National Association of State Energy Officials

Critical Energy-Related Minerals:

Considerations for State Energy Planning, Policy, and Programs

Contents

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Cover Photo: Small pieces of strong metal ore. *Credit: istockPhoto/dt03mbb*

Aerial view of the Rockwood Lithium mine in Silver Peak Nevada.
Credit: iStockphoto/Skyhobo

Introduction

An energy transition is underway. New technologies, including for power generation, transmission and distribution, energy storage, transportation, manufacturing, and buildings, are arising. They are increasingly deployed to reduce climate-altering emissions, enhance energy reliability and resilience, and strengthen economic competitiveness. They offer not only the hope for a sustainable energy future but also for new and growing economic development opportunities for states in every region of the nation. These technologies also engender worries about reliable availability of the minerals and elements essential to their production. The energy transition will be a commodities transition too.

Many state energy officials and their economic development, environmental, and natural resource management colleagues are considering how energy-related critical mineral and material[1] production, processing, and recycling may offer economic opportunities. But they should also be aware of the challenges of developing mines and processing facilities, including siting, environmental, and social impact concerns. It is becoming increasingly important—and time sensitive—for states and their private-sector partners to elevate the importance of supply chain vulnerabilities and risks that may affect the availability and cost of materials needed for producing and using clean energy technologies on which states may rely to meet their environmental, economic, and other objectives. This paper provides an overview of critical minerals considerations for State Energy Office planning, policy, and program activities as well as links to resources for additional exploration. Box 1 offers questions states may wish to elevate as new policies and programs are developed in partnership with the private sector.

Box 1. Key Questions about Critical Minerals for State Energy Officials

State Energy Offices have important planning, policy, and programmatic responsibilities for advancing state energy objectives. These encompass economic development, energy reliability and resilience, and environmental protection goals, including attention to equity and social justice impacts. Critical mineral availability and cost significantly affect all of these aspects. They do so for all states because their impacts are not limited to mineral production and processing but also to manufacturing and deployment of energy technologies everywhere. Multiple questions arise that State Energy Officials may consider:

- **What economic opportunities may be available to develop critical mineral resources and supply chains in one's state?**

  This encompasses not only mining but also unconventional resource extraction, processing, reuse, and recycling. This includes consideration of environmental and socioeconomic impacts, both positive and negative, on localities and vulnerable communities. At times, resource development can even help remediate environmental damage and provide new opportunities for workers and communities challenged by the energy transition.

- **How will critical mineral supply chain reliability or uncertainties affect production industries in one's state?**

  State officials should consider how critical mineral supply and price trends and vulnerabilities may affect current and prospective industrial production in their state. Growing demand for electric vehicles (EVs), energy storage, renewable energy, energy-efficient products, sensors and controls, and other technologies raise manufacturing opportunities but also may increase susceptibility to critical mineral supply challenges and disruptions. States can consider not only their own policies but also their views and input to federal critical mineral supply chain policies. They may wish to be attuned to technological changes that may affect critical mineral uses, including alternative and substitute options, in emerging technologies.

- **How will critical mineral availability, price, and supply chain issues affect deployment of energy technologies?**

  Similar to the previous point, critical mineral supply chains will affect the cost and availability of various energy technologies that states will rely on for assuring economical, reliable, resilient, and clean energy in their states. States may wish to pay attention to and provide input to federal policies as well as their own and track technological advances that may reduce supply chain vulnerabilities.

These are just a few questions that arise. This report explores options and opportunities with a state planning and policy lens to help State Energy Offices in understanding and addressing these issues.

Electric cars at a charging station - 3d rendering.
Credit: iStockphoto

Background and Overview

The concept of critical or strategic minerals and materials is not new, extending back at least to the World War II era. From then through the Cold War, and still today, critical material concerns have centered on national security and the ability to supply defense requirements, including materials needed for aerospace, electronics, and munitions.

In the 1970s, oil crises, high commodity price inflation, and a belief that demands from a growing population would outpace resource availability led to expansion of material scarcity and supply fragility concerns to include energy and the wider economy. Today, an energy transition impelled by both the climate crisis and the prospect of disruptive economic opportunity enabled by technological innovation is driving renewed attention to critical minerals and materials required for:

- renewable and nuclear power generation;
- electric vehicles (EVs), hydrogen, fuel cells, and energy storage;
- cleaner fossil fuel applications, including carbon capture, use, and storage (CCUS);
- highly efficient lighting, motors, space conditioning, industrial processes, building systems, and other equipment and processes; and
- sensors, controls, and associated information and communication technologies.

As an illustration, the International Energy Agency (IEA) notes that "[a] typical electric car requires six times the mineral inputs of a conventional car and an onshore wind plant requires nine times more mineral resources than a gas-fired plant of the same capacity. ...The transition to clean energy means a shift from a fuel-intensive to a material-intensive system."[2]

Though not specific to critical minerals, traditional apprehensions of supply disruptions from international tensions and conflicts—exacerbated by recent trade disputes, economic sanctions, war, and civil strife—are amplified by other stresses to supply chains, such as from the COVID-19 pandemic, natural disasters, and labor disputes. Also, many consumers, corporations, and governments are increasingly sensitive to poor labor conditions and human rights violations, corruption, funding of militants, and environmental damage that sometimes attend to mineral mining and processing operations. This leads to the shunning of "conflict minerals" and other products of operations not meeting environmental, social, and governance (ESG) standards.

Critical minerals whose production or processing are concentrated in one or a few regions or countries create particular worry, especially if those areas are politically unstable, autocratically governed, or may be rivalrous or unfriendly to the United States. For example, 71 percent of the world's cobalt (used in rechargeable batteries and superalloys) is mined from the Democratic Republic of Congo where significant ESG and conflict mineral concerns arise.[3] Chinese investors control much of Congo's mining sector and 80 percent of cobalt processing.[4] China produces 82 percent of the world's natural graphite (used in batteries and fuel cells) and 60 percent of its rare earth elements (used in permanent magnets, batteries, catalysts, electronics, and nuclear control rods), with estimates that the country controls 85 percent of rare earth element refining too.[5] U.S. imports are 76 percent, 100 percent, and over 90 percent, respectively, for cobalt, natural graphite, and rare earth elements.[6, 7]

Definitions of critical minerals vary but usually denote a combination of the importance of the minerals for key products and processes and a degree of vulnerability to supply disruption. The U.S. Geological Survey (USGS) notes that:

> ***"The Energy Act of 2020 defines a 'critical mineral' as a non-fuel mineral or mineral material essential to the economic or national security of the U.S. and which has a supply chain vulnerable to disruption. Critical minerals are also characterized as serving an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economy or national security."***[8]

So, iron, for making steel, and the minerals that constitute limestone, a key ingredient of cement and, hence, concrete usually do not appear on critical minerals lists despite their widespread necessity for products and facilities. Aluminum and copper, of great importance for energy technologies and the overall economy, feature in some critical minerals lists and analyses but not others. Table 1 provides the 2022 USGS critical minerals list, noting major uses—many of which are clean energy related—of the minerals.

Chunks of copper ore mineral rocks.
Credit: iStockphoto/wingedwolf

Table 1.

U.S. Geological Survey 2022 Critical Minerals List

*[bracketed figures are percent U.S. net import reliance, 2021; REE denotes rare earth elements of which >90% is net imported; * denotes data not provided.]*

