centralized or affiliated with manufacturers or recyclers, ensuring responsibility is challenging and batteries could end up going unrecycled, which would pose environmental and safety hazards.

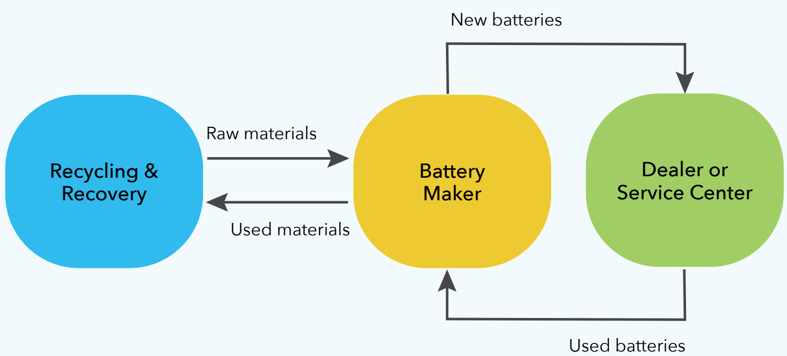
It is also important that producer responsibility requirements include incentives for batteries to be collected and sent to permitted recycling centers within the United States. Keeping recycling domestic is important for ensuring that batteries are recycled in facilities that are permitted and adhere to U.S. environmental regulations. Plus, shipping batteries outside of the United States to be recycled and then shipping the subsequent secondary materials back to the United States would result in unnecessary emissions and costs and could present logistical barriers to battery manufacturers' tracking and accessing secondary materials. In addition to increased emissions from shipping, recycling in other countries may also produce more emissions. For example, recycling in China instead of the United States results in more carbon and other pollutants due to differences in power sources.[281]

BATTERY COLLECTION SUCCESS STORY

Lead-acid car batteries (from gas-powered vehicles) have an almost 100 percent recycling rate in North America and Europe, which means that the majority of materials needed to produce new batteries can come from recycled old batteries instead of newly mined materials.[282] While the actual recycling process for lead-acid batteries is harmful to communities and the environment—and should not be emulated—successful policies to support closed-loop relationships among supply chain actors could be used as a model for EV battery collection. A "one for one" or "old for new" model has been implemented throughout the United States where old batteries are collected at the point of sale, which for lead-acid batteries is an auto dealer or service center.[283] Consumers either are charged a deposit that they can get back only by bringing in an old battery or are required to bring back an old battery in order to purchase a new one. This model, combined with mandatory take-back responsibility for battery or vehicle manufacturers and specific hazardous waste regulation for lead-acid batteries, closes the loop by ensuring that batteries are collected and delivered to a recycling plant. It also encourages use of recycled materials in new battery manufacturing since battery manufacturers already have relationships with recycling facilities due to producer responsibility mandates.

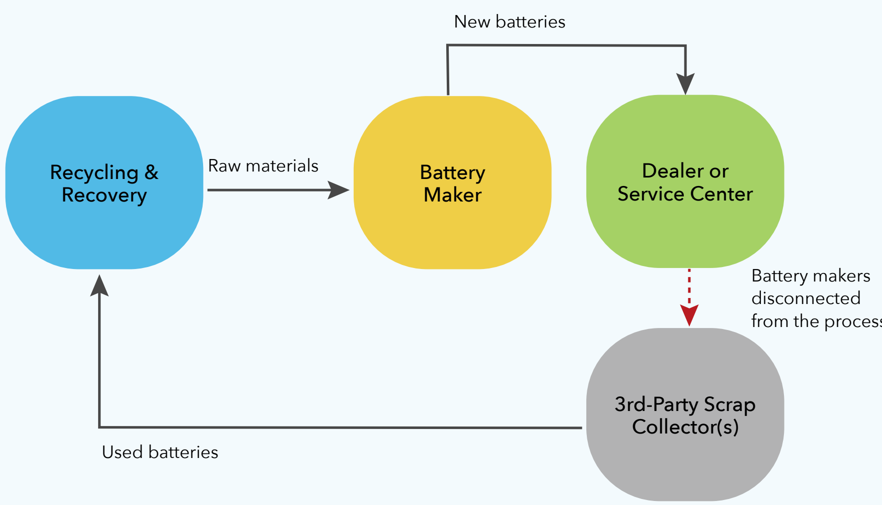
While other forms of closed-loop incentives and requirements have also proved successful in places like the European Union, the lead-acid battery model in the United States simplifies relationships between actors by setting up more direct lines of communication that don't require as many third parties. Regardless, education for stakeholders and consumers as well as data sharing throughout the loop is essential for ensuring battery collection, recycling, and recovered material use. The simplified diagrams below from the Sustainability Consortium and the Responsible Battery Coalition (Figures 7 and 8) illustrate the differences in relationships.[284] This model should be adjusted for EV batteries to account for the fact that they cannot be easily removed from a vehicle and brought into a dealer or service center by a car owner, like lead-acid batteries in gas-powered cars can.

Figure 7: Model for Closed-Loop Recycling for Lead-Acid Batteries in the United States



Infographic by Jessica Russo. Source image by the Sustainability Consortium and the Responsible Battery Coalition.[285]

Figure 8: Model for Closed-Loop Recycling for Lead-Acid Batteries in the European Union



Infographic by Jessica Russo. Source image by the Sustainability Consortium and the Responsible Battery Coalition.[286]

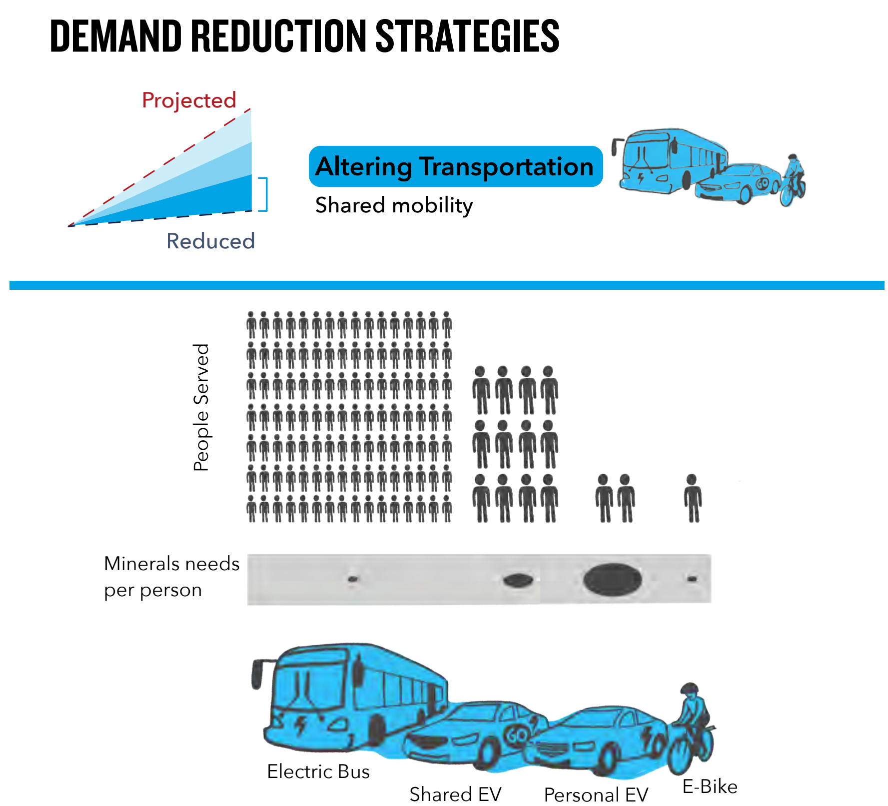
Topic 4: Reduce demand and improve material efficiency for personal vehicles

Topic 4 Top-Line Actors and Recommendations:

Policies that promote efficient passenger EVs and alternate modes of transportation can increase mobility options and access while reducing the amount of minerals needed. One analysis found that implementing such policies can reduce the amount of lithium needed to decarbonize the U.S. transportation system by 18–66 percent by 2050.[287]

- More efficient EVs require smaller batteries and less battery materials, but personal vehicle trends are shifting toward larger, less efficient vehicles.[288] Federal fuel economy and emissions standards should be updated to ensure that stringencies for sport-utility vehicles (SUVs) and pickup trucks match those for sedans and wagons and incentivize vehicle manufacturers to sell the most efficient vehicles.[289]
- More-efficient EVs compound mineral demand reduction by also reducing the grid generation and transmission expansion needed to accommodate transportation electrification. Transmission infrastructure is forecast to be the second-most mineral-intensive part of the clean energy transition, behind EVs.[290]
- EV carshare programs, like Evie Carshare in Minneapolis and Saint Paul, Minnesota, complement transit, biking, and walking and make it more feasible for individuals and households to own fewer vehicles, thereby decreasing demand for gas-powered and electric cars.
- Current federal investments in transportation disproportionately favor road expansion over alternate, shared, and electric transportation infrastructure. Formulas must be updated to shift investment toward underfunded projects and operation and maintenance of existing public transit.[291]
- To maximize the climate, equity, and safety benefits of transportation investments, those investments must be paired with complementary land-use reforms, policies, and programs—such as zoning law reforms that incentivize dense, transit-oriented, and mixed-use development—that ease expansion of mobility choices beyond privately owned vehicles.

Figure 9: Offering Alternate Transportation Options Reduces the Amount of Minerals Needed per Person



Infographic by Jessica Russo.

The United States is an extremely car-dependent nation. Electrifying the current transportation system in the United States would require a lot of individually owned electric vehicles, and therefore a lot of battery minerals. Reducing the number of individual vehicles people need to get around will reduce the amount of minerals needed to fully electrify the transportation system. Undoing the legacy of car dependence will require significant shifts in transportation infrastructure investment strategies and policy changes at all levels of government to provide diverse mobility choices and influence how much people in the United States need and choose to drive. Passenger EVs will still play a significant role in decarbonizing transportation in the United States alongside alternate modes of transportation like electric bikes and buses. Therefore, decision makers should advance policies that make it more desirable to travel by the most efficient passenger EVs as well as by electrified public transit, biking, walking, and carshare and other forms of shared mobility; they should also advance policies that reduce per-vehicle energy use, thereby reducing the battery materials required to power a rapidly growing electric vehicle market. A recent analysis by the Climate and Community Project found that taking these actions could reduce the amount of lithium needed to decarbonize the U.S. transportation system by 18–66 percent by 2050.[292]

Issue Area 4.1: Encourage use of the most energy-efficient personal vehicles

Just as some fossil fuel–powered vehicles get higher mileage per gallon, thus reducing demand for gasoline, different EV designs get different miles per kilowatt-hour (kWh). More-efficient EVs can travel the same distance with smaller batteries, and therefore less battery materials, than less-efficient EVs. Existing light-duty electric vehicles have a large range of efficiencies, consuming 25 to 40 kWh of electricity for every 100 miles traveled, or 62 to 150 miles per gallon energy-equivalent (the number of miles a vehicle can travel on 33 kWh—the same energy content as a gallon of gasoline).[293] Unfortunately, the personal vehicle market has shifted to larger vehicles that demand more energy and get the fewest miles per gallon or kWh, undermining climate goals and increasing material demand for all new vehicles, including battery materials for new electric vehicles.[294]

Even though fuel economy is at a record high for both gas-powered and electric vehicles, horsepower and vehicle footprint and weight are also at record highs, which undermines fuel economy improvements for all types of light-duty vehicles. Further, personal vehicle markets are trending away from more-efficient passenger sedans and wagons (down to 26 percent in 2021 compared with 50 percent in 2013) and toward less-efficient truck SUVs which now hold 45 percent of the total light-duty vehicle market share.[295] Pickups (16% market share), car SUVs (increasing market share), minivans, and vans (decreasing market share) make up the remainder of the personal vehicle market.[296] These trends not only have offset some of the fleetwide

A person using a public EV charging station in San Francisco, California.

emissions benefits from improved fuel economies but also have implications for mineral demand for electric vehicles, as larger and heavier vehicles will require larger and heavier batteries to achieve the same range as smaller vehicles.

Policies should be strengthened to encourage vehicle manufacturers to build and sell the most-efficient and lowest-emission vehicles. Fuel economy and emissions standards for vehicles should account for the energy and emissions associated with electricity production. To meet the standards, automakers would be incentivized to engineer vehicles to use as little energy as possible.

Vehicle fuel economy and emission standards should also remove incentives for automakers to sell larger vehicles. Currently passenger cars such as sedans and wagons are held to tougher standards than larger SUVs and pickup trucks, and the gap between the standards encourages automakers to up-size their offerings to ease regulatory compliance.[297] State and federal vehicle regulators have the tools to eliminate these incentives that increase battery demand in EVs.

Issue Area 4.2: Reduce demand for personal vehicles

If people can easily get where they need to go without owning a vehicle, they will need fewer vehicles overall and less of the materials used to build them. The United States can use several strategies to provide mobility choices that decrease the need for gas-powered and electric personal vehicles.

Strategy: Implement electric vehicle carsharing programs

Private carshare options like Zipcar, Turo, and Getaround allow people to use shared vehicles or borrow other people's vehicles for anywhere from an hour to days at a time. EV carshare programs can be used to complement transit, biking, and walking and can make it more feasible for individuals and households to own fewer vehicles. However, it is important to distinguish carshare options from rideshare options like Uber and Lyft, whose environmental impacts to date are mixed.[298]

PATHWAY FOR ADVOCACY: FUNDING AND IMPLEMENTATION SUPPORT AT THE FEDERAL, STATE, METROPOLITAN, AND/OR LOCAL LEVEL FOR ELECTRIC CARSHARING PROGRAMS

Publicly owned or subsidized carshare programs can be tailored to meet public sector goals like improving zero-emissions transportation access in low-income communities of color. For example, Evie Carshare is an all-electric carsharing program in Minneapolis and Saint Paul, Minnesota, for unemployed, underemployed, and low-income people. Designed with heavy input from local communities, it is managed by the city of Saint Paul and operated by local nonprofit Hourcar. Evie Carshare is paired with the EV Spot curbside charging network and was made possible by a combination of funding sources including federal, state, and local support, national grants, and the Bloomberg Philanthropies American Cities Climate Challenge.[299] This program demonstrates how collaborative funding, transportation electrification, and shifting away from private car use can benefit underserved communities in terms of both resource access and reduced pollution exposure. For programs like this to be successful, many innovative elements must come together—including institutional capacity building, funding, inclusive community engagement, program design, and careful implementation.

