Critical Minerals for Clean Energy

REFERENCE GUIDE

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A young man looks for copper standing in a pit in the Ruashi mine in the Democratic Republic of the Congo. Per-Anders Pettersson/Getty Images

Table of Contents

Open-pit copper mine in Peru. tifonimages/Getty Images

Forecasts estimate that the growing adoption of clean energy technology will mean a tripling of mineral demand by 2040.[1]

With the urgent threat of climate change, it is imperative that governments invest in and deploy clean energy technologies that can help lower greenhouse gas emissions and their associated consequences for public health, fish and wildlife habitat, and infrastructure. However, procuring the critical minerals and materials needed to create solar panels, wind turbines, electric vehicle (EV) batteries, and other renewable technologies at scale presents its own set of environmental and social concerns.

Clean energy technologies generally require more critical minerals to build than traditional fossil-fuel plants. For example, an electric car may require up to six times the minerals of a combustion engine car and an offshore wind plant may require as much as fifteen times more minerals than a gas-fired plant. Forecasts estimate that the growing adoption of clean energy technology will mean a tripling of mineral demand by 2040.[1]

Currently, the United States heavily relies on certain mineral imports vital to domestic economic and national security. This dependency can create vulnerabilities from foreign disputes, natural disasters, pandemics, and other events that can disrupt mineral supply.[2]

Critical Minerals and Clean Energy Products

Critical minerals are defined as naturally occurring, solid chemical compounds that are: essential to the economic or national security of the U.S.; have a supply chain that is vulnerable to disruption; or that serve an essential function in the manufacturing of a product for which the absence would have significant consequences on the economic or national security of the U.S.

We base our reference guide on the U.S. Geological Survey's 2021 critical minerals draft list, which recognizes 50 critical minerals, including several like cobalt and lithium, that are crucial to renewable energy development.[3] Among the 15 minerals added since the 2018 list are nickel and zinc, which both play a role in clean energy and battery storage technologies. The USGS did not include copper on the list despite its importance in renewable energy and transmission lines. For that reason, we have included it in this guide.

Wind and Solar

Domestic wind power deployment has increased significantly over the past decade thanks to policy support and decreasing costs. As large-scale wind projects are announced and underway, materials like aluminum, copper, zinc, and rare earth elements (a group of 17 soft heavy metals) will be increasingly needed to build turbines, and copper will be needed for cabling. Mineral needs vary by turbine

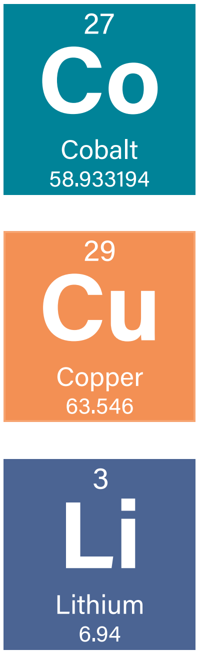
Critical mineral needs for clean energy technologies

	Copper	Cobalt	Nickel	Lithium	REEs	Chromium	Zinc	PGMs	Aluminium
Solar PV	High	Low	Low	Low	Low	Low	Low	Low	High
Wind	High	Low	Moderate	Low	High	Moderate	High	Low	Moderate
Hydro	Moderate	Low	Low	Low	Low	Moderate	Moderate	Low	Moderate
CSP	Moderate	Low	Moderate	Low	Low	High	Moderate	Low	High
Bioenergy	High	Low	Low	Low	Low	Low	Moderate	Low	Moderate
Geothermal	Low	Low	High	Low	Low	High	Low	Low	Low
Nuclear	Moderate	Low	Moderate	Low	Low	Moderate	Low	Low	Low
Electricity networks	High	Low	Low	Low	Low	Low	Low	Low	High
EVs and battery storage	High	High	High	High	High	Low	Low	Low	High
Hydrogen	Low	Low	High	Low	Moderate	Low	Low	High	Moderate

Relative importance of minerals for a particular clean energy technology: High: ● Moderate: ● Low: ●

Shading indicates the relative importance of minerals for a particular clean energy technology, which are discussed in their respective sections in this chapter. CSP = concentrating solar power; REEs = rare earth elements; PGM = platinum group metals. * In this report, aluminium demand is assessed for electricity networks only and is not included in the aggregate demand projections.