Aluminum	used in almost all sectors of the economy [44%; also, alumina 58%, bauxite >75%]
Antimony	used in lead-acid batteries and flame retardants [84%]
Arsenic	used in semi-conductors [100%]
Barite	used in hydrocarbon production [>75%]
Beryllium	used as an alloying agent in aerospace and defense industries [<20%]
Bismuth	used in medical and atomic research [90%]
Cerium	used in catalytic converters, ceramics, glass, metallurgy, and polishing compounds [REE]
Cesium	used in research and development [100%]
Chromium	used primarily in stainless steel and other alloys [80%]
Cobalt	used in rechargeable batteries and superalloys [76%]
Dysprosium	used in permanent magnets, data storage devices, and lasers [REE]
Erbium	used in fiber optics, optical amplifiers, lasers, and glass colorants [REE]
Europium	used in phosphors and nuclear control rods [REE]
Fluorspar	used in the manufacture of aluminum, cement, steel, gasoline, and fluorine chemicals [32%]
Gadolinium	used in medical imaging, permanent magnets, and steelmaking [REE]
Gallium	used for integrated circuits and optical devices like LEDs [100%]
Germanium	used for fiber optics and night vision applications [>50%]
Graphite	used for lubricants, batteries, and fuel cells [100% for natural graphite]
Hafnium	used for nuclear control rods, alloys, and high-temperature ceramics [*]
Holmium	used in permanent magnets, nuclear control rods, and lasers [REE]
Indium	used in liquid crystal display screens [100%]
Iridium	used as coating of anodes for electrochemical processes and as a chemical catalyst [*]
Lanthanum	used to produce catalysts, ceramics, glass, polishing compounds, and batteries, and in metallurgy [REE]
Lithium	used for rechargeable batteries [>25%]
Lutetium	used in scintillators for medical imaging, electronics, and some cancer therapies [REE]
Magnesium	used as an alloy and for reducing metals [<50% metal; 55% compounds]
Manganese	used in steelmaking and batteries [100%]
Neodymium	used in permanent magnets, rubber catalysts, and in medical and industrial lasers [REE]
Nickel	used to make stainless steel, superalloys, and rechargeable batteries [48%]
Niobium	used mostly in steel and superalloys [100%]
Palladium	used in catalytic converters and as a catalyst agent [37%]
Platinum	used in catalytic converters [70%]
Praseodymium	used in permanent magnets, batteries, aerospace alloys, ceramics, and colorants [REE]
Rhodium	used in catalytic converters, electrical components, and as a catalyst [*]
Rubidium	used for research and development in electronics [100%]
Ruthenium	used as catalysts, as well as electrical contacts and chip resistors in computers [*]
Samarium	used in permanent magnets, as an absorber in nuclear reactors, and in cancer treatments [REE]
Scandium	used for alloys, ceramics, and fuel cells [100%]
Tantalum	used in electronic components, mostly capacitors and in superalloys [100%]
Tellurium	used in solar cells, thermoelectric devices, and as alloying additive [>95%]
Terbium	used in permanent magnets, fiber optics, lasers, and solid-state devices [REE]
Thulium	used in various metal alloys and in lasers [REE]
Tin	used as protective coatings and alloys for steel [78%]
Titanium	used in metal alloys and as a white pigment [>90%]
Tungsten	primarily used to make wear-resistant metals [>50%]
Vanadium	primarily used as an alloying agent for iron and steel [100%]
Ytterbium	used for catalysts, scintillometers, lasers, and metallurgy [REE]
Yttrium	used for ceramic, catalysts, lasers, metallurgy, and phosphors [100%]
Zinc	primarily used in metallurgy to produce galvanized steel [76% refined]
Zirconium	used in high-temperature ceramics and corrosion-resistant alloys. [<25% ores, concentrates]

Source: U.S. Geological Survey, 2022b; net import figures from U.S. Geological Survey, 2022a, Figure 2 and Table 4.

In addition to the U.S. Geological Survey list, the U.S. Department of Energy (U.S. DOE) intends to develop its own list focused on materials critical to energy technologies with criteria that consider "the balance of domestic vs. non-domestic production or processing, relevance to national security, and potential for future commercial or strategic value."[9]

Demand Trends and Supply Concerns

The World Bank included 17 minerals, some not usually listed as "critical" (e.g., iron, lead), in an analysis of how the shift to a cleaner energy economy could affect mineral demand.[10] Table 2 matches these minerals to 10 categories of energy technologies. The report notes that numerous other minerals are also needed for clean energy technologies but were not assessed due to data constraints.[11] Also, there are other important energy transition technologies not included in the analysis. For example, neodymium, listed as critical to wind power in the analysis, is also important for permanent magnets used in high efficiency motors and generators.

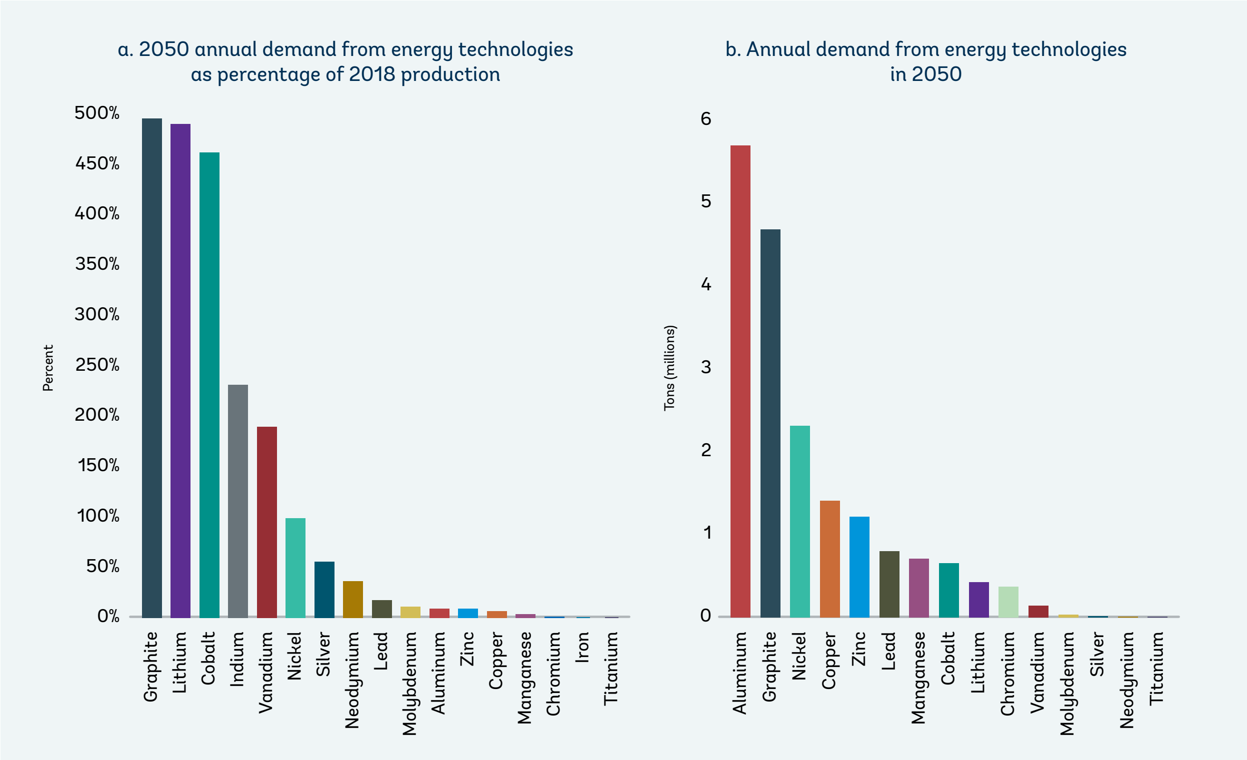
Table 2. Matching Minerals with Relevant Low-Carbon Technologies

	Wind	Solar Photovoltaics	Concentrated Solar Power	Hydro	Geothermal	Energy Storage	Nuclear	Coal	Gas	Carbon Capture and Storage
Aluminum	X	X				X	X	X	X	
Chromium	X		X	X	X	X	X	X	X	X
Cobalt						X		X	X	X
Copper	X	X	X	X	X	X	X	X	X	X
Graphite						X				
Indium		X					X			
Iron	X					X				
Lead	X	X		X		X	X			
Lithium						X				
Manganese	X			X	X	X		X	X	X
Molybdenum	X	X		X	X		X	X	X	X
Neodymium	X									
Nickel	X	X		X	X	X	X	X	X	X
Silver		X	X				X			
Titanium				X	X		X	X	X	
Vanadium						X	X	X		
Zinc	X	X		X		X	X			
	10	8	2	8	6	11	11	9	8	6

Source: Derived from Hund et al. (2020), Table 3.1. https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

The World Bank study projected global demand growth for these minerals for key energy technologies under a scenario that meets the Paris Agreement 2°C. temperature rise target (see Figure 1).

Figure 1. Projected World Annual Mineral Demand under 2°C. Scenario



Source: Hund et al. (2020), Figure 4.3. https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

The World Bank study also developed a demand-risk matrix (Figure 2) that considers both how a mineral's demand may increase to the year 2050 (production-demand index, vertical axis) and how widely or narrowly it is needed for relevant energy technologies (weighted coverage-concentration index, horizontal axis). For example, lithium and graphite are in the upper left quadrant (quadrant 2, "high-impact minerals") representing large projected increase (nearly five-fold) in demand but narrow application (batteries) while copper is in the lower right quadrant (quadrant 4, "cross-cutting minerals") for its nearly ubiquitous use and the small percentage increase in production to meet demand. Aluminum is in quadrant 3 ("high-impact, cross-cutting minerals") because of its wide use and its large absolute increase in projected demand (though modest percentage increase); the study notes that steel would also be in this quadrant if it were included in the analysis. Quadrant 1 includes "medium-impact minerals" (e.g., titanium for geothermal application, neodymium for magnets used in off-shore wind turbines) that are important for a few energy technologies, and for which projected demand increases are relatively modest.