One study on electric carshare estimates that 1 carshare vehicle could result in 9 to 13 fewer private vehicles on the road, which means that expanding carsharing could reduce the current average of 1.9 privately owned cars per household—and therefore the number of batteries.[300]

Having the right types of vehicles at locations and times that suit individual transportation needs is key to an efficient and appealing carsharing program.[301] For households, expanded carsharing programs including peer-to-peer (personal vehicle) sharing as well as one-way carsharing services (allowing trips to begin and end at different spots) could be useful tools. For instance, an electric truck carshare program could allow people to own a smaller EV that meets most of their transportation needs and still have access to larger vehicles for specific uses like moving or road trips.

Issue Area 4.3: Improve and expand mobility choices

Enabling and encouraging a shift from driving private vehicles toward affordable, zero-emissions mobility choices can reduce total demand for battery materials. To maximize the climate, equity, and safety benefits of transportation investments, those investments must be paired with complementary land use reforms and other policies and programs that encourage low-carbon mobility choices, especially in larger U.S. cities and metropolitan regions. Strengthening mobility choices like walking, biking, and public transit will ultimately require investment and policy reform at all levels of government: local, metropolitan, state, and federal.

Strategy: Reform zoning laws to promote density and mixed-use development

Zoning laws determine the type and density of developments different parcels of land can be used for. Not only are many zoning schemes outdated, but many were fueled by racism—designed to intentionally limit development and maintain low-density, wealthy, and white neighborhoods.[302] Zoning laws should be updated to prioritize transit-oriented development—high-density development around existing public transit—and mixed-use development as well as general densification of housing. These zoning updates will improve planning and increase density of communities, which will make strategies to expand and improve alternative forms of transportation, discussed below, much more viable. Zoning updates could be coupled with incentives like permitting approval prioritization, reduced developer fees, and tax incentives to encourage higher-density land use and affordable housing, especially around existing public transit.

Cyclists riding in a protected bicycle lane beside a ‘floating’ bus stop in Seattle.

Parking availability is a major driver of vehicle use, and therefore a considerable and largely hidden fossil fuel subsidy.[303] Planning techniques like transit-oriented development can improve public transit access and quality, thereby reducing the need for parking spaces. However, most commercial and residential building codes require that construction include a minimum number of parking spaces determined by formulas based on square footage, number of units, or occupancy.[304] Eliminating or lowering these minimum parking requirements can help prioritize land for other uses and incentivize people to choose alternative transportation options over private vehicles. Minimum parking requirements could also be replaced by more community-centered investments such as green space, commercial or community space, housing, or other communal or public transportation amenities.

Strategy: Adopt policies and programs to encourage low-carbon mobility choices

As a complement to zoning reforms that can change the built environment over time, public and private sector actors alike have an important role to play in informing the public about affordable, low-carbon mobility choices and incentivizing those choices. Programs and policies designed for this purpose can range from sharing information about public transit options at the time of physical moves or job changes, to offering subsidies for monthly public transit passes, to imposing public requirements for employers to achieve certain mobility choice targets among their workforces. In combination, these policies and programs can play an important role in reducing demand for driving, and therefore the need for more vehicles and associated materials.[305]

Strategy: Shift ongoing public investment away from highway expansions and toward walking, biking, public transit, EV charging, and shared mobility

Public investment in transportation disproportionately favors private vehicle–related infrastructure like road expansion over investment in public transit, walking and biking infrastructure, EV charging, and carshare and other shared mobility systems.[306] Many public funds are already eligible to be spent on supporting low-carbon mobility choices.[307] Yet states overwhelmingly choose to use transportation funds to play congestion "whack-a-mole," widening roads only to see them get congested again a few years later and exacerbating direct displacement, traffic safety issues, and pollution in the process.[308]

Breaking this cycle requires shifting public investment away from highways and toward walking, biking, and transit infrastructure by reallocating federal, state, and local funding to prioritize safe, affordable, and low-carbon mobility choices over polluting, inequitable, and costly highway expansions.

This shift in infrastructure investment toward public transit should be paired with a commensurate increase in funding for ongoing operation of public transit, to ensure that our most space-efficient transportation option can operate with sufficient frequency to be a reliable choice for as many travelers as possible. Investment in new infrastructure projects for public transit is important, but transit infrastructure is only as good as the services that run on it. Current federal funding is biased toward infrastructure, and most of the money eligible for operational expenses comes in the form of formula grants that prioritize infrastructure over service.[309] The federal government should dedicate increased funding specifically for public transit operating costs to ensure that existing public transit infrastructure is used to its full potential.

Enacting strong climate and equity criteria in federal discretionary grant programs as well as in state-, metropolitan-, and local-level project prioritization can help ensure that ongoing transportation investments align with both climate goals and the needs and priorities of the most impacted communities.

An oil pumpjack located near homes in the Signal Hill neighborhood of Los Angeles.

Topic 5: Update current mining and extraction regulations, laws, standards, and practices in parallel with reducing demand for newly mined materials

Topic 5 Top-Line Actors and Recommendations:

Current mining regulations, laws, standards, and practices need to be brought into the 21st century to mitigate negative impacts to ecosystems, communities, and Indigenous People. Slowing the transition to EVs will not solve the root cause of mining-related issues, but the reliance of EVs on the mining industry can be used as impetus for much-needed reform.

- Congress should reform the Mining Law of 1872 through legislation like the Clean Energy Minerals Reform Act, and the Interagency Working Group on Mining Reform should exercise regulatory authority to ensure that mining and mine permitting (1) prioritizes land uses besides mining, especially on or adjacent to Indigenous sacred sites and resources, (2) requires free prior and informed consent from Indigenous People, along with community engagement, and (3) improves environmental standards.[310]
- Federal grant programs and funding should support national lab and pilot projects that limit the environmental impacts of mining through development of alternate extraction methods, recovery of metals from mining waste, and improved by-product recovery efficiency.
- The White House should exercise authority over mining and waste management through special use permits, right of way, or land exchanges, and the Department of Interior and Bureau of Land Management should exercise existing authority over public land-use through the Organic Act. They should also require mining companies to adhere to best practices for mine siting and waste and tailings management and submit a waste management plan for each project as part of the permitting process.[311]

- Community organizations and local governments should facilitate legally binding contracts between mining companies and local and Indigenous communities; a good model is the Good Neighbor Agreement in Montana, which ensures engagement, impact monitoring, and a penalty structure for mining companies.[312]
- Coalitions of downstream consumers like the First Movers Coalition and upstream shared markets like metal exchanges can incentivize mining companies to commit to voluntary standards for environmental and human rights due diligence as long-term regulatory and legislative reform processes are occurring.[313]

The strategies laid out in Topics 1, 2, 3, and 4 should be prioritized to reduce the amount of newly mined materials we need to support the growing EV market. Still, some amount of new mineral extraction will need to move forward in the United States and elsewhere to meet climate goals—in addition to the immense amount of mining that is already occurring today for countless materials and uses beyond EVs. This need must be carefully balanced with community impacts, Indigenous rights, and environmental concerns and will require immediate prioritization of mining regulation and legislative updates in the United States and elsewhere to protect people and ecosystems.

Safety standards and health protections for U.S. mine workers are an improvement over the conditions in many other countries, especially compared with small-scale copper and cobalt mining in the DRC, where child and forced labor practices have been documented.[314] However, because of insufficient National Environmental Policy Act (NEPA) processes and outdated mining laws (i.e., the Mining Law of 1872), the U.S. mining industry (1) prioritizes extraction over other land uses, (2) monitors water use and contamination poorly and without independent oversight, (3) does not require stringent enough mining waste and tailings management, and (4) fail to provide sufficient information about potential impacts to communities.

As a result, the metals mining industry is the largest single source of toxic waste in the United States.[315] This waste can contaminate water, and tailings dams which contain piles of waste left over from hardrock mining can collapse, causing massive damage to the environment and local communities.[316] Mining processes can also be energy intensive, deplete water sources, and devastate biodiverse ecosystems—including those that are home to endangered species. Any new extraction projects occurring under the current regulatory structure are likely to cause future harm to the environment, and these impacts are especially felt by Indigenous communities. It is imperative these issues be remedied as new mining is being proposed and developed in the United States.

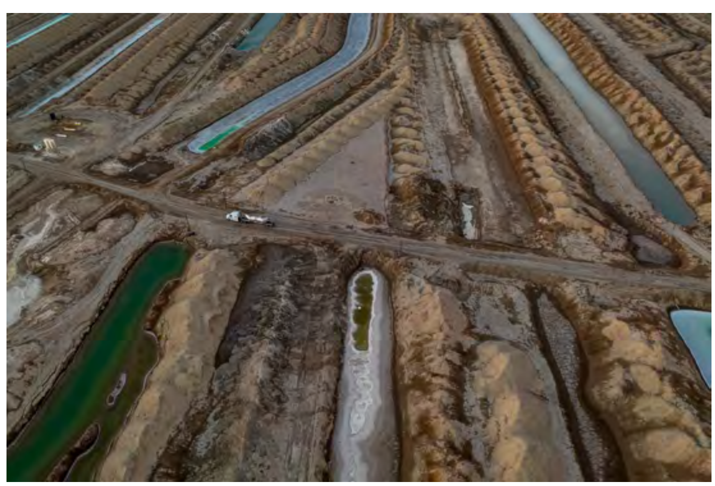
Of course, slowing the transition to electric transportation will not solve these mining challenges. Without EVs, extraction will still continue for minerals needed for countless items people use every day as well as for oil needed to power the current fossil fuel transportation system. Still, EVs could be the catalyst needed to bring mining reform efforts the attention and action they deserve.

Issue Area 5.1: Limit environmental impacts of extraction

All mines have some level of environmental impact.[317] When possible, the use of chemicals and pollutants should be minimized in mining processes, water use and contamination should be decreased, and waste should be contained and treated. Further, policymakers should utilize Indigenous land knowledge and encourage development and use of new technologies that can help limit the impacts of current extraction methods. Beyond that, decision makers will need to engage communities and evaluate potential environmental impacts, and they should leverage siting as a tool to avoid negative impacts on Indigenous and EJ communities, sensitive ecological areas, and watersheds. Mining companies should be penalized for lack of community engagement and waste management, which can be enforced through improved mining legislation and regulations.

Strategy: Research alternate extraction methods

Decision makers should support government grant programs and national labs that fund research, testing, and monitoring of alternate extraction methods that have the potential to decrease water use and waste and increase yield. One example is direct lithium extraction. This method uses electrochemical processes such as ion exchange, which can remove lithium from brine within hours rather than months.[318] Direct lithium extraction also has the potential to be combined with power production from geothermal brines. For this process, geothermal energy plant operators would use direct extraction technologies to remove lithium from brines pumped up during the energy production process and then reinject the rest of the brine back into the ground, forming a closed loop.[319] This process is being developed and tested in many places around the world including California's



© David McNew/Getty Images

Salt evaporation ponds on Bristol Dry Lake where Standard Lithium Ltd. is capturing lithium from brine.

Salton Sea in Coachella Valley and Imperial Valley. This technology has the potential to provide new mineral supplies while offering benefits to communities and reducing harms to the environment.[320]

However, these improvements are not a given. Communities surrounding the project must be engaged early and often during project development, community feedback must be implemented, and funding must be provided for outreach, workforce training programs, and any other resources requested by the community. Otherwise, the potential benefits of new projects could end up being overshadowed by negative impacts.

Strategy: Recover metals from mining waste and improve by-product recovery efficiency

Many critical minerals and rare earth elements crucial for clean energy technologies—including electric vehicle drive trains—are typically obtained as a by-product; they are extracted from ores that primarily contain a different mineral. For example, cobalt is usually sourced as a by-product of copper and nickel mining.[321] However, since they are found in trace amounts in mining operations that are focused on obtaining another mineral, often these by-products are not recovered efficiently, or at all, during initial extraction and processing of ores.[322] Therefore, waste produced during mining often contains reasonable sizeable amounts of critical materials that are left behind.[323]

Treating existing waste streams not only increases mineral yields but also decreases the impact these wastes have on the environment and can help transform linear economies into circular economies.[324] For example, researchers at West Virginia University are developing technologies that can recover rare earth elements from toxic acid mine drainage that is already produced at existing mines; researchers have found that these elements exist in this waste in much higher concentrations than in the ores from which they are traditionally drawn as a by-product.[325] Elsewhere, the company Nth Cycle is piloting electro-extraction technology that can increase mineral yields during upfront mining processes as well as from new and existing waste ponds.[326]

It may be more efficient to channel new recovery technology research toward increasing recovery efficiencies from waste streams that already have recovery before exploring wastes that are not already processed for recovery due to very low mineral concentrations.[330] Continuing with the cobalt example, cobalt has often been recovered from copper ores through inefficient flotation or smelting processes, so the resulting waste still contains cobalt.[331] Reprocessing this waste that has already been a resource for cobalt is often cheaper and less environmentally harmful than exploiting new resources because it requires little to no new physical extraction processes, such as excavation or grinding, and cobalt concentrations in these wastes are often still higher than in new resources.[332]

Strategy: Require best practices for tailings management

Tailings—mixtures of rock, trace minerals, water, and leftover chemicals from mining processes—can pose a threat to nearby communities and the environment.[333] There are ways that tailings can be better managed to prevent harmful impacts. Tailings dams are named for the direction in which the subsequent dykes that form the dam are added relative to the first dyke. Tailings are often stored in an upstream design supported by dams, as illustrated in Figure 10. However, this design has a high failure rate because each separate tailings pile relies on the structural integrity of the previous one, and tailings contain liquid, which makes them less structurally sound.[334] The failure of this kind of tailings dam has repeatedly resulted in toxic environmental pollution and loss of human life. For example, the failing of the Fundão tailings dam in Brazil in 2015 killed at least 19 people and impacted 1.4 million others due to waste deposits and destruction along a large corridor, damaging and polluting the ecosystem and impacting people's homes and nature-related livelihoods.[335] Because of incidents like this, upstream dams are illegal in a few countries including Brazil and Chile.[336]