Source: IEA 2022.



type and size. For example, the offshore wind market prefers lighter and more efficient turbines that require rare earth elements—specifically neodymium and praseodymium—of which demand will more than triple by 2040.[4] Onshore wind, however, does not require as much volume of rare earth elements because these turbines typically use gearbox generators rather than the permanent magnets that are preferred offshore. Onshore wind may also favor using aluminum for cabling rather than copper needed for submarine cabling.

Solar photovoltaics (PVs) are a rapidly growing market that has increased in size nearly 20 times over the past decade. The expected solar energy capacity additions by 2040 forecast a potential tripling of copper demand. Solar power will require high volumes of aluminum and copper and low volumes of cobalt, nickel, lithium, rare earth elements, chromium, zinc, and platinum group metals.

Solar technicians installing solar panels. Los Muertos Crew/Pexels

An electric vehicle being charged. Chuttersnap/Unsplash

Electric Vehicles and Batteries

Electric vehicles and battery storage will make up about half of the growth in mineral demand for clean energy over the next twenty years. Demand for graphite, copper, nickel, lithium, and cobalt will therefore rise substantially. Different chemistries of lithium-ion batteries have become available for electric vehicles. However, 90 percent of EVs marketed today require rare earth elements like neodymium, praseodymium, dysprosium, and terbium, which are concentrated and processed in China.

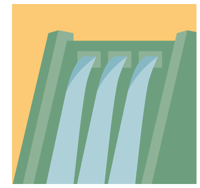
Like many technologies, raw materials account for the majority of EV battery cost. Despite becoming more affordable over the years, the fluctuating price of critical minerals can greatly affect battery price. Security in cost and supply chain of minerals essential to electric vehicle battery manufacturing is paramount in achieving electrification targets.

Geothermal

Although geothermal only accounts for a small portion of the United States' electricity generation, the U.S. still leads the world in geothermal power generation capacity. Geothermal systems use nickel, chromium, molybdenum, and titanium, and account for 80 percent of nickel demand and 40 percent of titanium demand of all low-carbon power sources.[5] Current geothermal energy capacity in the U.S. is less than 1 percent but has the potential to grow to more than 8 percent by 2050.

Hydropower, Bioenergy, and Nuclear

Hydropower, bioenergy, and nuclear energy all have low mineral intensity. Hydropower and bioenergy are expected to account for around two percent of total U.S. demand for copper from low-carbon power sources by 2040, while nuclear is expected to account for less than six percent of copper, nickel, and chromium demand.



Foreign and Domestic Supplies

Certain clean energy minerals are concentrated in just a few countries, making the current international supply chains for them vulnerable to political instability, price volatility, and export restrictions. Other events such as natural disasters, accidents, and labor strikes may also cause supply disruptions. For example, in the summer of 2021, as high commodity price and demand accelerated for metals used in renewable energy and electric vehicles, labor strikes in Chile, Canada, and the U.S. led to production declines and supply disruption.[6] Similarly, the output of refined copper in the United States decreased by an estimated 13% as a result of strikes, ongoing since October 2019, at a smelter in Arizona and an electrolytic refinery in Texas.[7]

Cobalt

The Democratic Republic of the Congo (DRC), Australia, and Russia are the top cobalt-producing countries. With only a few known domestic deposits of cobalt, the U.S. is heavily dependent on imports, with the majority imported from Norway, Canada, Japan, and Finland. Particular concerns from cobalt-producing countries like China, Russia, and the DRC revolve around their geopolitical instability and questionable labor and environmental laws. Negative impacts of cobalt mines in the DRC include heavy metal contamination of air, water, and soil, severe health impacts for miners and nearby communities, use of child labor, and dangerous working conditions in small-scale hand-dug mines.[8]