Figure 2. Demand Risk Matrix

Source: Hund et al. (2020), Figure 4.7. https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

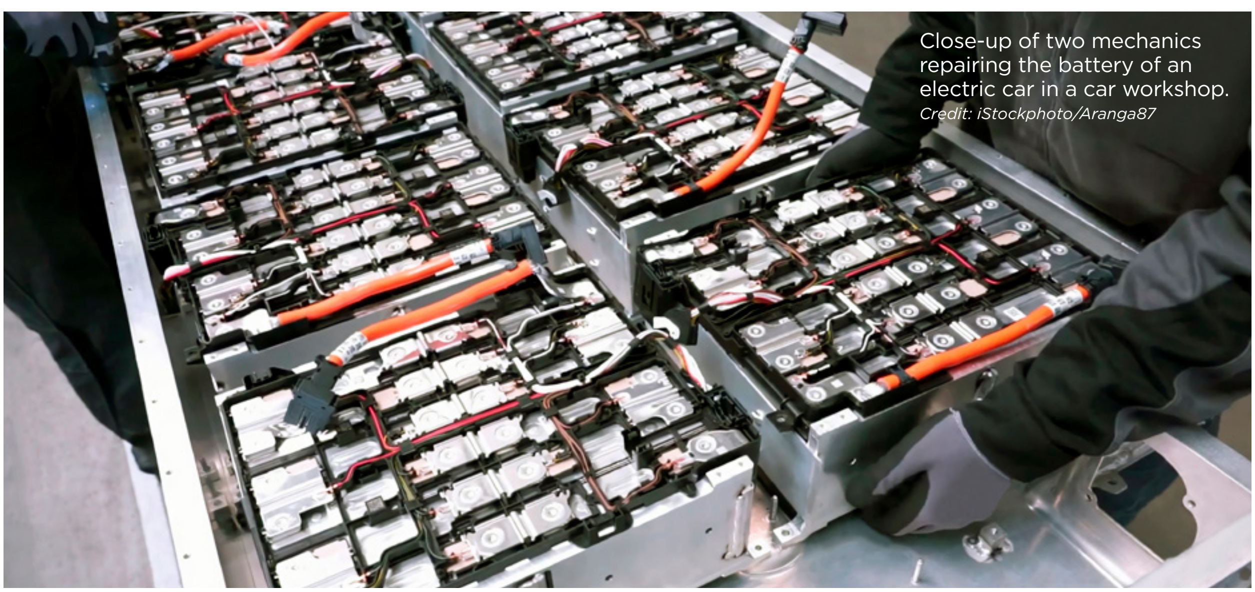
Another study, from the IEA, covering an overlapping set of clean technologies and minerals, projects a need to increase mineral production for clean energy technologies four-fold by 2040 relative to 2020 to meet a Sustainable Development Scenario (SDS) and six-fold by 2040 to meet a 2050 global net-zero emissions target.[12] For some individual minerals, IEA estimates extremely high growth in demand under the SDS scenario (though the report is ambiguous if the growth indicated is relative to base year total production or production for clean energy technologies only.) See Table 3.

Table 3. Growth in Demand for Selected Minerals from Clean Energy Technologies in 2040 Relative to 2020 Levels Under the Sustainable Development Scenario (Index: 2020 = 1)

Mineral/element	Index	Main clean energy technology use
Lithium	42	Battery-related
Graphite	25	Battery-related
Cobalt	21	Battery-related
Nickel	19	Battery-related
Manganese	8	Renewables and electricity networks
Rare Earth Elements	7	Renewables and electricity networks
Molybdenum	2.9	Renewables and electricity networks
Copper	2.7	Renewables and electricity networks
Silicon	2.3	Renewables and electricity networks

Source: Derived from International Energy Agency, 2021, Unnumbered figure, p. 47.

While projections vary and are subject to significant uncertainties, including of the rate and scale of technological advance that may markedly change mineral demand, projections consistently suggest large demand increases for certain base and niche minerals in relative or absolute terms or both. Supply may struggle to meet greatly increased demand and may be vulnerable to disruption, particularly if the control or locations of production are concentrated. Box 2 discusses such concerns relative to historic challenges of fuel, particularly petroleum, dependency.



Close-up of two mechanics repairing the battery of an electric car in a car workshop. *Credit: iStockphoto/Aranga87*

Box 2. Is Lithium (or Any Other Critical Mineral) the New Oil?

Is lithium—central to electric vehicles (EV) and other batteries—the new oil?[13] Or is copper, which is almost ubiquitous in energy technologies?[14] Or both?[15] Nickel? Cobalt? Rare earth elements?

Modest U.S. domestic production and dependence on a few foreign suppliers for various minerals due to geologic happenstance or industrial strategy bring up bad memories of the 1970s oil supply shocks that roiled U.S. and global economies and incited numerous energy policy measures and institutions, including establishment of the U.S. DOE and the State Energy Offices. Periodically, political tensions, war, and other incidents have triggered supply shocks and damaging price volatility of both oil and natural gas, which demonstrates the vulnerabilities that may arise when depending on non-diverse sources. Most recently, the Russian invasion of Ukraine has brightly highlighted resource dependency risks, especially related to Europe's dependence on Russian natural gas and the large role of Russian oil and natural gas in global supply.

While shorter-term responses to Russia's war and attendant sanctions center on shifting oil and gas trading patterns, increasing U.S. and other production, and releasing some oil reserve stockpiles, the more fundamental call is to accelerate the clean energy transition. But will critical mineral-rich "electrostates" replace "petrostates" as sources of geopolitical energy vulnerability? Notably, Russia is also a major source of nickel, cobalt, uranium, and other energy-related critical minerals.

The *Economist* wrote how the energy transition will also be a commodities transition, engendering large shifts in trade, investment, and income among nations with accompanying risks and vulnerabilities for both supplier and consumer countries. The article says:

> ***"This time the transition will bring windfalls to countries we dub the 'green-commodity superpowers.' We calculate that this club, many of which are poor economies and autocracies, could pocket more than $1.2trn in annual revenue from energy-related metals by 2040."***[16]

However, while growing demand for and dependence on certain critical minerals may have some resemblance to petroleum dependence and its accompanying hazards and risks, there are also large differences. Oil and natural gas, and coal too, are primarily fuels.[17] They must be continuously supplied and irrecoverably consumed (burnt) in large quantities to provide energy services. In contrast, critical energy transition minerals are almost entirely incorporated into products and technologies, such as batteries, permanent magnet motors and generators, PV panels, electrolyzers, fuel cells, electronics, and steel alloy products. Critical minerals can often be and in some cases are recycled at the end of a product's life.

Unlike oil supply shock impacts on gasoline and diesel fueled vehicles, a prospective future lithium or cobalt supply shock would not spike recharging costs, trigger recharging queues or rationing, or bring existing EVs to a standstill, though battery and EV manufacturing may be affected.

Will lithium or copper or nickel or rare earth elements or some other mineral be the next oil? Not exactly.

These demand trends and supply concerns point to key strategies and multiple options for helping meet energy transition technology mineral needs. These include:

- **Diversifying supply through:**
  - New and expanded mining[18] where geologic resources are favorable,
  - New and expanded processing facilities,
  - Development of unconventional resources, such as extraction of critical minerals from coal, coal wastes, acid mine drainage, combustion byproducts, produced water from oil and gas operations, mining and processing wastes, industrial byproducts, and sea water, and[19]
  - Developing technologies to allow mining/extraction where geologic resources are now less than favorable.
- **Moderating demand growth through:**
  - More efficient and innovative product and process design to reduce the need for certain minerals in some products,
  - Development of alternatives and substitutes to certain critical minerals, and
  - Reuse and recycling of critical mineral-containing products, including designing products for ease of disassembly and recycling.

These approaches interact and overlap. Improved extraction techniques may make viable production from lower grade deposits, mines previously considered depleted and uneconomic, unconventional resources, and industrial byproducts and wastes. They may also permit economic recovery from end-of-life products through recycling.

While the potential for these options and opportunities depends greatly on techno-economic factors, such as geologic endowments and technological capabilities, they also rely significantly on the policy and regulatory environment, including areas under state purview or influence. Siting, permitting, and regulation of mines and processing facilities; rights, title, liabilities, and regulatory treatment of minerals, byproducts, and wastes; financing mechanisms and tax provisions; research, development, and demonstration (RD&D) support; workforce development; product stewardship and recycling incentives; and procurement policies can all the affect the quantity and reliability of critical mineral supply.

Importantly, critical minerals and clean energy technology supply chain matters garner significant federal attention and support. Programs and initiatives of the U.S. Departments of Defense, Energy, and the Interior support activities ranging from resource characterization and RD&D to investment in production facilities and procurement preferences. Title III of the Defense Production Act has been used to help bolster domestic critical mineral production and revive U.S. rare earth element production and processing capabilities.[20] Multiple provisions of the Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law (BIL), will support pertinent resource mapping, RD&D, and demonstration and commercial industrial facilities, along with recycling program development (see Appendix A).

The following sections further outline some of the critical mineral options and opportunities and note state planning and policy considerations.