Where possible, tailings storage methods that are underground rather than at surface level, like backfilling or using mined-out pits, should be implemented. If storage must

PATHWAY FOR ADVOCACY: MORATORIUMS ON TRADITIONAL BRINE EXTRACTION METHODS IN WATER-STRESSED AREAS

Brine evaporation—a process that extracts minerals by evaporating surface water or groundwater that is heavy in salts and minerals—is reasonably thought to exacerbate water and ecological stress in surrounding environments. According to UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology, "When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm."[327] Following this logic, the extraction industry should have to prove that brine extraction does *not* harm the environment around their operation before being allowed to proceed.[328] Moratoriums on brine evaporation extraction methods in water-stressed areas should be mandated by permitting agencies and land-use regulators. These moratoriums would likely apply more to operations outside of the United States, especially in South America, where brine extraction for lithium is more common.[329] Methods like direct lithium extraction that waste less water should be prioritized in these areas.

be aboveground, safer options such as downstream designs should be used (Figure 10).[337] A more stable aboveground alternative, particularly applicable for smaller operations, is drystacking, where wastewater is separated from the waste rocks or other solids, leaving waste piles similar to dry dirt. Regardless of the type of storage or dam used, systems should be well constructed to withstand floods and earthquakes as well as normal wear and tear.[338] Also, minimizing water use during mining and filtering tailings to remove excess water before storage will improve storage stability.[339] Finally, to minimize impacts in the event that a tailings dam does fail, facilities should never be built with other infrastructure or communities in the line of failure.[340]

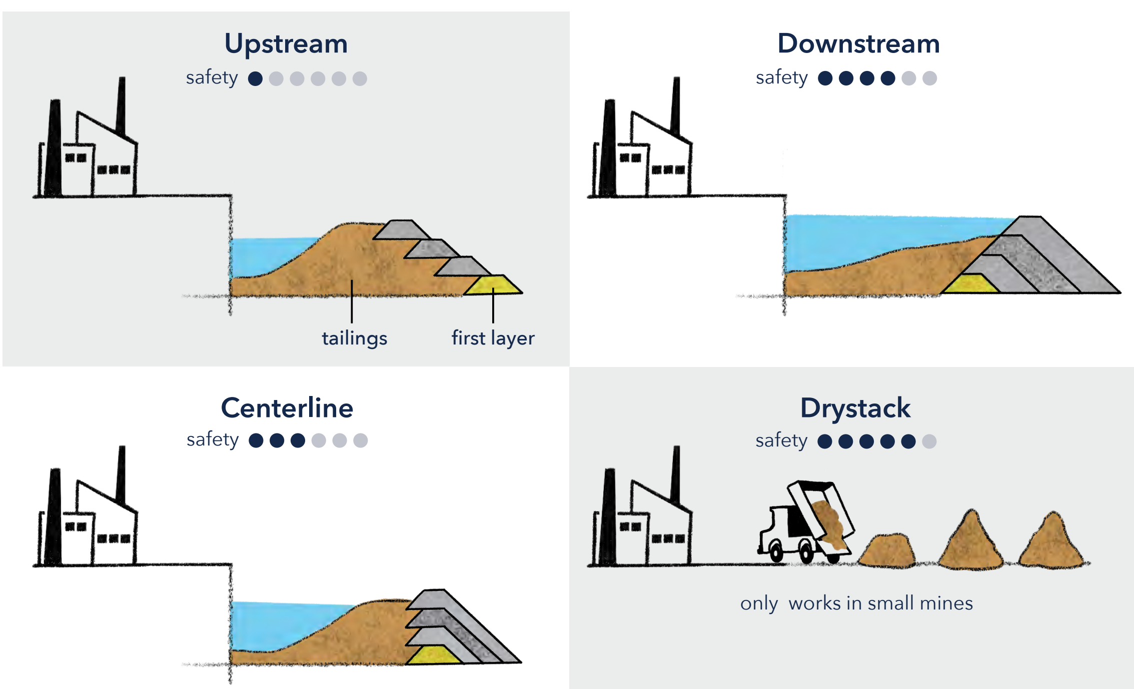
To ensure safer mining tailings management strategies, mining companies should be required to develop best practices for waste management and present a site-specific plan for a project *before* receiving a permit. In addition to stricter waste management standards during ongoing extraction, these best practices should include plans to minimize water waste and contamination throughout all stages of a mine's life—including initial exploration and drilling phases before extraction begins as well as post-closure (i.e., after mining companies are no longer extracting minerals from a mine site).[341] These plans should account for increased risks of extreme weather events due to climate change.[342] Companies should need to prove that they have adequate financial assurances to cover any reclamation costs, long-term treatment, or other remedies linked to waste contamination that could occur in normal operations or if tailings storage facilities fail.[343]

Further, decision makers should evaluate pathways to exercise more control over using public land for waste tailings dumping. The Clinton administration tried to restrict land that could be used for waste dumping under its overhaul of hardrock mining regulations, but the Bush administration that followed removed this restriction and eliminated other pathways for rejecting mining proposals.[345] As recommended in a report by Earthworks, the White House could exercise authority over mining and waste management through tools like special use permits, rights-of-way, or land exchanges, and agencies like the Department of Interior and Bureau of Land Management could use existing authority over public land use provided through legislation such as the Organic Act.[346] Any resulting regulations should specify stricter standards for waste tailings dumping and designate protected areas such as certain watersheds or areas in proximity to Indigenous lands and peoples.

Strategy: Utilize purchasing power to encourage improved global practices

Currently, industry actors and the federal government are pushing to increase minerals extraction within U.S. borders, as evidenced by IRA provisions, such as the 30D Clean Vehicles Tax Credit, that tie access to consumer tax credits for EVs to North American production of batteries and battery materials.[347] However, there are often barriers in terms of location, quantity, and quality of reserves in the United States. Another option that should be explored is procuring minerals from other countries that are working to implement stronger sustainability and human and

Figure 10: Types of Tailings Dams and Storage



Infographic by Jessica Russo. Source image by Reuters.[344]

Indigenous rights protections. This way, the United States can access minerals for EV batteries and other clean energy technologies that may be hard to mine within its borders while encouraging transparency and data sharing.

Issue Area 5.2: Protect Indigenous lands and include Indigenous communities in decision making

Too often throughout U.S. history, Indigenous People were forced to experience extreme physical, emotional, and cultural harms due to development and use of their lands without consent. These issues are ongoing in the mining industry today, as seen in the current struggle to protect the lands of the Shoshone and Paiute peoples from lithium mining in Nevada.[348]

Action is needed to ensure that this trend does not continue as we seek to supply key transition minerals in the United States. Some 97 percent of nickel, 89 percent of copper, 79 percent of lithium, and 68 percent of cobalt reserves lie within 35 miles of Native American reservations within U.S. borders.[349] Indigenous People are rarely properly consulted or engaged throughout the mining planning process.[350] Beyond the lack of engagement, communities, especially outside the United States, have experienced direct violations of their rights and safety in response to their protests of mining operations, with protest leaders and their families especially subject to violent attacks carried out by mining companies or other groups, like police or private security, believed to be acting on their behalf.[351] The Business & Human Rights Resource Centre's Transition Minerals Tracker shows that human rights defenders (i.e., land and environmental defenders, affected community members, journalists, labor leaders, and other activists speaking out against improper business practices), particularly Indigenous rights defenders, were especially likely to be harassed and denied basic rights.[352] This means that without action, EV supply chains will be linked to rights and safety issues just like those that have been documented in fossil fuel supply chains.[353]

Updated mining regulations must incorporate proper engagement requirements to involve and educate local communities and obtain consent, and they must require regular monitoring of mining companies and sites for any violations of requirements or rights. Engagement and monitoring requirements can also be incorporated through legally binding contracts between mining companies, local community organizations, and tribes, like the Good Neighbor Agreement in Montana that allows responsible mining on Crow, Cheyenne, and Blackfoot lands while protecting the quality of life of Indigenous and rural communities.[354] There should be a penalty structure for mining companies that fail to keep communities informed, manage waste appropriately, and protect Indigenous resources.

Strategy: Ensure free prior and informed consent

Pursuing free prior and informed consent (FPIC) is key to ensuring that Indigenous People are properly included in decision making processes that involve their lands, livelihoods, and resources. A United Nation' report titled *Thematic Advice on the Expert Mechanism on the Rights of Indigenous Peoples* explains FPIC well: "The element of 'free' implies no coercion, intimidation or manipulation; 'prior' implies that consent is obtained in advance of the activity associated with the decision being made, and includes the time necessary to allow Indigenous peoples to undertake their own decision-making processes; 'informed' implies that Indigenous peoples have been provided all information relating to the activity and that that information is objective, accurate and presented in a manner and form understandable to Indigenous peoples; 'consent' implies that Indigenous peoples have agreed to the activity that is the subject of the relevant decision, which may also be subject to conditions."[355]

FPIC is more than just a concept. It represents the rights to process as protected under the International Labor Organization Convention 169 and the U.N. Declaration on the Rights of Indigenous Peoples.[356] Additionally, President Biden signed a memorandum committing to strengthening the Nation-to-Nation relationship by respecting tribal self-governance and conducting regular tribal consultation.[357] This memorandum built on an executive order from 2000 and a presidential memorandum from 2009 by requiring federal agencies to engage in tribal consultation to develop action plans for continued tribal engagement. Since this memorandum was signed in January of 2021, 80 agencies have submitted plans for compliance to the Office of Management and Budget.[358] Federal agencies issue mining permits, so they must continue to increase proactive engagement with Indigenous People to prevent harmful impacts.

Strategy: Prioritize specific protections for Indigenous cultural resources

As mentioned above, there will always be some level of contamination and risk associated with mining waste. Therefore, specific protections should be in place to ensure that mines are not sited in the path of Indigenous cultural or shared resources like sacred sites and bodies of water. A good starting example is the Sacred Sites Memorandum of Understanding signed by eight federal agencies in November 2021. This agreement builds a framework for agencies to protect Indigenous sacred sites by identifying opportunities for these sites to be considered in any federal decision-making process that could have a regulatory or policy outcome and by requiring each agency to hold consultations with tribal nations if their actions have a chance of impacting Indigenous communities.[359] Another part of protecting cultural resources is ensuring that land-use regulations balance mining proposals with other land uses. The still in force Mining Law of 1872 prioritizes mining over all other land uses and must be reformed to appropriately consider other land-use needs and protect Indigenous resources.[360]

Issue Area 5.3: Reform outdated laws and regulations

Mining regulations in the United States are in need of an update. The most recent law on the books is the Mining Law of 1872. There are two ongoing parallel reform efforts in the United States—one legal and one regulatory—to alleviate the negative effects of mining.

Strategy: Reform the U.S. Mining Law of 1872

The Mining Law of 1872 is the United States's most recent legislation governing mining. Further, at the time of its passage, it was not intended to be a complete governance tool for the mining sector. The 1872 Congress used the Mining Law to bolster belief in manifest destiny and to validate and continue decades of mistreatment of Indigenous People. To illustrate the federal government's land-use priorities in the years leading up to the Mining Law, in 1863 it forced the Nez Perce Tribe to sign the "steal treaty," which reduced their homeland by 90 percent for mining purposes and allowed the government and others to seize and profit from the tribe's resources.[361] The Mining Law perpetuates this detrimental and severely outdated attitude since it continues to treat mining as the "highest and best use" of most federal lands which make up about 15 percent of the entire United States (more than 350 million acres, over twice the size of Texas) and allows companies to use public lands for extraction without requiring royalties or rent.[362]

Congress is currently considering updating this legislation through the Clean Energy Minerals Reform Act of 2023, introduced in the House by Rep. Raúl M. Grijalva (D-Ariz.) and in the Senate by Sen. Martin Heinrich (D-N.M.).[367] The bill would reform the existing archaic standards by including land leasing and royalty systems, industry financing of cleanup of waste, tribal consultation and land protection, and environmental and reclamation standards.[368] Similar bills have come up in Congress in the past, and any future iterations of this bill should be uplifted and advocated for where opportunities are available.

New language needs to be incorporated into any reform of the Mining Law to ensure that it prioritizes other land uses besides mining, requires Indigenous input on mining planning—including the right to say no to a project—and mandates the protection of lands and watersheds.[369] Mining reform should also modernize the staking and discovery process, formalize permitting within land management agencies, impose royalties on publicly owned resources, significantly improve environmental performance standards, and ensure that frontline communities have access to a transparent and robust review process that makes their voices, concerns, and perspectives part of the permitting process.

SOLVING PERMITTING ISSUES BY IDENTIFYING THE PRIMARY CAUSE OF DELAYS

Permitting delays are often cited as a barrier to deployment of all types of clean energy technologies, including mining for battery minerals. First off, typical mining permitting times are much shorter than most people may realize. The U.S. Government Accountability Office (GAO) did a study on hardrock mining permitting for mines approved from 2010 to 2014 on Bureau of Land Management and U.S. Forest Service lands. It found that the average time for approval was only two years, and 81 percent of mines approved in those years were approved in three years or less.[363] When significant delays did occur during the permitting process, GAO also looked into the primary causes of those delays, and neither environmental impact reviews (i.e., the NEPA process) nor the on-the-ground permitting process carried out by land management agencies were a source of meaningful delay.[364] Another study, in the *Columbia Journal of Environmental Law*, analyzed 41,000 NEPA decisions from 2004 to 2020 and found that when significant delays occurred, they were more often caused by "inadequate agency budgets, staff turnover, delays receiving information from permit applicants, and compliance with other laws."[365]

In short, delays are less common that people may think, and when delays do occur, lack of funds and staff at agencies responsible for permitting is the primary driver. The Climate Law (IRA) provides a total of $1.2 billion in additional funding to ensure that federal agencies can conduct robust environmental reviews and public engagement on large projects that use federal funds or are on federal lands.[366] The money was allocated to the individual agencies that are responsible for environmental reviews specifically for those purposes. However, not all of that funding will impact the mining permitting process, and the funding alone will not solve the ongoing issues with mining permitting in the United States. Permitting reform that attempts to weaken NEPA by limiting multi-agency and public engagement processes or the time or scope of review can actually have the opposite of the desired effect (reduced permitting timelines) and lead to more conflicts, more lawsuits, and greater delays.

