Critical Materials

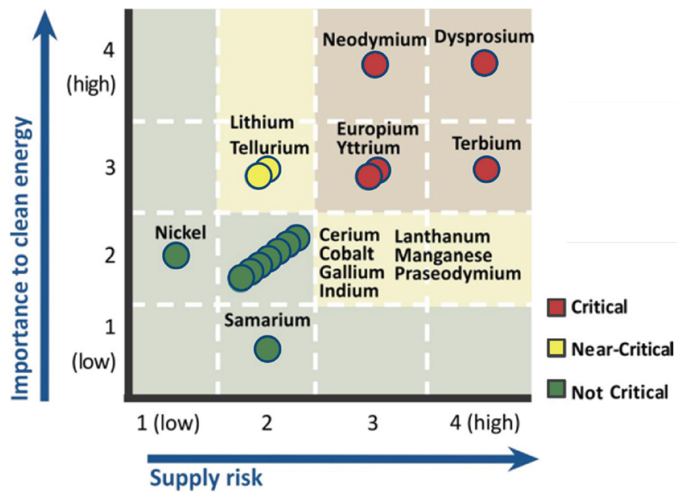
Minerals are integral to the functioning of modern society. They are found in alloys, magnets, batteries, catalysts, phosphors, and polishing compounds, which in turn are integrated into countless products such as aircraft, communication systems, electric vehicles (EV), lasers, naval vessels, and various types of consumer electronics and lighting.[1] However, some of these minerals are in limited supply and techniques for their extraction incur high environmental and financial costs. Given their necessity in a plethora of technological applications, concern exists over whether supply can meet the needs of the economy in the future. Material criticality can be assessed in terms of supply risk, vulnerability to supply restriction, and environmental implications.[2] Rare earth elements (REEs) are a group of 17 elements used in various products, many of which are vital for renewable energy and energy storage.[1] Global demand for critical materials is expected to rise over the next several decades as the world shifts to clean energy. Demand for lithium and graphite, used in EV batteries, is forecasted to increase as much as 4,000% and 2,500% respectively.[3] Unless action is taken, the U.S. could face an annual shortfall of up to $3.2 billion worth of critical materials.[4] The average amount of critical materials needed to generate a new unit of power has increased by 50% since 2010.[3]