Open Pit Mine, Morenci, Arizona. Morenci is the largest copper producer in North America.
Credit: iStockphoto/galinast

Critical Mineral Options and Opportunities

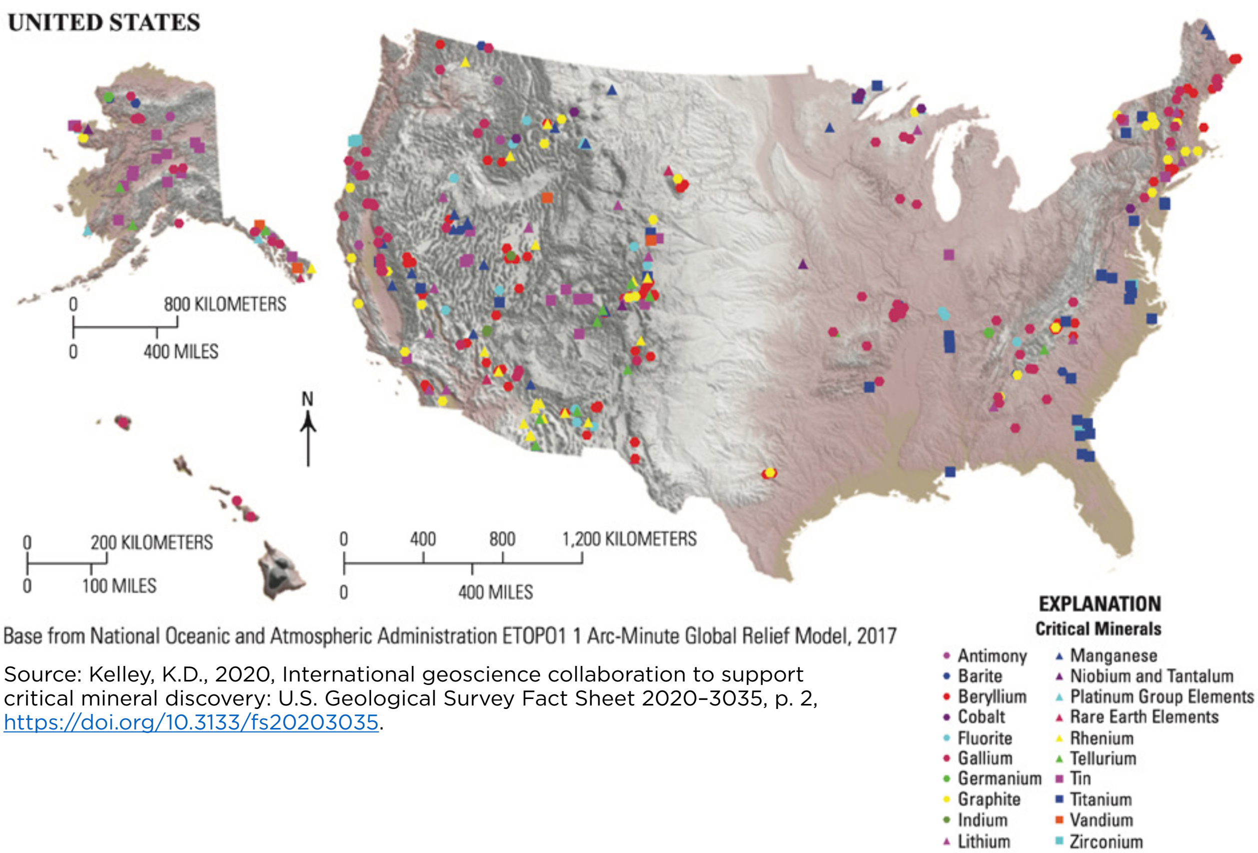
Conventional Mining, Extraction, and Processing

The quality of ores and concentration of elements are critical to the economic viability of resource extraction. Figure 3 depicts known U.S. locations for some critical minerals. It can take many years and large investment to develop a mine. After the prospecting and exploration stage, it may take 4 to 12 years and $1 million to $1 billion investment, depending on the type of mine, until production begins.[21] Siting of mining and extraction facilities as well as processing plants can rouse concerns about environmental and social impacts, including air and water pollution; potential depletion of surface and groundwater; waste management; impacts on landscape, fish, wildlife, farming, ranching, and cultural resources; and noise and quality of life for local communities. In some parts of the United States, mineral development in or near Native lands and communities may raise special sensitivities and concerns (see Box 3). Siting and permitting processes can be uncertain, opaque, lengthy, and costly.

Some critical minerals are produced mainly or exclusively as a byproduct of other mineral commodities. Thus, production viability for some minerals may depend largely on the economics of the main commodity being produced. For example, cobalt is a secondary product of nickel and copper ores.[22] Another example, indium, used in certain thin-film PVs and liquid crystal displays, is produced mostly as a byproduct of zinc smelting and refining, with small amounts as byproduct of other metal processing.[23] Even with projected demand growth, indium will remain a niche mineral, dependent on production of other metals. Growing critical mineral demand can make viable previously uneconomic recovery of minerals from the mining of larger volume commodities and from byproducts and wastes (see unconventional resources discussion below).

Sometimes innovative opportunities can arise. For example, Berkshire Hathaway, Controlled Thermal Resources, and Materials Research are developing a project to extract lithium from brines that are pumped up by existing geothermal power plants at the Salton Sea in California, linking clean power generation, lithium production, and local economic development.[24] California created a Lithium Valley Commission to review and assess lithium recovery opportunities in the state.[25] With U.S. lithium production currently relying on only one brine operation in Nevada, the Salton Sea initiative is just one of multiple lithium projects being considered or under development in Arkansas, California, Nevada, North Carolina, North Dakota, Oregon, and Tennessee.

Figure 3. Known Critical Mineral Locations in the United States



Source: Kelley, K.D., 2020, International geoscience collaboration to support critical mineral discovery: U.S. Geological Survey Fact Sheet 2020–3035, p. 2, https://doi.org/10.3133/fs20203035.

Box 3. Critical Minerals and Tribal Communities

Demand for critical minerals is growing at a rapid pace which also leads to a higher potential for environmental injustices and harm to vulnerable populations associated with mining and processing. In the United States, Native American communities are a particular focus of concern. According to a study done by MSCI, the majority of U.S. cobalt, copper, lithium, and nickel reserves are located within 35 miles of a Native American reservation.[26] Tribes are at particular risk from critical mineral mining and extraction processes, including potential effects on water availability and quality, air pollution, damage to culturally important sites, harm to fish and wildlife, and other adverse social and environmental impacts. However, Native communities can also benefit from economic opportunities as well. As Tribes are sovereign nations, it is particularly important that states, the federal government, and private firms engage them early in a full, meaningful, and respectful dialogue to identify, assess, and address risks, sensitivities, and concerns. Transparent communication and strong government-to-government relationships among federal, state, and Tribal authorities can help to reduce adverse environmental impacts, protect and conserve cultural and natural resources, and ensure fair distribution of economic benefits.

One example that elevates many concerns involves a lithium deposit located at the Nevada-Oregon border near the Fort McDermitt Indian Reservation, home to the Paiute and Shoshone Tribes.[27] The deposit is in an area known as Thacker Pass or, to the local Tribes, Peehee mu'huh. It is believed to be one of the largest deposits of lithium in the world and is also a site of significant importance to the Tribes. Lithium Americas is one company looking to develop this abundant source of lithium. While the company has received the necessary permits to begin construction from both the state and federal governments, and is in the process of applying for a loan from the U.S. DOE, the U.S. Bureau of Land Management determined that around 60 cultural and heritage sites would be at risk from the mining operation.[28] Peehee mu'huh is believed to be a mass burial site of the victims of an 1885 massacre of many Native men, women, and children and is also an area for harvest of traditional medicine.[29] According to Tribal members, many of them were not even made aware of the permitting process until it had already been approved.[30] This did not allow them to properly articulate their concerns about the potential mine and the impact it would have on their cultural heritage.

Lithium Americas is offering what it says will be over $600 million in benefits to the state of Nevada from this project. This includes increased tax revenue, workforce opportunities, and specific resources to the Reservation, including a day care center, road upgrades, and construction of green homes.[31] The company intends to use clean energy sources for its operations and utilize water recycling technologies to further minimize adverse impacts. The company plans to mine an estimated 80,000 tons of lithium carbonate every year from the site, an amount that will be increasingly valuable as electrification grows.[32]

As the United States accelerates towards a clean energy future reliant on many critical minerals, these conflicts will continue to surface. Stronger, earlier, and continued engagement with Native American tribes and, indeed, local communities generally will be critical for these kinds of projects.

Rio Tinto Borax mine and plant
Credit: Wikipedia

Unconventional Resources

Unconventional mineral resources can support U.S. mineral supply resilience while offering economic development opportunities, particularly for communities and regions struggling with declines in coal production and use, hard rock mining, and processing industries. At times, unconventional mineral production extracts value while also treating wastes and contaminated water to mitigate and remediate environmental damage.