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Ore containing copper, cobalt, and nickel at the Andover mine in Western Australia. Paul-Alain Hunt/Unsplash

Almost all of the known deposits in the U.S. overlap with high-value fish and wildlife habitats, such as the Boundary Waters in Minnesota and the Klamath and Rogue Rivers in California and Oregon. However, some alternative development locations may be suitable for mining cobalt, including the Blackbird Mining District west of Salmon, Idaho, or the Fredericktown Mining District in Missouri.[9]

Copper

Chile, China, and Peru are the top copper-producing countries. Between 2017 and 2020, around 62 percent of all imports of refined copper to the United States came from Chile.[10] Mining of copper can lead to heavy metal contamination of soil and groundwater and health impacts for workers and neighboring communities.

Building a clean energy grid will involve the expansion of transmission lines that require large amounts of copper for underground and subsea cables and aluminum for overhead lines. Switching to aluminum for more underground lines would decrease pressure for copper and provide a more affordable grid expansion. Nevertheless, wherever possible, clean energy technologies should be built near existing and upgraded electricity grids and those transmission lines repurposed for renewables.

Lithium

Australia, Chile, China, and Argentina are top producers of lithium. In 2018, the U.S. relied on imports for more than 50% of lithium consumed. The major environmental and social concerns of lithium mining are water contamination and poor worker compensation.

Lithium is found around the world, but few places have large deposits. Numerous deposits in the American West and South exist, such as the Clayton Valley brine operation in southern Nevada and the Smackover brine area of Arkansas.[11] One of the largest deposits in the world can be found in eastern Oregon, which is also home to an assortment of critical high desert species. Therefore, thoughtful consideration for lithium mine siting must be taken to ensure wildlife and communities are not affected.

Rare Earth Elements (REE)

Rare earths are a group of 17 soft heavy metals that have electronic and magnetic properties. REE are used to make magnets found in electric vehicles, plus catalytic converters, batteries, computers, and other products. The top producing countries of rare earth elements are China, the U.S., Myanmar, and Australia. Between 2017 and 2020, 78 percent of all rare earth imports to the United States came from China.[12] Major concerns include the large number of chemicals used in processing and the large volumes of solid waste, gas, and wastewater byproducts of production.

The Mountain Pass Mine and processing facility in southern California was the only producer in the U.S., and at one point was one of the top producers in the world. In recent decades, however, China has owned the vast majority of rare earth supply, largely due to its control of processing. Although MP Materials acquired the California mine in 2017, rare earth ore must still be sent to China for processing, making the U.S. completely reliant on imports of processed rare earths.[13] Some experts are examining alternative ways to extract rare earth elements, such as from active or abandoned coal mines, from water contaminated with coal ash, and from acid mine drainage at legacy hardrock mines in the western U.S.[14]

Key Critical Minerals and U.S. Supply

Critical Mineral	Clean Energy Uses	U.S. Net Import Reliance (2021)	Top Producing Countries (2021)	Major U.S. Import Sources (2017-2020)	Domestic Sources
Rare Earths Elements	Wind turbines	>90%	U.S., China, Myanmar, Australia	China, Estonia, Japan, Malaysia	Southeastern United States, California
Cobalt	Rechargeable EV batteries	76%	DRC, Australia, Russia	Norway, Canada, Japan, Finland	Michigan, Missouri, Alaska, California, Idaho, Montana, Oregon, Pennsylvania
Lithium	Rechargeable batteries, wind, solar, EV battery storage	>25%	Australia, Chile, China	Argentina, Chile, China, Russia	Nevada
Copper	Electricity-related technologies and transmission lines	45%	Chile, China, Peru, DRC	Chile, Canada, Mexico	Southern Utah, southeastern Arizona, Michigan, Missouri
Zinc	Solar, geothermal, EV battery storage, hydrogen, electricity networks	76%	China, Peru, Australia	Canada, Mexico, Peru, Spain	Tennessee, Missouri
Nickel	Battery performance, longevity, and density; hydrogen	48%	Indonesia, Philippines, Russia	Canada, Norway, Finland, Australia	Michigan

Source for imports USGS 2022.
Source for producers IEA 2021.