Solving issues and delays relating to mining permitting will require:

- Retaining and growing agency expertise on permitting and environmental review.
- Increasing staffing within agencies for permitting and environmental review.
- Clarity and guidance for what steps need to be taken and what types of information must be submitted to relevant agencies during the permitting process.
- Improved interagency coordination and cooperation (via such groups as the Interagency Working Group on Mining).
- Earlier and deeper community engagement (NEPA is the best available existing tool to facilitate and guide this process).

Strategy: Reform federal agency regulations

On the regulatory side, DOI's Bureau of Land Management and the Department of Agriculture's U.S. Forest Service have both been given the authority to manage hardrock mining on their respective lands through the Federal Land Policy and Management Act of 1976 and the Forest Service Organic Act of 1897.[370] Data from these agencies shows total of 872 authorized mines on federal lands.[371]

DOI is leading an interagency partnership to reform mining regulation through public land-use rules.[372] It released a request for comments, which were due in 2022, to solicit public input.[373] Opportunities like these to influence regulation reform are valuable for bringing much-needed environmental protections and community engagement and consent into permitting processes and preventing harmful extraction practices on specific lands that are extremely valuable as cultural, ecological, or water resources. The interagency working group should take these comments into account and continue to engage local and Indigenous communities, environmental and mining experts, and civil society organizations as it undertakes the reform process.

Issue Area 5.4: Incentivize voluntary supply chain standards

Mining reform through federal and international governing bodies is the ultimate goal, and advocates have been working on this for many years. In the near term, companies can proactively adopt voluntary standards for environmental and human health due diligence. Existing standards can provide a means for material buyers to evaluate suppliers and can incentivize those suppliers to adhere to existing standards. However, according to a report by the Berkeley Law and Natural Resource Governance Institute, while standards and initiatives "are collectively sufficient to promote good sustainability practice, their breadth and diversity also creates a significant coordination challenge in tracking adherence, comparing performance, and exchanging information across multiple initiatives."[374] Additionally, focusing on voluntary standards alone can distract from the ultimate mission of codifying human rights and environmental protections in laws that are properly implemented. Voluntary standards should be encouraged as a supplemental stepping stone on a path to building truly sustainable supply chains for transition minerals through mandatory standards.

There are many existing standards that industry actors can adhere to. Different standards cover different materials, entities, geographical areas, and content such as human rights, labor violations, local economic impacts, or environmental protections. Navigating these differences can be challenging for mineral purchasers such as battery cell manufacturers or automakers. The best standards will include continuous third-party monitoring and compliance determination, stepped compliance levels, and penalties for noncompliance. Without these components, it is difficult to determine compliance and can lead to greenwashing if companies say they meet certain standards without an independent party to confirm their claims. Mechanisms outlined below for helping mining companies and downstream buyers determine which voluntary standard suits them best can help maximize impact.

COMPARING VOLUNTARY SUPPLY CHAIN STANDARDS TO AID DECISION MAKING

NRDC has developed a tool to compare existing supply chain standards based on the EV battery supply chain standards taxonomy framework outlined by the U.C. Berkeley Center for Law, Energy, and the Environment and the Natural Resource Governance Institute in their report *Priorities to Improve the Electric Vehicle Battery Supply Chain*.[375] This tool is a matrix designed to compare existing human and labor rights initiatives and standards based on categories such as supply chain actors, minerals, and environmental and human rights priorities. The goal of the tool is to help companies decide which standard(s) would be best for them to adopt given their role in the mineral supply chain and the goals they hope to achieve through standard adoption (e.g., eliminate forced labor or increase transparency). NRDC initially used this tool to compare four existing standards—the Organisation for Economic Co-operation and Development Due Diligence Guidance, the Responsible Minerals Assurance Process of the Responsible Minerals Initiative, the Dodd-Frank Act, and E.U. Conflict Minerals Regulations.[376] Any opportunity to consider additional standards, to include more comprehensive issues, or to refine decision-making processes for material consumers or mining companies, either internally or by another party or coalition, should be supported.

Strategy: Leverage market demand and consumer preferences to incentivize mining companies to adopt voluntary standards

Coalitions of downstream consumers and upstream shared markets can be a tool to encourage mining companies to commit to voluntary standards. For example, the First Movers Coalition discussed in Topic 3—a partnership between the U.S. State Department and companies that want to procure lower-impact products by incentivizing commitment from supply chain actors—could require that mining companies meet certain standards to qualify for their procurement contracts. On the upstream end, investors, trading platforms, and exchanges could require adherence to certain standards for companies to participate. For example, the London Metal Exchange requires responsible sourcing for participation.[377]

CONCLUSION

Transitioning our transportation sector from fossil fuel–dependent vehicles to EVs will mitigate the worst impacts of climate change and improve the health and quality of life for the most burdened communities living near rail yards, highways, and ports. It will also reduce the environmental, economic, and human rights impacts of oil extraction and spills. With more than 30 percent of current U.S. GHG emissions coming from transportation, the transition to EVs is a crucial piece of climate action.[378]

However, the mineral extraction, material processing, and manufacturing of EV batteries come with their own set of harmful impacts. Demand for EVs—and EV batteries—is growing. We currently have an important window of opportunity to implement policies that improve extraction practices, support new battery technologies, promote reuse and recycling, and provide diverse mobility options that reduce demand for battery minerals and set up the regulatory environment and infrastructure required for a circular economy before the number of retired EV batteries grows exponentially. U.S. decision makers must adopt and implement these policies to limit the impacts of EV battery supply chains, so that we can meet climate and air quality goals while protecting already overburdened environmental justice communities and Indigenous People from shouldering additional harmful impacts.

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Health-harming smog from fossil fuels hanging over Los Angeles, California.

ENDNOTES

1 Moving Forward Network, *Making the Case for Zero-Emissions Solutions in Freight*, May 2021, 3–4, https://www.movingforwardnetwork.com/wp-content/uploads/2021/10/MFN_Making-the-Case_Report_May2021.pdf.

2 Colin McKerracher et al., *Electric Vehicle Outlook 2022*, BloombergNEF, June 1, 2022, 2.

3 Ibid., 121; Brandon S. Tracy, *Critical Minerals in Electric Vehicle Batteries*, Congressional Research Service, August 29, 2022, 2, https://crsreports.congress.gov/product/pdf/R/R47227.

4 Earthworks, *Revising Hardrock Mining Regulations to Protect Communities, Water, and Natural and Cultural Resources*, March 2021, https://earthworks.org/wp-content/uploads/2021/09/WHITE-PAPER-Revising-Hardrock-Mining-Regs-2021.pdf; Annie Callaway, *Powering Down Corruption: Tackling Transparency and Human Rights Risks From Congo's Cobalt Mines to Global Supply Chains*, The Enough Project, October 2018, 2, https://enoughproject.org/wp-content/uploads/PoweringDownCorruption_Enough_Oct2018-web.pdf.

5 Melissa Denchak, "Fossil Fuels: The Dirty Facts," NRDC, June 1, 2022, https://www.nrdc.org/stories/fossil-fuels-dirty-facts.

6 U.S. Energy Information Administration (hereinafter EIA), "Oil and Petroleum Products Explained," last updated July 1, 2022, https://www.eia.gov/energyexplained/oil-and-petroleum-products/use-of-oil.php.

7 Transport & Environment, "Recycling Drastically Reduces Dependence on Imported Electric Vehicle Battery Materials," March 30, 2021, https://www.transportenvironment.org/discover/recycling-drastically-reduces-dependence-imported-electric-vehicle-battery-materials/.

8 Federal Consortium for Advanced Batteries (hereinafter FCAB), "National Blueprint for Lithium Batteries, 2021–2030: Executive Summary," June 2021, 6, https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf.

9 Madeleine Stone, "Mining Is a Polluting Business. Can New Tech Make It Cleaner?" *National Geographic*, May 13, 2022, https://www.nationalgeographic.com/environment/article/mining-is-a-polluting-business-can-new-tech-make-it-cleaner.

10 The White House, "Fact Sheet: Biden-Harris Administration Driving U.S. Battery Manufacturing and Good Paying Jobs," news release, October 19, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/10/19/fact-sheet-biden-harris-administration-driving-u-s-battery-manufacturing-and-good-paying-jobs/.

11 Climate Watch, "Historical GHG Emissions," data for U.S. total and U.S. transportation sector, accessed October 12, 2022, https://www.climatewatchdata.org/ghg-emissions?breakBy=sector&end_year=2019&regions=USA&sectors=total-including-lucf percent2Ctransportation&start_year=1990; Climate Watch, "Historical GHG Emissions," data for United States, China, India, and Russia, accessed October 12, 2022, https://www.climatewatchdata.org/ghg-emissions?breakBy=countries&end_year=2019&regions=CHN percent2CIND percent2CUSA percent2CRUS&sectors=transportation&start_year=1990.

12 Michelle L. Bell and Keita Ebisu, "Environmental Inequality in Exposures to Airborne Particulate Matter Components in the United States," *Environmental Health Perspectives* 120, no. 12 (December 2012): 1699–1704, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3546368/; Moving Forward Network, "Moving Forward: Demand Zero Emission Freight Now," accessed March 20, 2023, https://www.movingforwardnetwork.com/zero-emissions/; U.S. Environmental Protection Agency (hereinafter EPA), Office of Transportation and Air Quality, "Near Roadway Air Pollution and Health: Frequently Asked Questions," August 2014, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100NFFD.PDF?Dockey=P100NFFD.PDF.

13 Denchak, "Fossil Fuels."

14 Moving Forward Network, *Making the Case*.

15 McKerracher et al., *Electric Vehicle Outlook*, 2.

16 David Reichmuth, Jessica Dunn, and Don Anair, *Driving Cleaner: Electric Cars and Pickups Beat Gasoline on Lifetime Global Warming Emissions*, Union of Concerned Scientists, July 2022, https://www.ucsusa.org/resources/driving-cleaner.

17 Ibid., 2, 11.

18 FCAB, "National Blueprint," 5–7.

19 Govind Bhutada, "Breaking Down the Cost of an EV Battery Cell," *Visual Capitalist*, February 22, 2022, https://www.visualcapitalist.com/breaking-down-the-cost-of-an-ev-battery-cell/; Jason Burton, "U.S. Geological Survey Releases 2022 List of Critical Minerals," U.S. Geological Survey (hereinafter USGS), news release, February 22, 2022, https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals.

20 Burton, "USGS Releases 2022 List."

21 Ibid.

22 David Roberts, "The Minerals Used by Clean-Energy Technologies," *Volts* (podcast), transcript, February 7, 2022, https://www.volts.wtf/p/the-minerals-used-by-clean-energy?s=r#details.

23 Tracy, *Critical Minerals*.

24 Tae-Yoon Kim et al., "Executive Summary," in *The Role of Critical Minerals in Clean Energy Transitions*, International Energy Agency (hereinafter IEA), May 2021, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary.

25 FCAB, "National Blueprint"; Ian Morse, "A Dead Battery Dilemma," *Science*, May 20, 2021, https://www.science.org/content/article/millions-electric-cars-are-coming-what-happens-all-dead-batteries.

26 FCAB, "National Blueprint," 17; IEA, *Global Supply Chains of EV Batteries*, July 2022, 16, 52, https://iea.blob.core.windows.net/assets/4eb8c252-76b1-4710-8f5e-867e751c8dda/GlobalSupplyChainsofEVBatteries.pdf.

27 IEA, *Global Supply Chains*, 19.

28 FCAB, "National Blueprint," 17.

29 Ibid.; Battery University, "BU-104b: Battery Building Blocks," last updated October 20, 2021, https://batteryuniversity.com/article/bu-104b-battery-building-blocks.

30 IEA, *Global Supply Chains*, 19.

31 Ibid.

32 Hanjiro Ambrose and Jimmy O'Dea, "Electric Vehicle Batteries: Addressing Questions About Critical Materials and Recycling," Union of Concerned Scientists, February 2021, https://ucsusa.org/sites/default/files/2021-02/ev-battery-recycling-fact-sheet.pdf.

33 Ethan N. Elkind, Patrick R. P. Heller, and Ted Lamm, *Sustainable Drive, Sustainable Supply: Priorities to Improve the Electric Vehicle Battery Supply Chain*, Berkeley Law Center for Law, Energy, and the Environment and the Natural Resource Governance Institute, July 2020, https://www.law.berkeley.edu/wp-content/uploads/2020/07/Sustainable-Drive-Sustainable-Supply-July-2020.pdf.

34 USGS, *Mineral Commodity Summaries 2022*, January 31, 2022, 7, https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf.

35 Ekta Meena Bibra et al., *Global EV Outlook 2022*, IEA, May 2022, 156, 160, https://iea.blob.core.windows.net/assets/ad8fb04c-4f75-42fc-973a-6e54c8a4449a/GlobalElectricVehicleOutlook2022.pdf.

36 Ibid., 154.

37 Robert Johnston, "Supply of Critical Minerals Amid the Russia-Ukraine War and Possible Sanctions," Columbia SIPA Center on Global Energy Policy, April 19, 2022, https://www.energypolicy.columbia.edu/research/commentary/supply-critical-minerals-amid-russia-ukraine-war-and-possible-sanctions.

38 Herbert Diess and Thomas Schmall, "Power Day" (presentation), Volkswagen, March 15, 2021, https://www.volkswagenag.com/presence/investorrelation/publications/presentations/2021/03/2021-03-15_PowerDayVWGroup.pdf.

39 U.S. Government Accountability Office (hereinafter GAO), *Hardrock Mining: BLM and Forest Service Have Taken Some Actions to Expedite the Mine Plan Review Process but Could Do More* (report to the chairman, Committee on Natural Resources, House of Representatives), January 2016, https://www.gao.gov/assets/gao-16-165.pdf.

40 Jessica Dunn et al., "Circularity of Lithium-Ion Battery Materials in Electric Vehicles," *Environmental Science & Technology* 55, no. 8 (March 25, 2021): 5189–5198, https://pubs.acs.org/doi/abs/10.1021/acs.est.0c07030.

41 Kim et al., "Executive Summary," 5.

42 Ibid.

43 Ibid.

44 Kirsten Hund et al., *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition,* World Bank Group, 2020, 59, https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf.