The U.S. DOE-funded Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) Initiative for U.S. Basins seeks these ends by supporting regional thrusts to advance "carbon ore" applications (coal as feedstock for high-value products, such as graphite for battery anodes, carbon fibers, nanomaterials, cement additives, and construction material) and the use of coal, coal wastes, acid mine drainage, and ash as sources for rare earth elements and other critical minerals.[33] The success of such endeavors can facilitate a just transition by providing productive jobs and income for coal and coal-fired power plant communities facing dislocations from the ongoing energy transition. This will be discussed more in Box 4 below.

Mining and processing wastes, including sludges, slag, and tailings, may offer beneficial mineral recovery possibilities. For example, Rio Tinto is piloting lithium recovery from a California boron mine, while in New York waste rocks from closed iron ore mines are being examined for recoverable amounts of rare earth elements.[34] Studies are underway to explore recovery of critical minerals from industrial waste products, such as scandium and rare earth elements from garnet sand (used as an abrasive and in sand blasting) and red mud (a caustic byproduct of processing bauxite into aluminum).[35, 36] Even beach sand can be a source of rare earth elements.[37]

Mineral recovery from unconventional resources may offer economic development opportunity (jobs, income, and tax base) but can also raise environmental, economic, and social impact concerns. Even ostensibly environmentally favorable mineral recovery from wastes and remediation sites can entail use of hazardous chemicals, potential for air and water pollution, waste generation, and adverse land impacts. As with mines and industrial production facilities, there are siting, permitting, and environmental regulatory considerations.

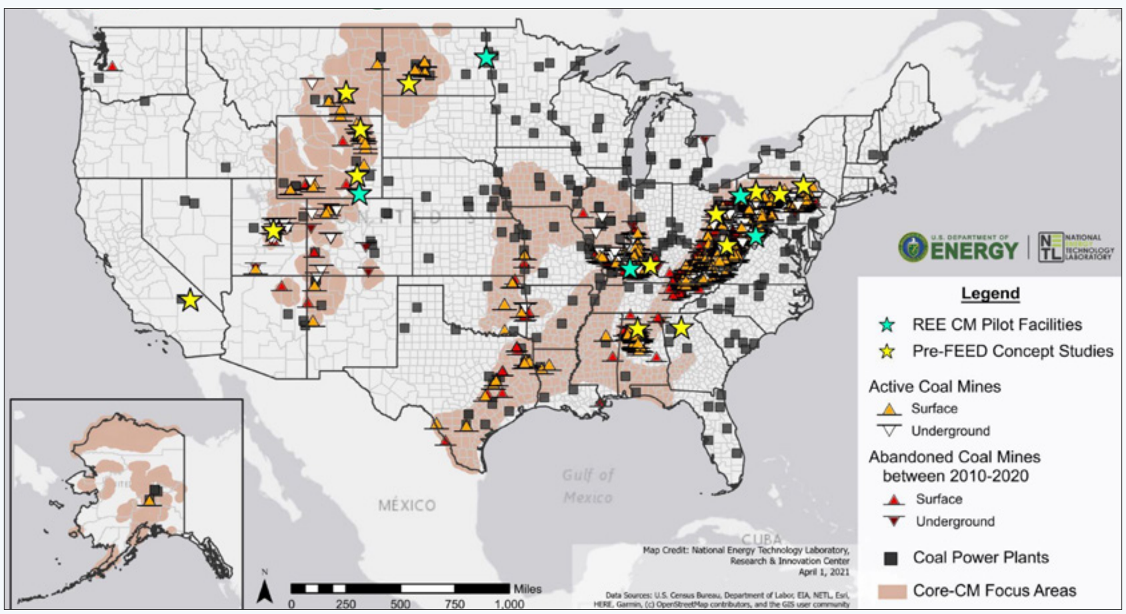
Box 4: Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) Initiative for U.S. Basins

With $19 million in awards to 13 recipients announced by U.S. DOE in April 2021, the Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) Initiative for U.S. Basins intends to jump-start recovery of rare earth elements and other critical minerals as well as to advance "carbon ore" applications in coal and power plant communities.[38] CORE-CM aims to support economic revitalization in communities traditionally reliant on fossil fuels, enabling them to benefit from locally producing materials and products vital to the energy transition.

Coal and coal-related wastes and byproducts, including acid mine drainage and coal ash, contain significant amounts of critical minerals; among them, rare earth elements, cobalt, manganese, lithium, and aluminum. U.S. DOE notes that coal ash impoundments typically contain 470 parts per million (ppm) of rare earth elements and yttrium.[39] Coal-related rare earth element recovery potential is very large, with estimates of about 30,000 metric tons per year (t/y) from current coal production, 12,300 t/y from active coal refuse, 10,000 t/y from active ash, and 400 to 1700 t/y from waterway-damaging acid mine drainage (AMD) in the Appalachian region.[40]

The carbon ore concept is to use coal as a feedstock to produce high-value carbon-based materials and products, such as graphite for battery anodes, carbon fibers, nanomaterials, cement additives, and construction materials.

Figure Box 4-1. REE/CM Potential and Coal Activities in the United States



Source: Justman, D., Bauer, J., and Rose, K., 2021, Unconventional REE/CM Potential versus Coal Activities, National Energy Technology Laboratory

The CORE-CM Initiative is concentrating on the following regional basins: Alaska, the Appalachian Basin, Green River - Wind River Basin, Gulf Coast Basin, Illinois Basin, Powder River Basin, San Juan River-Raton-Black Mesa Basin, Uinta Basin, and the Williston Basin.

Mineral-Efficient Design, Alternatives, and Substitutes

Costs and supply vulnerabilities also lead to research on reducing or eliminating the need for some minerals through efficient and innovative design and alternative or substitute materials and technologies. The quest for more material-efficient design is not new, it has long been a technique to reduce waste and lower costs. For example, in the energy sphere, newer PVs use less silicon and silver but are more efficient than those of the past, "light-weighting" has improved fuel economy of cars, trucks, and aircraft, and products from aluminum beverage cans to skyscrapers are designed to be more material-efficient.

A salient critical minerals example is the use of cobalt in lithium-ion battery cathodes. Cobalt is of particular concern because of cost and high dependence on Congolese supply and Chinese processing. It is vital for most EV batteries—a 100 kilowatt-hour EV battery pack can contain as much as 20 kilograms (kg) of cobalt—as well as for stationary energy storage and small batteries, such as for mobile phones and other electronics.[41] The U.S. DOE and national, academic, and corporate laboratories are working to reduce or eliminate cobalt requirements for lithium-ion batteries without greatly trading off battery performance. Analysts estimated that Tesla (which produces batteries with Panasonic in Nevada as a joint venture) reduced average cobalt usage from 11 kg to 4.5 kg per car in the 2010s.[42] Since 2020, Tesla has expanded use of lithium-iron-phosphate batteries in its vehicles to reduce cobalt and nickel reliance.[43, 44]

However, there can be tradeoffs. Avoiding cobalt in lithium-iron-phosphate batteries is accompanied by some safety and durability benefits but at the expense of greater weight and lower energy density. Solid-state lithium-based battery advances offer greater safety (less chance of thermal runaway and fire), possibly faster charging, and lower requirements for cobalt and nickel but may need more lithium.[45] Other battery chemistries and concepts, including flow and metal-air batteries, may reduce or obviate the need for cobalt and lithium and be better suited for some stationary energy storage uses, but come with tradeoffs and cost and performance challenges for some applications.

Batteries are just an example; opportunities exist for more efficient design and processes and possible alternative and substitute materials across various energy transition technologies.[46]

Lithium - ion batteries, metallic lithium and element symbol. 3d illustration.
Credit: iStockphoto/jroballo

Crushed and baled copper for recycling in recycling factory.
Credit: iStockphoto/freemixer

Reuse and Recycling

Reuse and recycling can support critical mineral supply reliability while reducing adverse environmental impacts by limiting waste disposal needs and lowering demand for primary mineral extraction and processing. Recycling is common for various metals, such as iron and steel, lead, aluminum, copper, nickel, and cobalt, but is nascent for some emerging energy transition materials such as lithium and rare earth elements and for newer products such as EV batteries and PVs. Where recycling is relatively common, such as for scrap electric motors, the bulk iron, aluminum, and copper may be recovered but their rare earth element and other minor but critical constituents may not be extracted for recycling.