Domestic Supply Chain

Securing domestic sources of critical minerals needed for clean energy technologies could help minimize risks from price volatility and supply interruptions and would support the needed energy transition. Greater domestic sourcing would also reduce reliance on foreign nations that have poor labor standards or even child and forced labor. However, mining on federal public lands has been known to impact fish and wildlife habitat, public health, and cultural resources. If America is to gain clean energy independence and develop a just domestic supply chain, strategic placement for mineral extraction will be crucial.

To meet climate targets, the U.S. will continue to rely on foreign imports of critical minerals in the near term. Advancing mining projects from discovery to first production can take more than 16 years, according to the International Energy Agency.[15] This timeline raises concerns about market supply as renewable energy is scaled up.

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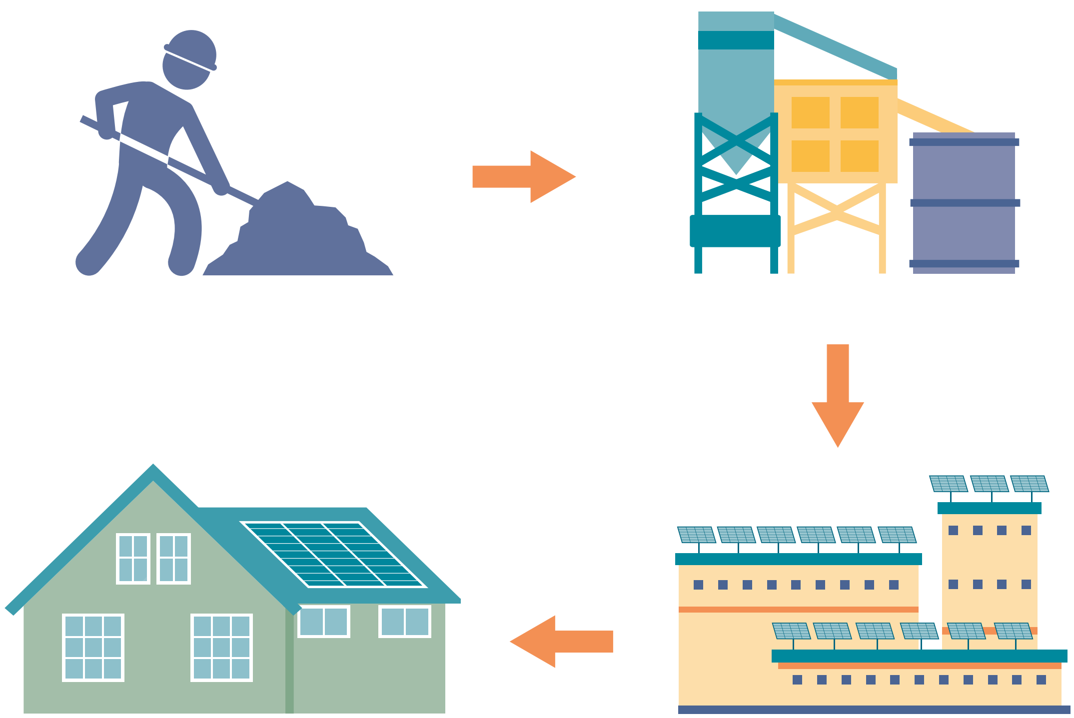

Infrastructure for mining gold and other minerals in Australia. Alfio Manciagli/Getty Images

Climate Change Impacts

Clean energy technologies will give us the footing we need to combat the climate crisis and lower emissions, but there are concerns about the effects climate change has on critical mineral extraction in the interim. Sustainable water sourcing is an important consideration as severe drought events become more frequent and prolonged. Certain minerals like copper and lithium are particularly vulnerable to water stress because their extraction requires large volumes of water. Major producing areas experiencing increasing drought—like Chile, Australia, China, and several countries on the African continent—face challenges to reliable and environmentally sustainable supplies. Many possible locations for American domestic mines are also in drought-prone western states. Areas that experience extreme heat and flooding also pose risks to reliable supply chains and worker safety.