45 Ibid., 12.

46 Ibid.

47 Ibid.

48 Ibid.

49 Office of Energy Efficiency & Renewable Energy, *Battery Critical Materials Supply Chain Challenges and Opportunities: Results of the 2020 Request for Information (RFI) and Workshop*, U.S. Department of Energy, December 2021, viii, https://www.energy.gov/sites/default/files/2022-01/Battery percent20Critical percent20Materials percent20Workshop percent20Report percent20- percent20FINAL.pdf.

50 Kim et al., "Executive Summary."

51 Ibid., 14.

52 Ibid.

53 Ibid.

54 Redwood Materials, "Recycle With Us," accessed April 27, 2023, https://www.redwoodmaterials.com/recyclewithus.

55 Dunn et al., "Circularity of Lithium-Ion Battery Materials."

56 Dario Latini, "A Comprehensive Review and Classification of Unit Operations With Assessment of Outputs Quality in Lithium-Ion Battery Recycling," *Journal of Power Sources* 546 (October 30, 2022): 16, https://www.sciencedirect.com/science/article/pii/S0378775322009594; Jessica Dunn, Alissa Kendall, and Margaret Slattery, "Electric Vehicle Lithium-Ion Battery Recycled Content Standards for the US – Targets, Costs, and Environmental Impacts," *Resources, Conservation and Recycling* 185 (October 2022): 3, https://www.sciencedirect.com/science/article/pii/S0921344922003317?via percent3Dihub.

57 Dunn, Kendall, and Slattery, "Electric Vehicle," 3.

58 Earthworks, *Revising Hardrock Mining Regulations*.

59 Ibid.; James J. A. Blair et al., *Exhausted: How We Can Stop Lithium Mining From Depleting Water Resources, Draining Wetlands, and Harming Communities in South America*, NRDC, April 2022, 18, https://www.nrdc.org/sites/default/files/exhausted-lithium-mining-south-america-report.pdf.

60 Earthworks, *Revising Hardrock Mining Regulations*.https://earthworks.org/wp-content/uploads/2021/09/WHITE-PAPER-Revising-Hardrock-Mining-Regs-2021.pdf.

61 BBC, "Vale Dam Disaster: $7bn Compensation for Disaster Victims," February 4, 2021, https://www.bbc.com/news/business-55924743.

62 Lisa Sumi and Bonnie Gestring, *Polluting the Future: How Mining Companies Are Contaminating Our Nation's Waters in Perpetuity*, Earthworks, May 2013, 4, https://earthworks.org/assets/uploads/archive/files/publications/PollutingTheFuture-FINAL.pdf.

63 EPA, "Releases of Chemicals," 2020 TRI National Analysis, February 2022, 36, https://www.epa.gov/system/files/documents/2022-03/2020_trina_releases.pdf.

64 Office of Land and Emergency Management, "Use of Brownfields Mine-Scarred Land Initiative to Clean Up Abandoned Mine," EPA, September 2017, https://www.epa.gov/sites/default/files/2018-01/documents/final_brownfields_mine-scarred_initiative_fact_sheet_9-14-17b_0.pdf.

65 Bureau of Land Management, "AML Inventory," U.S. Department of the Interior, January 5, 2017, https://www.blm.gov/programs/public-safety-and-fire/abandoned-mine-lands/blm-aml-inventory.

66 Tomás de Oliveira Bredariol, "Reducing the Impact of Extractive Industries on Groundwater Resources," IEA, March 22, 2022, https://www.iea.org/commentaries/reducing-the-impact-of-extractive-industries-on-groundwater-resources.

67 Blair et al., *Exhausted*, 20.

68 Ibid., 10; USGS, *Mineral Commodity Summaries*, 100.

69 Blair et al., *Exhausted*, 16–18.

70 Lindsay Delevingne et al., "Climate Risk and Decarbonization: What Every Mining CEO Needs to Know," McKinsey Sustainability, January 28, 2020, https://www.mckinsey.com/business-functions/sustainability/our-insights/climate-risk-and-decarbonization-what-every-mining-ceo-needs-to-know.

71 Ibid.https://www.mckinsey.com/business-functions/sustainability/our-insights/climate-risk-and-decarbonization-what-every-mining-ceo-needs-to-know

72 Samuel Block, "Mining Energy-Transition Metals: National Aims, Local Conflicts," MSCI, June 3, 2021, https://www.msci.com/www/blog-posts/mining-energy-transition-metals/02531033947.

73 Jessie Cato, Mercy Tochukwu Christopher, and Ana Zbona, *Transition Minerals Tracker: 2021 Analysis*, Business & Human Rights Resource Centre, May 2022, 8–10, https://media.business-humanrights.org/media/documents/Transition_Minerals_Tracker_Global_analysis.pdf.

74 USGS, *Mineral Commodity Summaries*, 18; Elkind, Heller, and Lamm, *Sustainable Drive*, 4.

75 Cato, Christopher, and Zbona, *Transition Minerals Tracker*, 8.

76 Jael Holzman and David Iaconangelo, "U.S. Shift on Child Labor May Scramble EV Sector," *Energywire*, October 5, 2022, https://www.eenews.net/articles/u-s-shift-on-child-labor-may-scramble-ev-sector/.

77 Callaway*, Powering Down Corruption*, 13.

78 Gary Burtless, "Workers' Rights: Labor Standards and Global Trade," Brookings, September 1, 2001, https://www.brookings.edu/articles/workers-rights-labor-standards-and-global-trade/; Business & Human Rights Resource Centre, "Transition Minerals Tracker," accessed June 6, 2022, https://www.business-humanrights.org/en/from-us/transition-minerals-tracker/?related_by=company.

79 Burtless, "Workers' Rights"; Business & Human Rights Resource Centre, "Transition Minerals Tracker."

80 Anne-Marie Fennell, "Mining on Federal Lands: More Than 800 Operations Authorized to Mine and Total Mineral Production Is Unknown" (letter to Raúl Grijalva, chairman, Committee on Natural Resources, House of Representatives), GAO, May 28, 2020, 4, https://www.gao.gov/assets/gao-20-461r.pdf; Earthworks, *Revising Hardrock Mining Regulations*, 5.

81 Jan Morrill et al., *Safety First: Guidelines for Responsible Mine Tailings Management*, Earthworks, May 2022, 11, https://earthworks.org/wp-content/uploads/2022/05/Safety-First-Safe-Tailings-Management-V2.0-final.pdf.

82 Tae-Yoon Kim et al., *The Role of Critical Minerals in Clean Energy Transitions*, IEA, May 2021, 220, https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf.

83 Global Electronics Council, "About EPEAT," accessed July 22, 2022, https://www.epeat.net/about-epeat; TCO Certified, "TCO Certified—Like an Ecolabel but So Much More," accessed July 22, 2022, https://tcocertified.com/tco-certified/.

84 Tae-Yoon Kim et al., "Mineral Requirements for Clean Energy Transitions," in *The Role of Critical Minerals in Clean Energy Transitions*, IEA, May 2021, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/mineral-requirements-for-clean-energy-transitions.

85 Dragonfly Energy, "Why Does Energy Density Matter in Batteries?," December 14, 2022, https://dragonflyenergy.com/why-does-energy-density-matter-in-batteries/.

86 Vehicle Technologies Office, "Volumetric Energy Density of Lithium-Ion Batteries Increased by More Than Eight Times Between 2008 and 2020," Office of Energy Efficiency & Renewable Energy, April 18, 2022, https://www.energy.gov/eere/vehicles/articles/fotw-1234-april-18-2022-volumetric-energy-density-lithium-ion-batteries.

87 McKerracher et al., *Electric Vehicle Outlook*, 139–141.

88 Circular Energy Storage, "The Good News About Battery Production Scrap, accessed April 25, 2023, https://circularenergystorage.com/articles/2022/6/16/the-good-news-about-battery-production-scrap.

89 Energy Saver, "How Lithium-Ion Batteries Work," U.S. Department of Energy, February 28, 2023, https://www.energy.gov/eere/articles/how-does-lithium-ion-battery-work.

90 Ibid.

91 Tracy, *Critical Minerals*, 4.

92 Ibid.

93 Ibid., 2; David Roberts, "The Many Varieties of Lithium-Ion Batteries Battling for Market Share," Canary Media, April 21, 2021, https://www.canarymedia.com/articles/batteries/the-many-varieties-of-lithium-ion-batteries-battling-for-market-share; National Renewable Energy Laboratory (hereinafter NREL), "NREL Enhances the Performance of a Lithium-Ion Battery Cathode," October 2012, https://www.nrel.gov/docs/fy13osti/55947.pdf.

94 NREL, "Lithium-Ion Battery Cathode."

95 Roberts, "Many Varieties."

96 Ibid.

97 Ibid.https://www.canarymedia.com/articles/batteries/the-many-varieties-of-lithium-ion-batteries-battling-for-market-share.

98 Kim et al., *Role of Critical Minerals*, 169.

99 Kyle Field, "BloombergNEF: Lithium-Ion Battery Cell Densities Have Almost Tripled Since 2010," *CleanTechnica*, February 19, 2020, https://cleantechnica.com/2020/02/19/bloombergnef-lithium-ion-battery-cell-densities-have-almost-tripled-since-2010/.

100 Charlie Bloch, James Newcomb, and Madeline Tyson, *Breakthrough Batteries: Powering the Era of Clean Electrification*, RMI, 2019, https://rmi.org/insight/breakthrough-batteries/.

101 Ibid., 61.

102 Group14 Technologies, "The Highest Performing Battery Material on the Market," accessed June 2, 2022, https://group14.technology/en/technology.

103 Elkind, Heller, and Lamm, *Sustainable Drive*, 4; Johnston, "Supply of Critical Minerals."

104 NREL, "Lithium-Ion Battery Cathode"; Bibra et al., *Global EV Outlook*, 140.

105 Roberts, "Many Varieties."

106 Bibra et al., *Global EV Outlook*, 138, 140.

107 Andrei Nedelea, "Almost Half of All Teslas Built in Q1 Had the LFP Battery Pack," *InsideEVs*, April 21, 2022, https://insideevs.com/news/581261/tesla-lfp-battery-nearly-half-deliveries/.

108 McKerracher et al., *Electric Vehicle Outlook*, 135.

109 Ibid.

110 K. M. Abraham, "How Comparable Are Sodium-Ion Batteries to Lithium-Ion Counterparts?," *ACS Energy Letters* 5 (2020): 3546, https://pubs.acs.org/doi/pdf/10.1021/acsenergylett.0c02181.

111 Ionic Materials, "Battery," accessed June 2, 2022, https://ionicmaterials.com/battery/; ARPA, "Ionic Materials: High-Throughput Manufacturing of Breakthrough Polymer Electrolyte to Enable Low-Cost Solid-State Batteries" (SCALEUP Launch Pad semi-finalist), accessed June 2, 2022, https://arpa-e.energy.gov/technologies/scaleup-launch-pad-2020/ionic-materials.

112 Fabian Duffner, "Post-Lithium-Ion Battery Cell Production and Its Compatibility With Lithium-Ion Cell Production Infrastructure," *Nature Energy* 6 (2021): 126, https://doi.org/10.1038/s41560-020-00748-8.

113 Energy Star, accessed July 7, 2022, https://www.energystar.gov/; U.S. Green Building Council, "Benefits of LEED," accessed April 13, 2023, https://www.usgbc.org/leed/benefits-leed.

114 TCO Certified, "Environmental and Social Criteria With Direct Impact," accessed July 22, 2022, https://tcocertified.com/criteria-overview/.

115 Battery Labeling Requirements, title 13, sec. 1962.6, California Code of Regulations, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/2acciifro1962.6.pdf; Jay N. Meegoda, Sarvagna Malladi, and Isabel C. Zayas, "End-of-Life Management of Electric Vehicle Lithium-Ion Batteries in the United States," *Clean Technologies* 4, no. 4 (2022): 1168–1169, https://doi.org/10.3390/cleantechnol4040071.

116 Elkind, Heller, and Lamm, *Sustainable Drive*, 25.

117 Global Electronics Council, "EPEAT Registry," accessed July 22, 2022, https://www.epeat.net/.

118 Global Electronics Council, "GEC's Business Case and the Selection of Product/Service Categories," June 2021, https://globalelectronicscouncil.org/wp-content/uploads/GEC-Business-Case-_-Selection-of-Product_Service-Categories-June-2021.pdf; Global Electronics Council, "EPEAT Registry."

119 Global Electronics Council, "Criteria Modules by Sustainability Impact," last updated April 4, 2022, 3, https://globalelectronicscouncil.org/wp-content/uploads/criteria-modules-sustainability-impact.pdf.

120 EPA, "Electronic Product Environmental Assessment Tool (EPEAT)," last updated November 23, 2022, https://www.epa.gov/greenerproducts/electronic-product-environmental-assessment-tool-epeat.

121 The White House, "Fact Sheet: President Biden Signs Executive Order Catalyzing America's Clean Energy Economy Through Federal Sustainability," news release, December 8, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/12/08/fact-sheet-president-biden-signs-executive-order-catalyzing-americas-clean-energy-economy-through-federal-sustainability/.; EPA, "EPEAT."

122 TCO Certified, "Environmental and Social Risks With IT Products," accessed July 22, 2022, https://tcocertified.com/sustainability-issues-connected-to-it-products/.

123 TCO Certified, "Answers to Frequently Asked Questions," accessed July 22, 2022, https://tcocertified.com/frequently-asked-questions/.

124 CalSAFER, "Cobalt," State of California, last updated January 12, 2023, https://calsafer.dtsc.ca.gov/cms/candidatechemical/?rid=22100.

125 EPA, "Stationary Sources of Air Pollution," last updated February 16, 2023, https://www.epa.gov/stationary-sources-air-pollution; EPA, "Industrial Effluent Guidelines," last updated March 8, 2023, https://www.epa.gov/eg/industrial-effluent-guidelines.

126 EPA, "Summary of the Toxic Substances Control Act," last updated October 4, 2022, https://www.epa.gov/laws-regulations/summary-toxic-substances-control-act.

127 EPA, "Defining Hazardous Waste: Listed, Characteristic and Mixed Radiological Wastes," last updated June 15, 2022, https://www.epa.gov/hw/defining-hazardous-waste-listed-characteristic-and-mixed-radiological-wastes; EPA, "Learn the Basics of Hazardous Waste," last updated July 6, 2022, https://www.epa.gov/hw/learn-basics-hazardous-waste#hwid.