Rapid projected growth of lithium-ion batteries, PV panels, and other energy transition products signal not only accelerated demand for critical minerals but also rapidly expanding waste streams that can be secondary sources for the minerals. The IEA projects that by 2040, under a scenario that meets the Paris Agreement 2°C warming target, 50 percent of the world's automobile stock will be EVs and there will be 1.3 terawatt-hours of spent EV and storage batteries to be managed for second use, recycling, or disposal, as compared to 2 gigawatt-hours today.[47] Extensive reuse and recycling of batteries would not obviate primary production needs because the demand for new batteries will overwhelm the stock of spent batteries taken out of service for quite some time. However, reuse and recycling could lower requirements for primary copper, lithium, nickel and cobalt by around 10 percent.[48]

Effective recycling requires not only recycling technologies but also a system for collecting spent products, getting them to processing facilities, and distributing recovered materials for use in new production. Product reuse or "second use"—such as employing EV batteries for stationary service when they are no longer adequate for vehicle use—also requires collection of products, evaluation to determine adequacy for reuse applications (or recycling), perhaps some refurbishment, and distribution to re-users. The reuse and recycling system may require that there be material and product quality specifications and evaluations; environmental and safety standards for handling, processing, use, and disposal; and clarification of warranties and liabilities, among other matters. A value stream must flow with the reuse and recycling supply chain to incite effective participation. (Policy considerations are discussed further below.)

State Planning and Policy Considerations

This section briefly reviews some planning and policy issues for State Energy Offices and other state officials to consider.

For many of the topics below, there are federal programs that offer funding and technical assistance. Prominently, the IIJA includes multiple provisions pertinent to critical minerals and related batteries, EVs, and other clean technologies. The IIJA provisions will support resource mapping, RD&D, pilot and commercial facilities, and the establishment of battery recycling programs. (See Appendix A.) Other programs and resources from the U.S. Department of Defense (including Defense Production Act, Title III provisions), U.S. DOE (Critical Minerals Division and Advanced Manufacturing Office), U.S. Department of the Interior, and the U.S. Environmental Protection Agency may also provide support. For federally recognized Tribes and Alaska Native Villages, the Division of Energy and Mineral Development of the U.S. Department of the Interior, Bureau of Indian Affairs provides technical assistance.[49]

Resource Identification and Characterization

States should take stock of their mineral resource endowments. This includes traditional geologic mineral deposits as well as potential unconventional resources, such as coal, coal-associated resources (coal waste, ash, acid mine drainage, produced waters from coal-bed methane recovery), mine tailings, sand, produced water from oil and natural gas operations, and mineral processing wastes and byproducts. Byproducts and wastes of industrial processes can sometimes be viable sources of minerals. Product reuse and recycling also offer valuable resources and economic development opportunities.

Along with the U.S. Department of the Interior (U.S Geological Survey and Office of Surface Mining Reclamation and Enforcement) and U.S. DOE (Mineral Sustainability Division), State Energy Offices should consult with their state geological survey;[50] natural resources department and similar agencies; environmental agency; and economic development programs to discern and consider resource availability and potential development opportunities.

States, with federal partners, should also work with localities, academia, the private sector (including existing mining, processing, and resource companies), and non-governmental stakeholders not only to identify resources but also to inform potential investors, entrepreneurs, and the public of resource sites and their characteristics by using geographical information systems (GIS) to provide online maps, spreadsheets, and other readily accessible tools. This may include consolidating data from geological surveys, environmental permits, brownfield eligible and remediation sites, and economic development information (such as zoning, utility access, transportation access, and other information) for potential developers to consider.

RD&D and Commercialization Assistance

Federal and state governments can support relevant RD&D directly through funding and encourage private funding, including through tax incentives. Similarly, states can directly support and encourage private, university, and philanthropic backing of technology incubators, accelerators, and related technical and business assistance. State economic development programs, including those targeting clean tech and "greening" of economic sectors can help advance relevant technology development, commercialization, and deployment.[51] It is important to not only consider RD&D for mining, but also for mineral processing and recycling, as well as for efficient use of and alternatives to critical minerals in clean energy technologies.

Siting, Permitting, and Facility Regulation

Mines and similar extraction facilities (e.g., lithium extraction from brines, extraction from unconventional resources) as well as processing facilities will often be subject to federal, state, and local environmental permitting requirements and siting procedures, and local land-use regulation. There are often strong community concerns and sensitivities to proposed mines and facilities. States can pay attention to such processes and requirements and, where warranted, try to streamline reviews and approvals but with care to remain protective of communities and the environment. Potential facilities at current or former mining, processing, and other industrial sites may be eligible for federal and state brownfield development funding and technical assistance.

Financing, Taxes, and Fiscal Incentives

Federal and state tax incentives can support relevant RD&D. States can consider offering tax credits, deductions, exemptions, and other incentives to support commercial mining and processing projects as well as investments in reuse and recycling applications and infrastructure. They can also offer grants, loans, and credit enhancements in accordance with their economic development funding programs, including, as appropriate, brownfield development incentives. As noted below, states have used fees and charges on certain products to fund and incentivize recycling.

For example, the Wyoming Infrastructure Authority was created by the Wyoming legislature in 2004 to advance infrastructure development and was authorized to issue up to $1 billion to finance energy infrastructure.[52] Authority was expanded in 2021 to include bond funding for critical mineral and rare earth element production.[53] Several states, including California, Connecticut, Hawaii, New York, and Rhode Island, have green banks that offer loans, loan guarantees, and other credit enhancements and services to advance clean energy development and deployment.[54] Such state-affiliated green banks, infrastructure banks, and other financing institutions can be authorized and encouraged to support clean energy-related mineral projects, including production and recycling facilities. States could also choose to directly fund or finance pertinent projects. States can work with project developers to seek various federal funding opportunities. Some funding may be directly applicable to projects. Other funding may support important complementary activities, such as infrastructure development, workforce training, and state and local planning and policy development. Multiple provisions of the IIJA will support critical minerals related work, from RD&D to commercial facility development. Defense Production Act, Title III authority is being used to support domestic critical minerals production and revive a domestic supply base for rare earth elements.[55] Economic development funding may also be available through such agencies as the U.S. Department of Commerce Economic Development Administration and the Regional Development Commissions (e.g., the Appalachian Regional Commission and Delta Regional Authority).

Crushed aluminum cans recycled into building blocks.
Credit: iStockphoto/Gary Kavanagh

Stewardship, Reuse, and Recycling

As noted, reuse and recycling can provide significant supply resources and reduce environmental impacts through avoided disposal and lower primary mineral production. However, recycling and reprocessing facilities also engender environmental and safety concerns. Collection, refurbishment, and recycling of EV batteries, PV panels, and other clean energy products need not necessarily occur at or near mines or other primary mineral sources, meaning that economic development opportunities—jobs, income, and tax base expansion—may occur more widely.

Policies can play a strong role in the development of robust reuse and recycling supply chains. First, as with other industries, government has important regulatory responsibilities for environment, health, and safety (EHS). Material collection, transport, storage, and processing needs to abide by EHS requirements, including federal and state standards, permitting, and land-use regulation.

State and federal authorities can work with industry, labor, and non-governmental organizations to develop product and material technical specifications for refurbishment and recycling. They can fund technical training to assure not only EHS standard compliance but also that products and materials meet quality standards.[56]

States can also encourage reuse and recycling by extending producer responsibilities for products, creating mechanisms to fund recycling, financially incentivizing consumers to recycle, and regulating disposal. Sometimes these mechanisms are combined. For example, along with landfill disposal prohibitions, all 50 U.S. states allow, and 30 require, retailers to impose a “core charge” on sales of automotive lead-acid batteries that is refunded if a spent battery is returned at sale or by a specified number of days afterwards.[57] California imposes a fee on retail sales of certain electronic devices with displays (liquid crystal displays [LCDs], plasma televisions, cathode-ray tubes) to support collection and recycling and prevent hazardous metal disposal.[58] Tire disposal fees and beverage container deposit-refund systems are also familiar recycling incentives.

Long-lasting, expensive capital products, like EV batteries, PV panels, and wind turbine components, may not be as amenable to a small fee and deposit-refund system as are lead-acid car batteries, tires, or beverage containers, but they are also less likely to be casually discarded. Some combination of financial incentive, producer or seller responsibilities, and disposal regulation may foster robust recycling. For large clean energy technology installations, such as at utility, commercial, and industrial facilities, regulation or market opportunity may impel reuse and recycling.

Public utility regulators can also be supportive by preferring or requiring utilities to assure reuse and recycling of pertinent utility equipment at the end of their service life. Regulators can direct utilities to procure “second use” EV batteries where technically and economically practicable and, perhaps, specify recycled content preference for new products and equipment.

State, federal, and local officials can, likewise, assure reuse or recycling of their clean energy technology assets and procure second use and recycled content technologies.

Procurement Policies

Government and government-funded procurement can be a tool to stimulate markets for new technologies and processes and buttress domestic industry. “Buy American” provisions in federally funded acquisition (such as through the IIJA) and, to the extent it is legally permitted, preferences in state-funded procurement can support domestic production, though that can come with tradeoffs in cost and product availability. A phased approach of state procurement preferences might be employed by states to avoid curtailing deployment of clean energy technologies that are now produced abroad. One could also consider a pricing allowance, e.g., offer some points or percentage of bid allowance preference, for domestic or North American products.