Critical Materials Categories

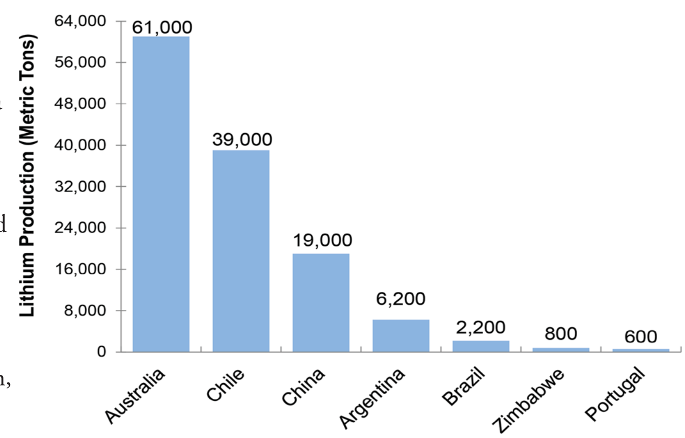
Energy Critical Elements

- Energy critical elements (ECEs) are elements integral to advanced energy production, transmission, and storage. This category includes lithium, cobalt, selenium, silicon, tellurium, indium, and REEs.[6]
- An element might be classified as energy critical because of rarity in Earth's crust, economically extractable ore deposits are rare, or lack of availability in the U.S. The U.S. is reliant on other countries for more than 90% of most ECEs.[6]
- Some ECEs form deposits on their own, others are obtained solely as byproducts or coproducts from the mining of other ores.[6]
- Silicon, tellurium, and indium are necessary parts of solar photovoltaic (PV) panels.[7]
- Platinum group elements (PGEs) are necessary components of fuel cells and have potential for other advanced vehicle uses.[6] Platinum and palladium production are concentrated in South Africa (74% and 38%, respectively) and Russia (11% and 42%, respectively).[8]
- Lithium is an element of growing importance due to its use in batteries for cell phones, laptops, and electric vehicles. Chile, Bolivia, and Argentina account for 53% of worldwide lithium resources. Australia, Chile, China, and Argentina accounted for 96% of world lithium production in 2022.[8]
- Efforts are underway to extract elements from lower quality resources. Lithium, along with materials such as vanadium and uranium, is present in seawater in small concentrations. Researchers have recently developed a method for extracting these materials from seawater.[9]
- The U.S. Department of Energy (DOE) defines materials criticality based on the material's supply risk and importance to clean energy. As of 2011, DOE found five elements to be critical in the short-term (2011 to 2015) and medium-term (2015-2025): dysprosium, terbium, europium, neodymium, and yttrium. These elements are used in magnets for wind turbines and electric vehicles or as phosphors in energy efficient lighting.[5]
- DOE's Critical Materials Institute has more recently focused on key materials including graphite, manganese, cobalt, lithium, gallium, indium, and tellurium.[10]
- Current DOE strategies for addressing material criticality include diversifying supply, developing substitutes, and improving reuse and recycling of critical materials.[11]
- Copper is a key element in electrical wiring and appliances and may also be a limiting factor in future renewable energy deployment. At current production levels, existing copper resources may only last another 60 years and its extraction will become more energy intensive as ore quality decreases.[12] Top copper producing countries include Chile (23.6%), Peru (10.0%), Congo (10.0%) China (8.6%), and the U.S. (5.9%).[8] Copper is unique in that it does not degrade or lose its physical and chemical properties when it is recycled.[13] In 2022, only 32% of copper came from recycled sources. Old (post-consumer) scrap accounted for almost 20% of this total recovered scrap, while more than 80% was recovered new (manufacturing) scrap.[8]

Materials Criticality Matrix, Medium Term (2015-2025)[5]

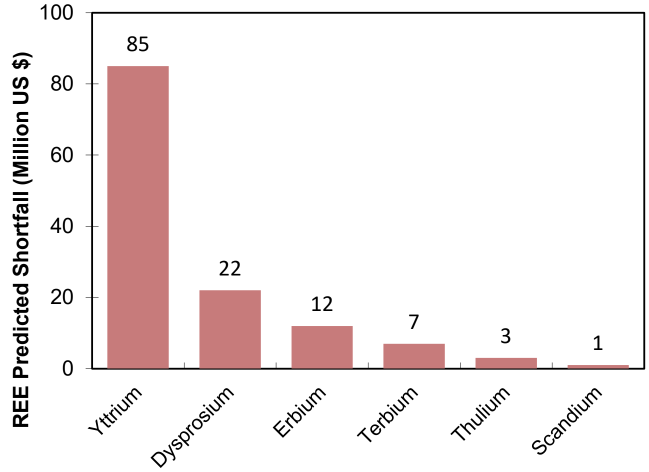


World Lithium Production, 2022[8]



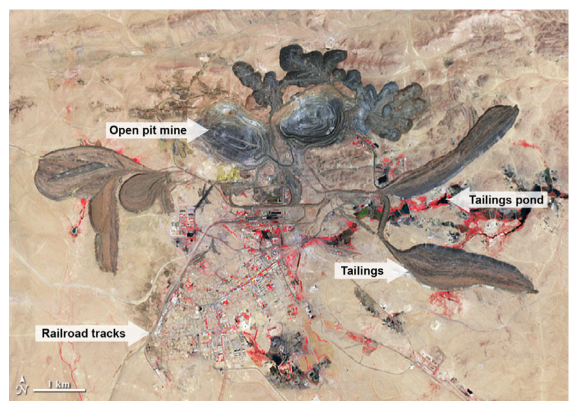
Rare Earth Elements

Rare Earth Element Predicted Shortfall[14]