128 Anna Reade, "New EPA Data: Huge Amounts of PFAS Underreported and Burned," NRDC, October 21, 2021, https://www.nrdc.org/experts/yiliqi/new-epa-data-huge-amounts-pfas-underreported-and-burned-0.

129 EPA, "Information About the Green Chemistry Challenge," last updated December 15, 2022, https://www.epa.gov/greenchemistry/information-about-green-chemistry-challenge.

130 EPA, "Green Chemistry Challenge Award Recipients by Industry Sector: Electronics and Semiconductors," last updated June 6, 2022, https://www.epa.gov/greenchemistry/green-chemistry-challenge-award-recipients-industry-sector#electronics.

131 Cradle to Cradle Products Innovation Institute, "Get Certified," accessed July 7, 2022, https://c2ccertified.org/get-certified.

132 Ibid.

133 Cradle to Cradle Products Innovation Institute, *Cradle to Cradle Certified Product Standard Version 4.0*, 2021, 3, https://cdn.c2ccertified.org/resources/STD_C2C_Certified_V4.0_FINAL_101921.pdf.

134 Ibid., 14.

135 Cradle to Cradle Products Innovation Institute, "Certified Products," accessed July 7, 2022, https://www.c2ccertified.org/products/registry.

136 European Commission, "Chemicals Strategy," accessed July 8, 2022, https://environment.ec.europa.eu/strategy/chemicals-strategy_en.

137 European Commission, "Chemicals Strategy for Sustainability: Towards a Toxic-Free Environment" (communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions), October 14, 2020, https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf.

138 https://www.steptoe.com/en/news-publications/the-european-commission-issues-sustainable-chemicals-strategy-paper-major-overhaul-of-eu-chemicals-legislation-announced.html

139 Ruxandra Cana, Darren Abrahams, and Anna Gergely, "Chemicals Strategy for Sustainability: Towards a Toxic-Free Environment," Steptoe, October 14, 2020, https://www.steptoe.com/en/news-publications/the-european-commission-issues-sustainable-chemicals-strategy-paper-major-overhaul-of-eu-chemicals-legislation-announced.html.

140 European Commission, "Chemicals Strategy," 5.

141 Ibid.

142 Federal Highway Administration, "Infrastructure and Investment Jobs Act Request for Information," *Federal Register*, December 1, 2021, https://www.federalregister.gov/documents/2021/12/01/2021-26145/infrastructure-and-investment-jobs-act-request-for-information; U.S. Department of Treasury and Internal Revenue Service, "Request for Comments on Credits for Clean Vehicles," notice 2022-46, accessed October 7, 2022, https://www.irs.gov/pub/irs-drop/n-22-46.pdf.

143 Office of Energy Efficiency & Renewable Energy, "Advanced Manufacturing at EERE," accessed May 23, 2022, https://www.energy.gov/eere/amo/advanced-manufacturing-office.

144 Amy Antoniolli and Evgeny Magidenko, "The IRA's New and Expanded Tax Credits for Projects to Support Clean Energy Manufacturing and Recycling," *National Law Review*, August 22, 2022, https://www.natlawreview.com/article/ira-s-new-and-expanded-tax-credits-projects-to-support-clean-energy-manufacturing.

145 U.S. Department of Energy, "Bipartisan Infrastructure Law Battery Materials Processing and Battery Manufacturing & Recycling Funding Opportunity Announcement: (DE-FOA-0002678) Selections," last updated November 1, 2022, https://www.energy.gov/sites/default/files/2022-11/DOE percent20BIL percent20Battery percent20FOA-2678 percent20Selectee percent20Fact percent20Sheets.pdf.

146 EPA, "Universal Waste," last updated January 3, 2023, https://www.epa.gov/hw/universal-waste; Pipeline and Hazardous Materials Safety Administration, "Transporting Lithium Batteries," U.S. Department of Transportation, last updated March 30, 2023, https://www.phmsa.dot.gov/lithiumbatteries.

147 Alissa Kendall, Margaret Slattery, and Jessica Dunn, *Lithium-Ion Car Battery Recycling Advisory Group Final Report*, California Environmental Protection Agency, March 16, 2022, 53, https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-Recycling-Advisory-Goup-Final-Report.pdf.

148 California Air Resources Board, *Staff Report: Initial Statement of Reasons*, April 12, 2022, 84–85, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/isor.pdf.

149 EPA, "State Adoption of California Standards," in "Vehicle Emissions California Waivers and Authorizations," last updated April 28, 2023, https://www.epa.gov/state-and-local-transportation/vehicle-emissions-california-waivers-and-authorizations; EPA, "Resource Conservation and Recovery Act (RCRA) Overview," last updated June 29, 2022, https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-overview.

150 EPA, "Battery Collection Best Practices and Battery Labeling Guidelines," last updated April 14, 2023, https://www.epa.gov/infrastructure/battery-collection-best-practices-and-battery-labeling-guidelines.

151 California Air Resources Board, *Staff Report*, 72.

152 Jessica Dunn, "Battery State of Health—What Is It? Why Is It Important?," *Equation* (blog), Union of Concerned Scientists, October 7, 2022, https://blog.ucsusa.org/jessica-dunn/battery-state-of-health-what-is-it-why-is-it-important/.

153 Kendall, Slattery, and Dunn, *Lithium-Ion Car Battery Recycling*, 51; California Air Resources Board, *Staff Report*, 71; SAE International, "Battery Electric Vehicle Energy Consumption and Range Test Procedure J1634_202104," April 6, 2021, https://www.sae.org/standards/content/j1634_202104.

154 Kendall, Slattery, and Dunn, *Lithium-Ion Car Battery Recycling*, 22.

155 J. Neubauer et al., *Identifying and Overcoming Critical Barriers to Widespread Second Use of PEV Batteries*, NREL, February 2015, v, https://www.nrel.gov/docs/fy15osti/63332.pdf.

156 Lluc Canals Casals, B. Amante García, and Camille Canal, "Second Life Batteries Lifespan: Rest of Useful Life and Environmental Analysis," *Journal of Environmental Management* 232 (February 15, 2019): 354, https://doi.org/10.1016/j.jenvman.2018.11.046; Neubauer et al., *Identifying and Overcoming*, v.

157 Neubauer et al., *Identifying and Overcoming*, 61.

158 Elsa Dominish, Nick Florin, and Rachael Wakefield-Rann, *Reducing New Mining for Electric Vehicle Battery Metals: Responsible Sourcing Through Demand Reduction Strategies and Recycling*, Earthworks, Institute for Sustainable Futures, University of Technology Sydney, April 2021, 22, https://earthworks.org/assets/uploads/2021/04/UTS-EV-battery-metals-sourcing-20210419-FINAL.pdf.

159 Casals, García, and Canal, "Second Life Batteries Lifespan," 357.

160 RePurpose Energy, accessed May 6, 2022, https://www.repurpose.energy/.

161 Neubauer et al., *Identifying and Overcoming*, vi.

162 Union of Concerned Scientists, "Electric Vehicle Batteries," February 2021, 5, https://www.ucsusa.org/sites/default/files/2021-02/ev-battery-recycling-fact-sheet.pdf.

163 Dale Hall and Nic Lutsey, "Effects of Battery Manufacturing on Electric Vehicle Life-Cycle Greenhouse Gas Emissions," International Council on Clean Transportation, February 2018, 8, https://theicct.org/sites/default/files/publications/EV-life-cycle-GHG_ICCT-Briefing_09022018_vF.pdf.

164 Dominish, Florin, and Wakefield-Rann, *Reducing New Mining*, 23.

165 Ibid.

166 Julia Pyper, "Second Life: Carmakers and Storage Startups Get Serious About Reusing Batteries," *GTM*, June 30, 2020, https://www.greentechmedia.com/articles/read/car-makers-and-startups-get-serious-about-reusing-batteries.

167 Hauke Engel, Patrick Hertzke, and Giulia Siccardo, "Second-Life EV Batteries: The Newest Value Pool in Energy Storage," McKinsey & Company, April 30, 2019, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage; RePurpose Energy.

168 EPA, "Summary of the Resource Conservation and Recovery Act," last updated September 12, 2022, https://www.epa.gov/laws-regulations/summary-resource-conservation-and-recovery-act.

169 EPA, "Characteristic Wastes," in "Defining Hazardous Waste: Listed, Characteristic and Mixed Radiological Wastes," last updated June 15, 2022, https://www.epa.gov/hw/defining-hazardous-waste-listed-characteristic-and-mixed-radiological-wastes#characteristic.

170 EPA, "'Watt's' the Buzz About Lithium Batteries" (presentation), accessed October 7, 2022, slide 13, https://www.epa.gov/sites/default/files/2021-05/documents/april_29_2021_epa_and_dot_speaker_slides_508.pdf.

171 EPA, "EPA's Cradle-to-Grave Hazardous Waste Management Program," in "Learn the Basics of Hazardous Waste," last updated July 6, 2022, https://www.epa.gov/hw/learn-basics-hazardous-waste#cradle.

172 Taylor L. Curtis et al., *A Circular Economy for Lithium-Ion Batteries Used in Mobile and Stationary Energy Storage: Drivers, Barriers, Enablers, and U.S. Policy Considerations*, NREL, March 2021, 13–14, https://www.nrel.gov/docs/fy21osti/77035.pdf.

173 Code of Federal Regulations, title 40, ch. I, sec. 266.80 (last updated May 9, 2023), https://www.ecfr.gov/current/title-40/chapter-I/subchapter-I/part-266/subpart-G/section-266.80.

174 EPA, "Universal Waste."

175 Code of Federal Regulations, title 40, ch. I, sec. 266.80.

176 Ibid.

177 Curtis et al., *Circular Economy*, 36.

178 Kevin Dooley et al., *A Case Study—Lead-Acid Battery Recycling Success: Policy + Reverse Supply Chains*, December 2020, Sustainability Consortium and the Responsible Battery Coalition, 8.

179 Curtis et al., *Circular Economy*, 37.

180 EPA, "State Authorization Under the Resource Conservation and Recovery Act (RCRA)," last updated November 6, 2022, https://www.epa.gov/rcra/state-authorization-under-resource-conservation-and-recovery-act-rcra; EPA, "State Universal Waste Programs in the United States," last updated March 2, 2023, https://www.epa.gov/hw/state-universal-waste-programs-united-states.

181 EPA, "State Authorization."

182 Kendall, Slattery, and Dunn, *Lithium-Ion Car Battery Recycling*, 53.

183 Ibid., 53.

184 Vivienne Halleux, "New EU Regulatory Framework for Batteries: Setting Sustainability Requirements," European Parliament, March 2022, 7, https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf.

185 EPA, "RCRA Overview."

186 EPA, "Battery Collection Best Practices."

187 Battery Labeling Requirements, California Code of Regulations.

188 Ibid., 4–5; California Air Resources Board, *Staff Report*, 84–85.

189 Battery Labeling Requirements, California Code of Regulations, 3–4.

190 Ibid., 5–6.

191 California Air Resources Board, "Appendix D Summary of Comments to ZEV Assurance Measures and Agency Response," in *Final Statement of Reasons for Rulemaking, Including Summary of Comments and Agency Response*, August 25, 2022, 66–67, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/fsorappd.pdf.

192 Appendix F-8, Battery Labeling Requirements, title 13, sec. 1962.6, California Code of Regulations (April 12, 2022), https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appf8.pdf.

193 EPA, "State Adoption of California Standards."

194 EPA, "Vehicle Emissions California Waivers and Authorizations," last updated April 28, 2023, https://www.epa.gov/state-and-local-transportation/vehicle-emissions-california-waivers-and-authorizations.

195 California Air Resources Board, "Advanced Clean Cars II Regulations: All New Passenger Vehicles Sold in California to be Zero Emissions by 2035," accessed March 27, 2023, https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii; Sierra Club Delaware Chapter, "Cleaner Air and Economic Prosperity for Delaware With Electric Cars," accessed April 26, 2023, https://www.sierraclub.org/sites/www.sierraclub.org/files/2023-03/ACCII percent20Delaware percent20Fact percent20Sheet percent20 percent283 percent29.pdf.

196 Global Battery Alliance, "About the GBA," accessed April 25, 2023, https://www.globalbattery.org/about/.

197 Ibid.

198 Global Battery Alliance, "Battery Passport," accessed April 25, 2023, https://www.globalbattery.org/battery-passport/.

199 European Commission, *Proposal for a Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020*, December 10, 2020, 12, https://eur-lex.europa.eu/resource.html?uri=cellar:4b5d88a6-3ad8-11eb-b27b-01aa75ed71a1.0001.02/DOC_1&format=PDF; Kendall, Slattery, and Dunn, *Lithium-Ion Car Battery Recycling*, 23.

200 Curtis et al., *Circular Economy*, 41.

201 U.S. Department of Energy, "Bipartisan Infrastructure Law Electric Drive Vehicle Battery Recycling and Second Life Applications Funding Opportunity Announcement: (DE-FOA-0002680) Selections—Factsheets," November 2022, https://www.energy.gov/sites/default/files/2022-11/Recycling percent20and percent20Second-Use percent20Selections percent20Factsheets percent2011-16.pdf; U.S. Department of Energy, "Bipartisan Infrastructure Law Battery Materials Processing and Battery Manufacturing & Recycling Funding Opportunity Announcement (DE-FOA-0002678) Selections—Factsheets," last updated November 1, 2022, https://www.energy.gov/sites/default/files/2022-11/DOE%20BIL%20Battery%20FOA-2678%20Selectee%20Fact%20Sheets.pdf.

202 U.S. Department of Energy, "Bipartisan Infrastructure Law Battery Materials Processing and Battery Manufacturing & Recycling Funding Opportunity Announcement: (DE-FOA-0002678) Selections—Factsheets," October 19, 2022, 10, https://www.energy.gov/sites/default/files/2022-10/DOE percent20BIL percent20Battery percent20FOA-2678 percent20Selectee percent20Fact percent20Sheets percent20- percent201_2.pdf.