Federal, state, and local government “green” procurement and lead-by-example policies that stimulate demand for critical mineral-using clean technologies (e.g., renewable power, EVs, and batteries) can be fashioned to give preferences for products that are designed for ease of reuse and recycling and/or that include recycled content. This can include, for example, acquisition of second-use EV batteries for stationary applications where technically and financially practicable. Governments can also implement policies to recycle their products at end-of-life.

Also, states can direct Public Utility Commissions to favor reuse and recycled content where practicable for regulated utility acquisition and that, at end-of-life or on replacement, those products be recycled.

Stakeholder Engagement and Equity Considerations

State Energy Offices have a long tradition of engaging with key stakeholders on energy issues, policies, and programs. As critical mineral mining and processing grow in the United States, equity and energy justice considerations will have to be addressed. During the permitting and application process for these installations, State Energy Offices can ensure that communities impacted are an integral part of the process and that costs and benefits are clearly outlined by developers. Critical minerals are vital to support the clean energy transition, but it is important that critical minerals developers do not exacerbate or create new environmental justice concerns nor impose adverse impacts disproportionately on vulnerable communities. Beyond individual development proposals, State Energy Offices can help ensure that energy justice and community impact considerations are incorporated in planning, policymaking, regulation, and other decision-making processes.

For example, the California Energy Commission (CEC) set up the Lithium Valley Commission, as a result of state legislative action, to study lithium opportunities in California. The Commission will review potential issues around lithium mining in the state and develop a report that looks at extraction methods, economic impacts, environmental concerns, workforce development, and other key topic areas.[59] Members of the Commission include representatives from state agencies, developers, local communities, and Tribes.

Open-pit mine worker
Credit: iStockphoto/izusek

Workforce Development

New or expanded domestic critical mineral production and processing, whether from traditional or unconventional resources will require a capable workforce. Likewise, a system for reuse and recycling will require a trained workforce. Quantifying potential workforce needs and skill requirements could be an early step for states to pursue. Training and education needs will range from equipment operators and technicians to engineers and research scientists. Both the training of new workers in schools and enhancing the skills of existing and transitioning workers are needed. State officials should consider employment and income opportunities for vulnerable communities and individuals, including those that may see adverse consequences from the energy transition.

As with other industries, states can support development and delivery of training and education at vocational institutions, community colleges, colleges and universities, labor unions, and workplaces. State officials may wish to review research, facilities, and expertise present in their state's colleges and universities, private firms, federal laboratories, and non-governmental organizations for RD&D opportunities and innovation and commercialization possibilities. Colleges and universities and other institutions can also support relevant workforce development, from technicians and equipment operators to engineers and research scientists.

Brine pools for lithium carbonate mining, in Silver Peak, NV, USA
Credit: iStockphoto/Cavan Images

Conclusion

The energy transition will also be a commodities transition, in which our energy systems will depend less on fuels and more on minerals critical to new technologies. As demand for energy transition technologies grow, so will demand for both bulk and niche minerals on which they depend. Supply may struggle to meet greatly increased demand and may be vulnerable to disruption, particularly if the control or locations of production are concentrated.

The United States is highly and sometimes completely dependent on imports for many critical minerals. In some cases, like for natural graphite, cobalt, and rare earth elements, the United States and the world depend largely on one or a few countries, leading to strong concerns about supply disruption vulnerabilities, whether due to natural calamity, political instability and social unrest, or geopolitical rivalries and tensions. There is worry that "electrostates" may replace "petrostates" as sources of energy vulnerability.

These trends and concerns point to key strategies and multiple options for helping meet energy transition technology mineral needs. These include:

- Diversifying supply through new production and processing, including tapping unconventional resources and
- Moderating demand growth through more efficient designs that conserve minerals, use of alternatives and substitutes, and reuse and recycling of critical mineral-containing products.

Supply diversification can offer economic development opportunities that may support a just transition, such as deriving critical minerals from coal, ash, acid mine drainage, and other fossil fuel-related sources. Mineral recovery from previously uneconomic mines and industrial byproducts, and development of reuse and recycling supply chains also provide economic opportunities while supporting the energy transition. However, critical mineral mining, extraction, and processing, like other industries also prompt concerns about pollution and wastes, water use, impacts on habitat and landscape, and potentially adverse effects on local communities and cultural resources.

State Energy Offices and other state agencies can have important planning and policy roles for enhancing the benefits and mitigating the costs (financial, environmental, and other) of advancing dependable critical mineral resources availability. Federal technical and financial resources available to states and other key stakeholders can help states meet their economic, environmental, and energy goals while supporting national objectives.

Resources

Association of American State Geologists	State Geological Surveys https://www.stategeologists.org/surveys
California Energy Commission	Lithium Valley Fact Sheet https://www.energy.ca.gov/filebrowser/download/4041
Center for Strategic and International Studies	Nakano, J., 2021, "The Geopolitics of Critical Minerals Supply Chains," CSIS, https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/210311_Nakano_Critical_Minerals.pdf?DR03x5jIrwLnNjmPDD3SZjEkGEZFEcgt
International Energy Agency	2021, "The Role of Critical Minerals in Clean Energy Transitions," https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf
Minerals Education Council	https://mineralseducationcoalition.org/
National Research Council	2008, "Minerals, Critical Minerals, and the U.S. Economy," https://nap.nationalacademies.org/catalog/12034/minerals-critical-minerals-and-the-us-economy
U.S. Department of Commerce	"A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," nd, https://www.commerce.gov/sites/default/files/2020-01/Critical_Minerals_Strategy_Final.pdf
U.S. Department of Energy	Ames Laboratory, Critical Materials Institute, https://www.ameslab.gov/cmi Federal Consortium for Advanced Batteries, "National Blueprint for Lithium Batteries 2021-2030" (June 2021) https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf National Energy Technology Laboratory, Critical Minerals Sustainability https://netl.doe.gov/coal/rare-earth-elements Office of Fossil Energy and Carbon Management, Division of Mineral Sustainability https://www.energy.gov/fecm/division-minerals-sustainability Office of Fossil Energy and Carbon Management, Division of Mineral Sustainability, "Multi-Year Program Plan for Division of Minerals Sustainability" (October 2021) https://www.energy.gov/sites/default/files/2021-10/MSD%20Multi-Year%20Program%20Plan%202021_0.pdf Office of Policy, "America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition" (February 2022) https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain (includes links to full report, individual chapter, and fact sheet)
U.S. Department of the Interior	Schulz, K.J., DeYoung, J.H., Jr., Seal, R.R., II, and Bradley, D.C., eds., 2017, "Critical Mineral Resources of the United States—Economic and environmental geology and prospects for future supply," https://pubs.er.usgs.gov/publication/pp1802 Bureau of Indian Affairs, Division of Energy and Mineral Development, https://www.bia.gov/bia/ots/demd U.S. Geological Survey, Critical Mineral Commodities in Renewable Energy, https://www.usgs.gov/media/images/critical-mineral-commodities-renewable-energy U.S. Geological Survey, "International Geoscience Collaboration to Support Critical Mineral Discovery," Fact Sheet 2020-3035 (June 2020) https://pubs.usgs.gov/fs/2020/3035/fs20203035.pdf U.S. Geological Survey, "List of Critical Materials" (Feb 22, 2022), https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals U.S. Geological Survey, **"**Mineral Commodity Summaries 2022," available via https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries U.S. Geological Survey, National Mineral Information Center, https://www.usgs.gov/centers/national-minerals-information-center U.S. Geological Survey, Rare Earths Statistics and Information, https://www.usgs.gov/centers/national-minerals-information-center/rare-earths-statistics-and-information
White House	"Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth 100-Day Reviews under Executive Order 14017" (June 2021), https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf
West Virginia University Rare Earth Extraction Facility	https://wvwri.wvu.edu/programs/minerals/rare-earth-recovery
World Bank	Hund, K., D. La Porta, T.P. Fabregas, T. Laing, and J. Drexhage, 2020, "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition." International Bank for Reconstruction and Development/The World Bank https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf
Wyoming State Geological Survey	"Critical Minerals in Wyoming Summary Report" https://sales.wsgs.wyo.gov/critical-minerals-in-wyoming-summary-report-2019/

Appendix A. Infrastructure Investment and Infrastructure Act/Bipartisan Infrastructure Law Provisions Concerning Critical Minerals

The following are critical minerals and materials relevant excerpts from the White House, "Building a Better America, A Guidebook to the Bipartisan Infrastructure Law for State, Local, Tribal, and Territorial Governments, and Other Partners."[60] There may be other relevant provisions, including for energy technology research, development, and demonstration (RD&D) affecting materials used in or to produce such technologies.

