Critical Materials

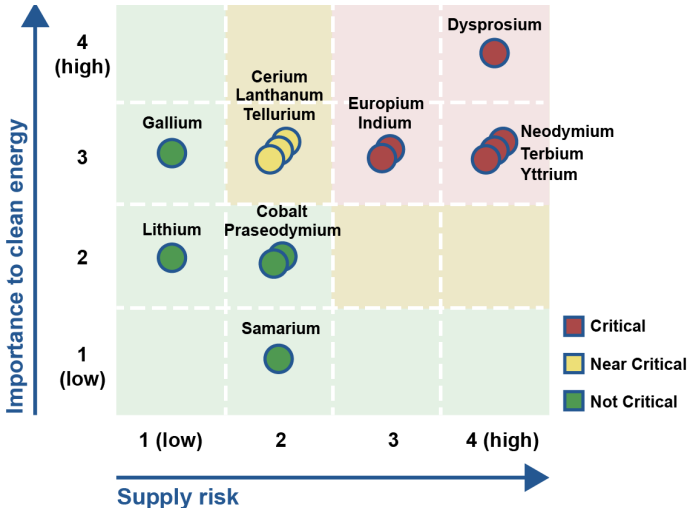
Minerals are integral to the functioning of modern society. They are found in countless products such as aircraft, communication systems, electric vehicles, lasers, naval vessels, and various types of consumer electronics and lighting.[1] However, some of these minerals are in limited supply and techniques 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 is assessed in terms of supply risk, vulnerability to supply restriction, and environmental implications.[2] Several rare earth elements (REEs) and other minerals critical to producing solar panels, wind turbines, electric vehicles, and energy-efficient lighting could face supply shortages within the next five to ten years.[3] Unless action is taken, the U.S. could face an annual shortfall of up to $3.2 billion worth of critical materials.[4]

Critical Materials Categories

Energy Critical Elements

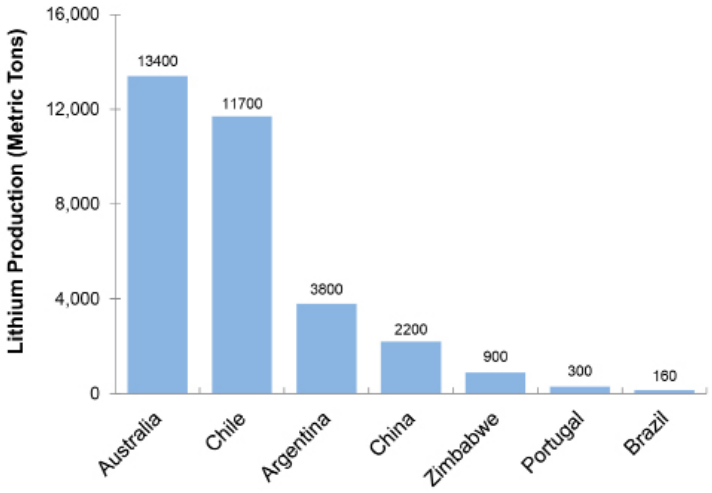
- Energy critical elements (ECEs) are elements integral to advanced energy production, transmission, and storage. This category includes lithium, cobalt, selenium, silicon, tellurium, indium, and Rare Earth Elements (REEs).[5]
- An element might be classified as energy critical because of rarity in Earth's 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 used in the economy.[5]
- Some ECEs form deposits on their own, others are obtained solely as byproducts or coproducts from the mining of other ores.[5]
- Silicon, tellurium, and indium are necessary parts of solar photovoltaic (PV) panels.[6]
- Platinum group elements (PGEs) are necessary components of fuel cells and have the potential for other advanced vehicle uses.[5] Platinum and palladium production are concentrated in South Africa (70% and 35%, respectively) and Russia (13% and 38%, respectively).[7]

Materials Criticality Matrix, Short Term[3]



- Lithium is an element of growing importance due to its use in batteries used in cell phones, laptops, and electric vehicles.[5] Chile, Bolivia, and Argentina account for over 50% of easily extractable world lithium reserves.[5] Australia, Argentina, and Chile account for a significant share of world lithium production.[7]
- 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.[8]
- 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.[3]
- Other key elements assessed by DOE include nickel, manganese, cobalt, lithium, gallium, indium, and tellurium. While these are important for renewable energy technology, they are not currently subject to nor predicted to be subject to supply disruptions.[3]
- Current DOE strategies for addressing material criticality include diversifying supply, developing substitutes, and improving recycling of critical materials.[3]
- Although not an ECE, copper is a key element in electrical wiring and appliances and may be a limiting factor in future renewable energy deployment. 26% of all available copper resources are either currently in use or have been discarded and are not feasibly recoverable.[9] Top copper producing countries include Chile (30.5%), China (9.4%), Peru (8.5%), and the U.S. (6.7%).[7] Copper is highly recyclable. Experts estimate that more than 99% of discarded copper is potentially recoverable and reusable.[10]