203 Cirba Solutions, "Battery Recycling Services," accessed March 16, 2023, https://www.cirbasolutions.com/services/.

204 California Air Resources Board, *Staff Report*, 71.

205 Ibid., 72.

206 Ibid., 71; SAE International, "Battery."

207 "Appendix A-6: Proposed Regulation Order," title 13, sec. 1962.5, California Code of Regulations (April 12, 2022), https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa6.pdf.

208 Dunn, "Battery State of Health."

209 Kendall, Slattery, and Dunn, *Lithium-Ion Car Battery Recycling*, 51.

210 Ethan N. Elkind, *Reuse and Repower: How to Save Money and Clean the Grid With Second-Life Electric Vehicle Batteries*, UCLA Law and Berkeley Law, September 2014, 18, https://www.law.berkeley.edu/files/ccelp/Reuse_and_Repower_--_Web_Copy.pdf.

211 Neubauer et al., *Identifying and Overcoming*, 3.

212 Dominish, Florin, and Wakefield-Rann, *Reducing New Mining*, 40.

213 Kendall, Slattery, and Dunn, *Lithium-Ion Car Battery Recycling*, 22.

214 Ibid., 45.

215 Engel, Hertzke, and Siccardo, "Second-Life EV Batteries."

216 Halleux, "New EU Regulatory Framework for Batteries," 6; Simona Bonafè and Achille Variati, "New Batteries Regulation," European Parliament Legislative Train, February 2023, https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-revision-of-the-eu-battery-directive-(refit)?sid=6701.

217 White House, "Memorandum on Presidential Determination Pursuant to Section 303 of the Defense Production Act of 1950, as Amended," March 31, 2022, https://www.whitehouse.gov/briefing-room/presidential-actions/2022/03/31/memorandum-on-presidential-determination-pursuant-to-section-303-of-the-defense-production-act-of-1950-as-amended/.

218 Ibid.

219 NRDC, *Working With the Department of Defense: Siting Renewable Energy Development*, April 2013, https://www.nrdc.org/sites/default/files/nuc_13112001a.pdf; Helen O'Shea, "Progress on Smart From the Start Solar in California and Nevada," NRDC, June 2, 2015, https://www.nrdc.org/experts/helen-oshea/progress-smart-start-solar-california-and-nevada; Bureau of Land Management, "Interior Department Approves First Solar Energy Zone Projects," news release, June 1, 2015, https://www.blm.gov/press-release/interior-department-approves-first-solar-energy-zone-projects.

220 ACS Green Chemistry Institute, "12 Principles of Green Chemistry," accessed July 8, 2022, https://www.acs.org/content/acs/en/greenchemistry/principles/12-principles-of-green-chemistry.html; e-Stewards, "What's the e-Stewards Standard?," accessed July 8, 2022, https://e-stewards.org/learn-more/for-enterprises/overview/whats-the-e-stewards-standard/.

221 Hall and Lutsey, "Effects of Battery Manufacturing," 8.

222 Dunn, Kendall, and Slattery, "Electric Vehicle," 7.

223 Kendall, Slattery, and Dunn, *Lithium-Ion Car Battery Recycling*, 18–20.

224 Dunn, Kendall, and Slattery, "Electric Vehicle," 7.

225 White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth*, June 2021, 195–199, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

226 Dunn, Kendall, and Slattery, "Electric Vehicle," 3.

227 Linda Gaines et al., "Direct Recycling R&D at the ReCell Center," *Recycling* 6, no. 2 (2021): 4, https://doi.org/10.3390/recycling6020031.

228 Li-Feng Zhou et al., "The Current Process for the Recycling of Spent Lithium Ion Batteries," *Frontiers in Chemistry* 8 (2020): 3–5, table 1, https://doi.org/10.3389/fchem.2020.578044.

229 Dominish, Florin, and Wakefield-Rann, *Reducing New Mining*, 5.

230 Dunn, Kendall, and Slattery, "Electric Vehicle," 3.

231 Redwood Materials, "Recycling, Refining, and Remanufacturing Battery Materials for a Clean Energy Future," accessed April 27, 2023, https://www.redwoodmaterials.com/solutions/; Redwood Materials, "We're Building a Circular Supply Chain to Power a Sustainable World," accessed April 27, 2023, https://www.redwoodmaterials.com/.

232 Gaines et al., "Direct Recycling," 5.

233 Ibid., 7.

234 Dunn, Kendall, and Slattery, "Electric Vehicle," table S3.

235 Gaines et al., "Direct Recycling," 13.

236 FCAB, "National Blueprint"; Morse, "A Dead Battery Dilemma."

237 Gaines et al., "Direct Recycling," 4–5.

238 Argonne National Laboratory, "Recycling," accessed May 6, 2022, https://www.anl.gov/manufacturing/recycling; Oak Ridge National Laboratory, "ORNL Supports New DOE Lithium-Ion Battery Recycling Center," news release, February 25, 2019, https://www.ornl.gov/news/ornl-supports-new-doe-lithium-ion-battery-recycling-center; NREL, "Battery Reuse and Recycling," accessed May 6, 2022, https://www.nrel.gov/storage/battery-reuse-recycling.html.

239 ReCell Center, "About," accessed May 4, 2022 https://recellcenter.org/about/.

240 Gaines et al., "Direct Recycling," 14.

241 Infrastructure Investment and Jobs Act, H.R.3684, 117th Cong. (2021), https://www.congress.gov/bill/117th-congress/house-bill/3684/text.

242 U.S. Department of Energy, "(DE-FOA-0002680) Selections—Factsheets"; White House, "Fact Sheet: Biden-Harris Administration Driving U.S. Battery Manufacturing and Good-Paying Jobs," October 19, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/10/19/fact-sheet-biden-harris-administration-driving-u-s-battery-manufacturing-and-good-paying-jobs/.

243 Halleux, "New EU Regulatory Framework for Batteries," 6; Bonafè and Variati, "New Batteries Regulation."

244 Dunn, Kendall, and Slattery, "Electric Vehicle," table S3.

245 ECOS et al., *Enhancing the Sustainability of Batteries: A Joint NGOs' Position Paper on the EU Battery Regulation Proposal*, March 17, 2021, https://www.duh.de/fileadmin/user_upload/download/Projektinformation/Kreislaufwirtschaft/210317_Joint_position_paper_on_the_EU-Batteries-Regulation.pdf.

246 Zhou et al., "Current Process," 2–3, table 1.

247 ACS Green Chemistry Institute, "12 Principles"; e-Stewards, "What's the e-Stewards Standard?"

248 ACS Green Chemistry Institute, "12 Principles."

249 Dunn, Kendall, and Slattery, "Electric Vehicle," 6.

250 Ibid., 7.

251 Ibid.

252 Ibid.

253 Ibid.

254 Ibid., 6.

255 White House, “Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability,” December 8, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/12/08/executive-order-on-catalyzing-clean-energy-industries-and-jobs-through-federal-sustainability/.

256 California Department of General Services, “Buy Clean California Act,” last updated April 26, 2023, https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act; New York Senate Bill S542A (2021–2022), https://www.nysenate.gov/legislation/bills/2021/S542.

257 First Movers Coalition, “First Movers Coalition: Introduction and overview of commitments,” May 2023, https://weforum.ent.box.com/s/3do0gx4v0hyx3fhco7f7f8ft7wwlj66e.

258 World Economic Forum, “First Movers Coalition,” accessed March 21, 2023, https://www.weforum.org/first-movers-coalition.

259 White House, “Fact Sheet: President Biden’s Leadership to Tackle the Climate Crisis at Home and Abroad Galvanizes Unprecedented Momentum at Start of U.N. Climate Conference (COP27),” November 7, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/11/07/fact-sheet-president-bidens-leadership-to-tackle-the-climate-crisis-at-home-and-abroad-galvanizes-unprecedented-momentum-at-start-of-u-n-climate-conference-cop27/.

260 World Economic Forum, “First Movers Coalition.”

261 White House, “Memorandum on Presidential Determination.”

262 Halleux, “New EU Regulatory Framework for Batteries.”

263 Dunn, Kendall, and Slattery, “Electric Vehicle,” 8.

264 White House, “Memorandum on Presidential Determination.”

265 Recycling: Lithium-Ion Vehicle Batteries: Advisory Group, California Assembly Bill 2832, ch. 822 (2018), https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB2832; California Environmental Protection Agency, “Lithium-Ion Car Battery Recycling Advisory Group,” accessed November 7, 2022, https://calepa.ca.gov/lithium-ion-car-battery-recycling-advisory-group/.

266 Recycling, California Assembly Bill 2832.

267 Kendall, Slattery, and Dunn, *Lithium-Ion Car Battery Recycling*.

268 Curt Barry, “California Faces ‘Big Fight’ Over Recycling Bill For Lithium-Ion Car Batteries,” *Inside EPA*, December 15, 2022.

269 Aleksandra O’Donovan et. al., “1Q 2023 Electrified Transport Market Outlook,” BloombergNEF, March 2, 2023, 17.

270 Ira Boudway, “More Than Half of US Car Sales Will Be Electric by 2030,” Bloomberg, September 20, 2022, https://www.bloomberg.com/news/articles/2022-09-20/more-than-half-of-us-car-sales-will-be-electric-by-2030.

271 Christina Ospina, “What Are Pre-Competitive Partnerships?,” Resonance, August 5, 2022, https://www.resonanceglobal.com/blog/what-are-pre-competitive-partnerships.

272 Alissa Kendall, Margaret Slattery, and Jessica Dunn, *Lithium-ion Car Battery Recycling Advisory Group: Draft Report*, AB 2832 Advisory Group, February 17, 2022, 34, https://calepa.ca.gov/wp-content/uploads/sites/6/2022/03/AB-2832-Final-Draft-Policy-Recommendations-Lithium-ion-Car-Battery-Recycling-Advisory-Group-As-of-3-11-22.a.hp_.pdf.

273 “Rules and Regulations,” *Federal Register* 84, no. 236 (December 9, 2019): 67206 https://www.govinfo.gov/content/pkg/FR-2019-12-09/pdf/2019-25674.pdf; Code of Federal Regulations, title 40, ch. I, sec. 273.60 (last updated May 9, 2023), https://www.ecfr.gov/current/title-40/chapter-I/subchapter-I/part-273/subpart-E/section-273.60; Code of Federal Regulations, title 40, ch. I, sec. 261.6 (last updated May 9, 2023), https://www.ecfr.gov/current/title-40/chapter-I/subchapter-I/part-261/subpart-A/section-261.6.

274 NRDC, *Working With the Department of Defense*; O’Shea, “Progress on Smart From the Start”; Bureau of Land Management, “Interior Department.”

275 Office of Energy Efficiency & Renewable Energy, “Solar Futures Study,” accessed April 19, 2022, https://www.energy.gov/eere/solar/solar-futures-study.

276 Ellen MacArthur Foundation, *Extended Producer Responsibility*, 2021, https://ellenmacarthurfoundation.org/extended-producer-responsibility/overview.

277 CalRecycle, “Product Stewardship and Extended Producer Responsibility (EPR),” State of California, accessed July 20, 2022, https://calrecycle.ca.gov/epr/.

278 Chaz Miller, “An American EPR: Monopolies and Other Unintended Consequences,” *Waste360*, March 30, 2021, https://www.waste360.com/legislation-regulation/american-epr-monopolies-and-other-unintended-consequences.

279 Kendall, Slattery, and Dunn, *Lithium-Ion Car Battery Recycling*, 45.

280 Ibid., 45–46.

281 Dunn, Kendall, and Slattery, “Electric Vehicle,” 7.

282 Dooley et al., *A Case Study*, 9.

283 Ibid., 7, fig. 4.

284 Ibid., 7.

285 Dooley et al., *A Case Study*, 7, fig. 4.

286 Ibid., 7, fig. 5.

287 Thea Riofrancos et al., *Achieving Zero Emissions With More Mobility and Less Mining*, Climate and Community Project, January 2023, 38, https://www.climateandcommunity.org/_files/ugd/d6378b_3b79520a747948618034a2b19b9481a0.pdf.

288 Andrew Van Dam, “The Real Reason Trucks Have Taken Over U.S. Roadways,” *Washington Post*, April 7, 2023, https://www.washingtonpost.com/busisness/2023/04/07/trucks-outnumber-cars/.

289 EPA, “Executive Summary,” in *The 2022 EPA Automotive Trends Report*, December 2022, ES-2, https://www.epa.gov/system/files/documents/2022-12/420s22001.pdf; Code of Federal Regulations, title 49, subtitle B, ch. 5, sec. 533.5, https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-533/section-533.5; Code of Federal Regulations, title 49, subtitle B, ch. 5, sec. 531.5, https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-531/section-531.5.

290 Kim et al., *Role of Critical Minerals*, 9.

291 Steven Higashide et al., *A Green New Deal for City and Suburban Transportation*, TransitCenter, Transportation for America, and the McHarg Center, March 2020, https://transitcenter.org/wp-content/uploads/2020/03/20.03_GND-Transit_use_v4.pdf.

292 Riofrancos et al., *Achieving Zero Emissions*, 38.

293 Alternative Fuels Data Center, "Electric Vehicle Benefits and Considerations," U.S. Department of Energy, accessed December 8, 2022, https://afdc.energy.gov/fuels/electricity_benefits.html; Alternative Fuels Data Center, "Alternative Fuel and Advanced Vehicle Search," U.S. Department of Energy, accessed March 29, 2023, https://afdc.energy.gov/vehicles/search/results/?view_mode=grid&search_field=vehicle&search_dir=desc&per_page=8&current=true&display_length=25&fuel_id=41,-1&all_categories=y&manufacturer_id=365,377,355,211,231,215,223,409,219,213,209,351,385,275,466,424,361,387,243,227,469,229,239,425,263,217,462,391,349,470,383,237,221,347,395,-1; Alternative Fuels Data Center, "Glossary," U.S. Department of Energy, accessed December 8, 2022, https://afdc.energy.gov/glossary.html.

294 EPA, "Highlights of the Automotive Trends Report," last updated December 12, 2022, https://www.epa.gov/automotive-trends/highlights-automotive-trends-report.

295 Ibid.

296 Ibid.

297 EPA, "Executive Summary," ES-2; Code of Federal Regulations, title 49, subtitle B, ch. 5, sec. 533.5; Code of Federal Regulations, title 49, subtitle B, ch. 5, sec. 531.5.