A young man holds cobalt from the Ruashi mine in the Democratic Republic of the Congo. Per-Anders Pettersson/Getty Images

The extraction and processing of these minerals must be appropriately managed to avoid negative environmental and social justice impacts.

Social and Environmental Considerations

As the domestic deployment of renewable energy technologies and batteries ramps up, so will the demand on higher volumes of environmentally sensitive minerals. The extraction and processing of these minerals must be appropriately managed to avoid and mitigate for negative environmental and social justice impacts. Mining of key metals can create pollution and heavy metal contamination of water and agricultural soils that impact the health of workers and local communities.[16]

In addition to where minerals are sourced, their quality and associated emissions from production influence total environmental impact. For example, the quality of certain minerals like copper ore has decreased in the past couple of decades, requiring more energy for extraction and processing, which increases their associated CO_2 emissions.

As the nation works to address climate change through deploying zero-carbon technologies, environmental and social responsibility must be a priority in the procurement and processing of critical minerals. Development should minimize and address impacts to local communities, wildlife habitats, water use and contamination, and emissions from mining and processing, while ensuring Tribal sovereignty, worker safety, and human and worker rights.

Policy Recommendations

The National Wildlife Federation recommends these policies for responsible critical mineral development:

1. Before seeking new sources of raw materials, prioritize and fully utilize alternatives, such as recycling, substitutes to critical minerals, reprocessing old mine waste piles and ash material, and engineering advancements to reduce use and the need for new mines. Federal legislation to provide incentives and improve economic viability of these alternatives is needed.

2. Evaluate critical mineral mine site proposals on public land through transparent, effective and predictable public processes – ones that include public land users, affected communities and Indigenous Tribes, as well as appropriate state and local governments and other stakeholders.

3. Avoid and minimize critical mineral development impacts to important fish and wildlife habitat, including focusing operations on landscapes that already have established infrastructure.

4. Encourage federal and state policies that support responsible critical minerals mining and avoid impacts to special places, recreational assets and high-quality fish and wildlife habitat. Where impacts are unavoidable, effects must be mitigated including through the use of compensatory mitigation.

5. Ensure that environmental safeguards, such as the National Environmental Policy Act and current public land protections, are not circumvented, repealed, or weakened for the purposes of developing critical minerals.

If implemented, these tenets will help prevent unnecessary environmental, social, and economic harm as the nation strives to satisfy its critical minerals needs.

6. Utilize the best available science to map critical mineral resources, identify key fish and wildlife habitat, and develop avoidance and mitigation strategies.

7. Some places are simply too special or sensitive to mine. Where other values are deemed more important and risks too high, critical mineral mine proposals should not be approved.

8. Impose a new federal minerals royalty for critical minerals extracted on public lands, and allocate a portion of the revenues generated to fund mine reclamation that creates good-paying, equitable jobs and restores affected fish and wildlife habitat.

9. Develop new policies in formalized collaboration with Tribes and with all affected stakeholders, including hunters and anglers, outdoor recreation interests, labor, manufacturers and the mining industry.

10. Seek to build enduring trust, transparency, and partnership with all stakeholders and impacted communities, which should result in more responsible and successful mining projects.

If implemented, these tenets will help prevent unnecessary environmental, social, and economic harm as the nation strives to satisfy its critical minerals needs. To this end, we intend to work with a diverse group of partners to translate these tenets into specific state and federal policy recommendations. Read more about National Wildlife Federation's recommendations for critical minerals.

Raw copper ore. wingedwolf/Getty Images

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