Battery Manufacturing and Recycling Grants Department of Energy $3,000,000,000	
Description:	To provide grants to ensure that the United States has a viable domestic manufacturing and recycling capability to support a North American battery supply chain.
Funding Mechanism:	Grant
Recipients:	(1) Institutions of higher education. (2) National Laboratories. (3) Nonprofit and for-profit private entities. (4) State and local governments. (5) Consortia of entities described in paragraphs (1) through (4)
Eligible Uses:	Demonstration projects, construction of commercial-scale facilities, and retrofit or retooling of existing facilities for battery component manufacturing, advanced battery manufacturing, and recycling.

Battery Materials Processing Grants Department of Energy $3,000,000,000	
Description:	To provide grants for battery materials processing to ensure that the United States has a viable battery materials processing industry. Funds can also be used to expand our domestic capabilities in battery manufacturing and enhance processing capacity.
Funding Mechanism:	Grant
Recipients:	(1) Institutions of higher education. (2) National Laboratories. (3) Nonprofit and for-profit private entities. (4) State and local governments. (5) Consortia of entities described in paragraphs (1) through (4)
Eligible Uses:	Demonstration projects, construction of commercial-scale facilities, and retrofit or retooling of existing battery material processing facilities.

Advanced Energy Manufacturing and Recycling Grants Department of Energy $750,000,000	
Description:	To provide grants to small- and medium-sized manufacturers to enable them to build new or retrofit existing manufacturing and industrial facilities to produce or recycle advanced energy products in communities where coal mines or coal power plants have closed.
Funding Mechanism:	Grant
Recipients:	Manufacturing firm: (A) the gross annual sales of which are less than $100,000,000; (B) that has fewer than 500 employees at the plant site of the manufacturing firm; and (C) the annual energy bills of which total more than $100,000 but less than $2,500,000.
Eligible Uses:	To re-equip, expand, or establish a manufacturing or recycling facility for the production or recycling of advanced energy technologies (including clean electricity, industrial decarbonization, clean transportation, clean fuels, etc.); or to reequip an industrial of manufacturing facility with equipment designed to reduce greenhouse gas emissions of that facility.

Critical Material Innovation, Efficiency, And Alternatives Department of Energy $600,000,000	
Description:	To conduct a program of research, development, demonstration, and commercialization to develop alternatives to critical materials, to promote their efficient production and use, and ensure a long-term secure and sustainable supply of them.
Funding Mechanism:	Grant
Recipients:	Industry Partner
Eligible Uses:	(A) Alternative materials, particularly materials available in abundance within the United States and not subject to potential supply restrictions, that lessen the need for critical materials; (B) alternative energy technologies or alternative designs of existing energy technologies (C) technologies or process improvements that minimize the use and content, or lead to more efficient use, of critical materials across the full supply chain; (D) innovative technologies and practices to diversify commercially viable and sustainable domestic sources of critical materials (E) technologies, process improvements, or design optimizations that facilitate the recycling of critical materials (F) advanced critical material extraction, production, separation, alloying, or processing technologies that decrease the energy consumption, environmental impact, and costs of those activities (G) commercial markets, advanced storage methods, energy applications, and other beneficial uses of critical materials; and (H) advanced theoretical, computational, and experimental tools necessary to support the crosscutting research and development needs of diverse critical minerals stakeholders.

Earth Mapping Resources Initiative Department of the Interior $320,000,000	
Description:	To accelerate the U.S. Geological Survey mapping mission by providing integrated topographic, geologic, geochemical, and geophysical mapping; accelerating the integration and consolidation of geospatial and resource data; and providing an interpretation of both critical mineral resources still in the ground and critical mineral resources that may be reprocessed from legacy mine wastes.
Funding Mechanism:	Cooperative Agreement, Direct Federal Spending
Recipients:	State Geological Surveys, Private Entities
Eligible Uses:	Cooperative agreements or contracts for mapping and data.

Energy and Minerals Research Facility Department of the Interior $167,000,000	
Description:	For design, construction and tenant build out of a facility to support energy and minerals research and associated structures, through a cooperative agreement with an academic partner. The new building will establish a center of excellence in minerals and energy science and providing opportunities for science collaboration that will leverage U.S. Geological Survey science; support the development of science, technology, engineering and mathematics talent by engaging students in U.S. Geological Survey science; and expand the diversity of the U.S. Geological Survey workforce.
Funding Mechanism:	Cooperative Agreement, Direct Federal Spending
Recipients:	State Academic Institutions
Eligible Uses:	For design, construction, and tenant build out of a new federally owned facility.

Rare Earth Elements Demonstration Facility Department of Energy $140,000,000	
Description:	To demonstrate the feasibility of a full-scale integrated rare earth element extraction and separation facility and refinery.
Funding Mechanism:	Grant
Recipients:	Industry Partner
Eligible Uses:	The facility established shall: (A) provide environmental benefits through use of feedstock derived from acid mine drainage, mine waste, or other deleterious material; (B) separate mixed rare earth oxides into pure oxides of each rare earth element; (C) refine rare earth oxides into rare earth metals; and (D) provide for separation of rare earth oxides and refining into rare earth metals at a single site.

Rare Earth Security Activities Department of Energy $127,000,000	
Description:	To conduct a program of research and development to improve the security of rare earth elements.
Funding Mechanism:	Grant
Recipients:	Industry Partner
Eligible Uses:	(A) Development and assessment of advanced separation technologies for the extraction and recovery of rare earth elements and other critical materials from coal and coal byproducts; and (B) Determine if there are, and mitigate, any potential environmental or public health impacts that could arise from the recovery of rare earth elements from coal-based resources.

Battery and Critical Mineral Recycling Department of Energy $125,000,000	
Description:	To award grants for research, development, and demonstration projects to create innovative and practical approaches to increase the reuse and recycling of batteries.
Funding Mechanism:	Grants
Recipients:	(i) An institution of higher education; (ii) a National Laboratory; (iii) a Federal research agency; (iv) a State research agency; (v) a nonprofit organization; (vi) an industrial entity; (vii) a manufacturing entity; (viii) a private battery-collection entity; (ix) an entity operating 1 or more battery recycling activities; (x) a State or municipal government entity; (xi) a battery producer; (xii) a battery retailer; or (xiii) a consortium of 2 or more entities described in clauses (i) through (xii).
Eligible Uses:	Research, development, and demonstration to address (i) recycling activities; (ii) the development of methods to promote the design and production of batteries that take into full account and facilitate the dismantling, reuse, recovery, and recycling of battery components and materials; (iii) strategies to increase consumer acceptance of, and participation in, the recycling of batteries; (iv) the extraction or recovery of critical minerals from batteries that are recycled; (v) the integration of increased quantities of recycled critical minerals in batteries and other products to develop markets for recycled battery materials and critical minerals; (vi) safe disposal of waste materials and components recovered during the recycling process; (vii) the protection of the health and safety of all persons involved in, or in proximity to, recycling and reprocessing activities, including communities located near recycling and materials reprocessing facilities; (viii) mitigation of environmental impacts that arise from recycling batteries, including disposal of toxic reagents and byproducts related to recycling processes; (ix) protection of data privacy associated with collected covered battery-containing products; (x) the optimization of the value of material derived from

Critical Material Supply Chain Research Facility Department of Energy $75,000,000	
Description:	To support construction of a Critical Materials Supply Chain Research Facility.
Funding Mechanism:	Contract
Recipients:	Industry Partner
Eligible Uses:	(A) Further enable research, development, demonstration, and commercialization activities throughout the supply chain for critical materials; and (B) Provide an integrated, rapidly reconfigurable research platform.

Lithium-Ion Recycling Prize Department of Energy $10,000,000	
Description:	To provide a prize for recycling of lithium-ion batteries and convene a task force on battery producer requirements.
Funding Mechanism:	Prize
Recipients:	Prize dependent
Eligible Uses:	(i) To increase the number of winners of Phase III of the prize competition; (ii) to increase the amount awarded to each winner of Phase III of the competition; and (iii) to carry out any other activity that is consistent with the goals of Phase III of the competition, as determined by the Secretary.

Battery Collection Best Practices Environmental Protection Agency $10,000,000
Provides $10 million for fiscal year 2022, to remain available until September 30, 2026, for Environmental Protection Agency to develop best practices that may be implemented by State, Tribal, and local governments with respect to the collection of batteries.

Endnotes

1 This report uses the term critical minerals to also encompass elements and other materials. Formally, a mineral is a naturally occurring solid with well-defined crystallographic structure and fairly well-defined chemical composition. However, many entries on critical mineral lists are elements (e.g., lithium, nickel) or groups of elements (e.g., rare earth elements, platinum group metals) rather than the mineral or other form from which the elements are derived (e.g., lithium is produced from lithium chloride in brine and from the ores spodumene and lithium-cesium-tantalum pegmatites).

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