298 NRDC, "Report: The Role of Uber and Lyft in Sustainable Cities," news release, November 17, 2021, https://www.nrdc.org/media/2021/211117.

299 Carrie Hampel, "Electric Car-Sharing in Minneapolis and Saint Paul," Electrive.com, May 23, 2022, https://www.electrive.com/2022/05/23/electric-car-sharing-in-minneapolis-and-saint-paul/.

300 Susan Shaheen and Nelson Chan, "Mobility and the Sharing Economy: Impacts Synopsis," Transportation Sustainability Research Center, Spring 2015, http://innovativemobility.org/wp-content/uploads/Innovative-Mobility-Industry-Outlook_SM-Spring-2015.pdf; Pete Ortiz, "How Many Cars Does the Average American Own (2023 Update)," House Grail, January 12, 2023, https://housegrail.com/how-many-cars-does-the-average-american-own/.

301 Mark Boada, "Fleet Right-Sizing: It's About More Than Just Reducing Vehicle Numbers," *Fleet Management Weekly*, accessed April 28, 2022, https://www.fleetmanagementweekly.com/fleet-right-sizing-its-about-more-than-just-reducing-vehicle-numbers/.

302 Richard Rothstein, *The Color of Law: A Forgotten History of How Our Government Segregated America* (New York: Liveright, 2017), https://www.epi.org/publication/the-color-of-law-a-forgotten-history-of-how-our-government-segregated-america/.

303 Adam Millard-Ball et al., "What Do Residential Lotteries Show Us About Transportation Choices?," *Transfers Magazine*, December 2021, https://transfersmagazine.org/magazine-article/issue-8/what-do-residential-lotteries-show-us-about-transportation-choices/.

304 Comprehensive and Neighborhood Planning Commission, "Parking Study: Proposed Amendments for 'Parking Reductions' or 'Full Elimination,'" City of Saint Paul, March 12, 2021, 6, 9–10, https://www.stpaul.gov/sites/default/files/2021-03/Final percent20Parking percent20Memo-corrected percent20all percent20sections percent20combined percent20PC percent2003.19.21.pdf.

305 Zak Accuardi, "New Guidance for City Leaders on Parking & Mobility Choices," NRDC, May 12, 2022, https://www.nrdc.org/experts/zak-accuardi/new-guidance-city-leaders-parking-mobility-choices.

306 Higashide et al., *Green New Deal*.

307 Transportation Planning Capacity Building Program, "Flexible Funding for Transit Access," U.S. Department of Transportation, accessed May 2, 2022, https://www.planning.dot.gov/flex.aspx.

308 Erin Blakemore, "Interstate Highways Were Touted as Modern Marvels. Racial Injustice Was Part of the Plan," *Washington Post*, August 17, 2021, https://www.washingtonpost.com/history/2021/08/16/interstate-highways-were-touted-modern-marvels-racial-injustice-was-part-plan/; Liam Dillon and Ben Poston, "Freeways Force Out Residents in Communities of Color—Again," *Los Angeles Times*, November 11, 2021, https://www.latimes.com/projects/us-freeway-highway-expansion-black-latino-communities/; RMI, "SHIFT Calculator," accessed April 29, 2022, https://shift.rmi.org/.

309 Higashide et al., *Green New Deal*.

310 Raúl M. Grijalva, "Clean Energy Minerals Reform Act," House Natural Resources Committee, May 2023, https://democrats-naturalresources.house.gov/imo/media/doc/clean_energy_mineracts_reform_act_of_2023.pdf; U.S. Department of the Interior, "Interior Department Launches Interagency Working Group on Mining Reform," news release, February 22, 2022, https://naturalresources.house.gov/imo/media/doc/FACT SHEET - Clean Energy Minerals Reform Act[28].pdf (MISSING PUNCTUATION HERE) https://www.doi.gov/pressreleases/interior-department-launches-interagency-working-group-mining-reform; UN Office of the High Commissioner for Human Rights (hereinafter OHCHR), *Thematic Advice of the Expert Mechanism on the Rights of Indigenous Peoples: A Compilation (2009–2013)*, 2013, https://www.ohchr.org/sites/default/files/Documents/Issues/IPeoples/EMRIP/CompilationEMRIP2009_2013_en.pdf.

311 Earthworks, *Revising Hardrock Mining Regulations*, 7.

312 Northern Plains Resource Council, "Good Neighbor Agreement," accessed May 5, 2022, https://northernplains.org/good-neighbor-agreement/.

313 London Metal Exchange, "LME Responsible Sourcing," June 2021, https://www.lme.com/en/education/online-resources/lme-insight/lme-responsible-sourcing.

314 Lamm, *Sustainable Drive*, 4; Holzman and Iaconangelo, "U.S. Shift on Child Labor"; Burtless, "Workers' Rights."

315 EPA, "Sectors," in "TRI National Analysis: Executive Summary 2020," accessed July 15, 2022, https://awsgispub.epa.gov/trina2020/execsum/#sectors.

316 Earthworks, "Tailings," accessed February 28, 2023 https://earthworks.org/issues/tailings/.

317 Stone, "Mining Is a Polluting Business."

318 Blair et al., *Exhausted*, 28.

319 Ibid.

320 Ibid.

321 White House, *Building Resilient Supply Chains*, 104.

322 Robert U. Ayres and Laura Talens Peiró, "Material Efficiency: Rare and Critical Metals," *Philosophical Transactions of the Royal Society A* 371, no. 1986 (March 13, 2013): 11, https://doi.org/10.1098/rsta.2011.0563.

323 Natalia Araya, Andrzej Kraslawski, and Luis A. Cisternas, "Towards Mine Tailings Valorization: Recovery of Critical Materials From Chilean Mine Tailings," *Journal of Cleaner Production* 263 (August 1, 2020): 1, https://doi.org/10.1016/j.jclepro.2020.121555.

324 Robert Šajn, Ivica Ristović, and Barbara Čeplak, "Mining and Metallurgical Waste as Potential Secondary Sources of Metals—A Case Study for the West Balkan Region," Minerals 12, no. 5 (2022): 2, https://doi.org/10.3390/min12050547.

325 Paul F. Ziemkiewicz, "Rare Earth Elements in Acid Mine Drainage Become High-Grade Concentrates at WVU's Rare Earth Extraction Facility" (written testimony to the U.S. Senate Committee on Energy and Natural Resources), March 31, 2022, https://www.energy.senate.gov/services/files/3FE0D2F4-1001-44FF-B0C1-9B535DA41935.

326 Nth Cycle, "More Profits From Existing Critical Mineral Mining," accessed January 11, 2023, https://nthcycle.com/applications/critical-mineral-mining/.

327 Ibid.; World Commission on the Ethics of Scientific Knowledge and Technology, *The Precautionary Principle*, 2005, 14, https://unesdoc.unesco.org/ark:/48223/pf0000139578.

328 Blair et al., *Exhausted*, 28.

329 Ibid., 4.

330 Ayres and Peiró, "Material Efficiency," 11.

331 Quentin Dehaine et al., "Geometallurgy of Cobalt Ores: A Review," *Minerals Engineering* 160 (January 1, 2021): 23, https://doi.org/10.1016/j.mineng.2020.106656.

332 Ibid., 20.

333 Earthworks, "Tailings."

334 Ibid.

335 Paul Robson, *The River Is Dead*, London Mining Network, October 2017, https://londonminingnetwork.org/wp-content/uploads/2017/09/Fundao-Report-Final-lowres.pdf.

336 Moira Warburton et al., "The Looming Risk of Tailings Dams," Reuters, last updated January 3, 2020, https://www.reuters.com/graphics/MINING-TAILINGS1/0100B4S72K1/index.html.

337 Ibid.

338 Earthworks, "Tailings."

339 Ibid.

340 Ibid.

341 Earthworks, *Revising Hardrock Mining Regulations*, 8.

342 Earthworks, *Revising Hardrock Mining Regulations*.

343 Ibid.

344 Warburton et al., "Looming Risk."

345 Ibid., 7.

346 Ibid.

347 U.S. Department of Treasury and Internal Revenue Service, "Request for Comments."

348 SIRGE Coalition, "Coalition Calls for Securing Indigenous Peoples' Rights in the Transition to Clean Energy," news release, August 9, 2022, https://www.sirgecoalition.org/statements/launch.

349 Block, "Mining Energy-Transition Metals."

350 SIRGE Coalition, "Coalition Calls for Securing"

351 Cato, Christopher, and Zbona, *Transition Minerals Tracker*; Business & Human Rights Resource Centre, "Human Rights Defenders & Civic Freedoms," last updated May 12, 2023, https://www.business-humanrights.org/en/big-issues/human-rights-defenders-civic-freedoms/.

352 Cato, Christopher, and Zbona, *Transition Minerals Tracker*, 11; Business & Human Rights Resource Centre, "Human Rights Defenders."

353 Business & Human Rights Resource Centre, "Azerbaijan: Abuses by Oil Companies Include Wage Delays, Workplace Discrimination, Illegal Termination of Contracts, Health & Safety Violations, Environmental Pollution, Says NGO Report," March 20, 2023, https://www.business-humanrights.org/en/latest-news/azerbaijan-dozens-of-violations-of-oil-workers-rights-in-2022-tracked-in-new-report-incl-cos-responses-non-responses/.

354 Northern Plains Resource Council, "Good Neighbor Agreement"; Native Land Digital, accessed December 13, 2022, https://native-land.ca/.

355 OHCHR, *Thematic Advice*, 20.

356 International Labour Organization, Indigenous and Tribal Peoples Convention, no. 169 (1989) https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C169; United Nations, United Nations Declaration on the Rights of Indigenous Peoples, September 13, 2007, https://www.un.org/esa/socdev/unpfii/documents/DRIPS_en.pdf.

357 White House, "Memorandum on Tribal Consultation and Strengthening Nation-to-Nation Relationships," January 26, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/26/memorandum-on-tribal-consultation-and-strengthening-nation-to-nation-relationships/.

358 White House, "Fact Sheet: Building A New Era of Nation-to-Nation Engagement," November 15, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/15/fact-sheet-building-a-new-era-of-nation-to-nation-engagement/.

359 U.S. Department of the Interior et al., "Memorandum of Understanding Regarding Interagency Coordination and Collaboration for the Protection of Indigenous Sacred Sites," November 9, 2021, https://www.doi.gov/sites/doi.gov/files/mou-interagency-coordination-and-collaboration-for-the-protection-of-indigenous-sacred-sites-11-16-2021.pdf.

360 Earthworks, "The 1872 Mining Law," accessed December 8, 2022, 1, https://earthworks.org/wp-content/uploads/2021/09/FS_1872MiningLaw_EW-EJ-WORC_201903.pdf.

361 Michael Lopez, "Tribal Rights: The 1872 Mining Law's Past and Future," American Bar Association, January 1, 2020, https://www.americanbar.org/groups/environment_energy_resources/publications/natural_resources_environment/2019-20/winter/tribal-rights-1872-mining-laws-past-and-future/.

362 Pew Environment Group, "The 1872 Mining Law: Time for Reform," Pew Charitable Trusts, January 2009, https://www.pewtrusts.org/~/media/assets/2009/01/24/mining-law-time-for-reform.pdf; U.S. Forest Service, "Appendix A: Inventoried Roadless Area Acreage Categories of NFS Lands Summarized by State," accessed January 17, 2023, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm8_037652.htm.

363 GAO, *Hardrock Mining*.

364 Ibid.

365 John C. Ruple, Jamie Pleune, and Erik Heiny, "Evidence-Based Recommendations for Improving National Environmental Policy Act Implementation," *Columbia Journal of Environmental Law* 47, no. S (2022): 273, https://journals.library.columbia.edu/index.php/cjel/article/view/9479/4840.

366 Bipartisan Policy Center, "Inflation Reduction Act (IRA) Summary: Energy and Climate Provisions," August 4, 2022, https://bipartisanpolicy.org/blog/inflation-reduction-act-summary-energy-climate-provisions/.

367 Clean Energy Minerals Reform Act of 2023, 118th Cong. (2023), https://www.heinrich.senate.gov/imo/media/doc/clean_energy_minerals_reform_act_text.pdf. Clean Energy Minerals Reform Act of 2023, 118th Cong. (2023), https://democrats-naturalresources.house.gov/imo/media/doc/Clean%20Energy%20Minerals%20Reform%20Act%20of%202023_Bill%20Text.pdf.

368 Grijalva, "Clean Energy Minerals Reform Act."

369 Pew Environment Group, "The 1872 Mining Law."

370 Earthworks, *Revising Hardrock Mining Regulations*, 4.

371 Fennell, "Mining on Federal Lands."

372 U.S. Department of the Interior, "Interagency Working Group on Mining Reform."

373 Office of the Secretary, "Request for Information to Inform Interagency Working Group on Mining Regulations, Laws, and Permitting," U.S. Department of the Interior, March 31, 2022, https://www.federalregister.gov/documents/2022/03/31/2022-06750/request-for-information-to-inform-interagency-working-group-on-mining-regulations-laws-and.

374 Lamm, *Sustainable Drive*, 11.

375 Ibid., 17–19.

376 Regulation 2017/821 of the European Parliament and of the Council Laying Down Supply Chain Due Diligence Obligations for Union Importers of Tin, Tantalum and Tungsten, Their Ores, and Gold Originating From Conflict-Affected and High-Risk Areas, May 17, 2017, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02017R0821-20201119&from=EN; Organisation for Economic Co-operation and Development, *OECD Due Diligence Guidance for Responsible Supply Chains of Minerals From Conflict-Affected and High-Risk Areas*, 3rd ed., 2016, https://www.oecd.org/daf/inv/mne/OECD-Due-Diligence-Guidance-Minerals-Edition3.pdf; Responsible Minerals Initiative, "RMAP Assessment Introduction," accessed April 21, 2023, https://www.responsiblemineralsinitiative.org/responsible-minerals-assurance-process/; Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010, sec. 1502, 12 U.S.C. § 5301 (2010), https://www.govinfo.gov/content/pkg/PLAW-111publ203/pdf/PLAW-111publ203.pdf.

377 London Metal Exchange, "LME Responsible Sourcing."

378 EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks," last updated April 19, 2023, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.