- REEs are a particularly important group of critical minerals. Although these minerals are moderately abundant in Earth's crust, they are distributed diffusely and thus difficult to extract in large quantities.[15]
- There are 17 REEs, including the lanthanide elements (atomic numbers 57 through 71 on the periodic table), scandium, and yttrium. Light REES (LREEs) consist of elements 57 through 64, and heavy REEs (HREEs) consist of yttrium and elements 65 through 71.[1]
- REEs have a variety of uses, including components in cell phones, energy efficient lighting, magnets, hybrid vehicle batteries, and catalysts for automobiles and petroleum refining.[15] The REEs terbium, neodymium, praseodymium, and dysprosium are key components of the permanent magnets used in wind turbines.[7] Substitutes for REEs are available but are less effective.[8]
- In 2022, China controlled an estimated 70% of REE production, a 12% increase from its control of 58% in 2021.[8] The U.S. is 100% reliant on imports for 14 critical minerals and more than 75% reliant on imports for another 10. These materials are key to industrial and commercial processes as well as national defense.[7]
- The U.S. has increased REE production to 43,000 metric tons (t) in 2022. U.S. REE reserves are estimated 2.3 million metric tons (Mt). In comparison, China produced 210,000 t of REEs in 2022 and possesses reserves of 44 Mt. Vietnam had a 975% increase in REE production between 2021 and 2022, making it the 6th largest REE producing country in the world.[8]
- Demand for ECEs, coupled with rising mining standards in many countries, has caused production to shift to countries with low costs and lax environmental regulations, thus increasing the impacts of ECE extraction. Nevertheless, developing nations naturally contain greater quantities of ECE ore deposits.[6]
- The U.S. used $613 million of REEs which in turn generated $496 billion in economic activity in other sectors, including petroleum refining, and electromedical device and automotive manufacturing in 2016.[3]

Rare Earth Mining Damage in China[18]



Life Cycle Impacts

- Mining is a destructive process that disrupts the environment and widely disperses waste. Chemical compounds used in extraction processes can enter the air, surface water, and groundwater near mines.[16]
- The grinding and crushing of ore containing critical elements often releases dust, which can have carcinogenic and negative respiratory effects on exposed workers and nearby residents.[16]
- Beyond health impacts, mining can also negatively impact human rights. For example, the Democratic Republic of Congo is the world's leading producer of cobalt, widely used in advanced battery technology, but child labor is routine there as a result of lax regulation and oversight.[17]
- Some REE deposits contain thorium and uranium, which pose significant radiation hazards. While thorium and uranium can be used to generate nuclear energy, they are rarely economically recoverable and thus are left in the tailings, where they can pose risks to environmental and human health.[6]
- Recycling critical materials results in much lower human health and environmental impacts compared to mining virgin material. Nevertheless, improper recycling and recovery procedures, which often occur in developing nations where regulations to limit worker exposure are lax or nonexistent, can lead to exposure to carcinogenic and toxic materials.[16]

Solutions and Sustainable Alternatives

- Recycle your electronics. Currently, less than 1% of REEs are recycled. Every year, thousands of electronic products such as cell phones, televisions, and computers are thrown away. Metals recovered from these products can be effectively reused or recycled.[5]
- Buy refurbished rather than new products. Rent products from companies with take-back programs that require material recycling.[6]
- Support government programs like the DOE's Advanced Manufacturing Office, which funds projects related to reducing environmental impacts, lowering costs, and improving the process of manufacturing clean energy technologies in the U.S.[19]

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Cite as: Center for Sustainable Systems, University of Michigan. 2023. "Critical Materials Factsheet." Pub. No. CSS14-15. **August 2023**