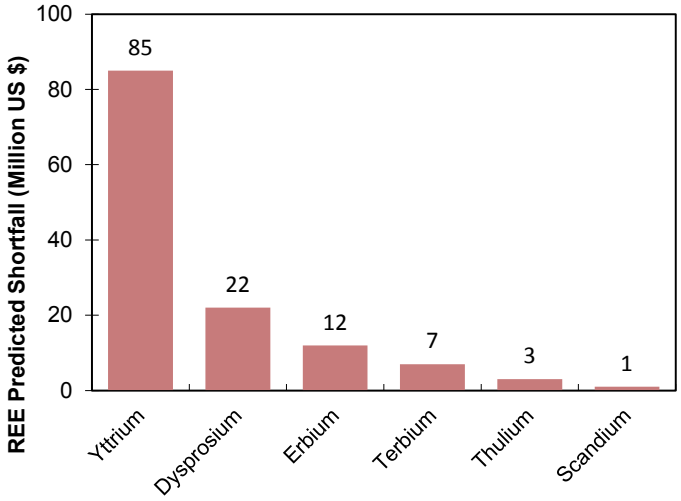
World Lithium Production, 2015[7]



Rare Earth Elements

- Rare earth elements (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.[11]
- 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 elements 65 - 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.[11] The REEs terbium, neodymium, and dysprosium are key components of the magnets used in wind turbine gearboxes.[6]
- In 2015, China controlled 85% of REE production, while the U.S. was almost fully reliant on REE imports. No readily available substitute exists for most REEs.[7] Excess supply of REEs, due to illegal production, caused pricing to decline significantly in 2015.[7]
- The U.S. has decreased REE production in recent years, from 5,400 tonnes in 2014 to 4,100 tonnes in 2015. U.S. REE reserves are estimated at 1.8 million tonnes. In comparison, China produced 105,000 tonnes of REEs in both 2014 and 2015 and possesses reserves estimated at 55 million tonnes. Australia and Russia are making significant strides in REE extraction but remain far below China's production capacity.[7]
- 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, it is worth noting that developing nations naturally contain greater quantities of ECE ore deposits.[5]

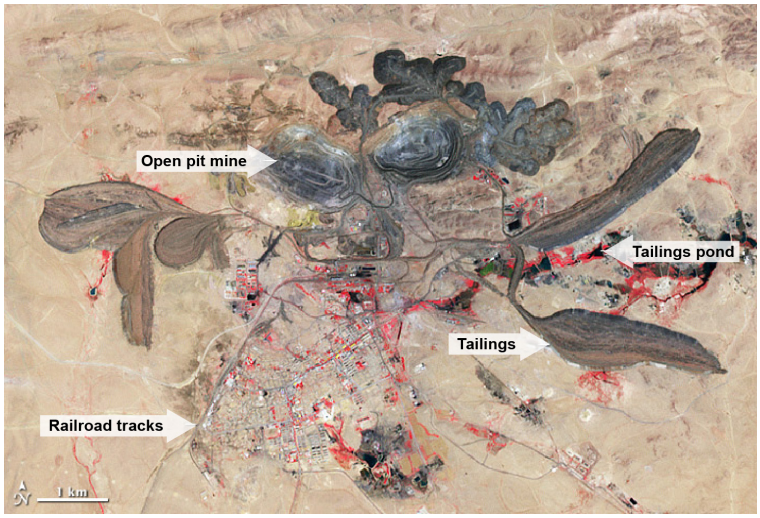
Rare Earth Element Predicted Shortfall[4]



Life Cycle Impacts

- Mining is a destructive process that disrupts the environment and disperses waste widely. Chemical compounds used in extraction processes can enter the air, surface water, and groundwater near mines.[12]
- The grinding and crushing of ore containing critical elements often release dust, which can have carcinogenic and negative respiratory effects on exposed workers and nearby residents.[12]
- Some REE deposits contain thorium and uranium, which pose significant radiation hazards. While thorium and uranium can be used to generate nuclear energy, in this case, they are rarely commercially recoverable and thus are left in the tailings, where they can pose risks to environmental and human health.[5]
- Recycling critical materials results in much lower human health and environmental impacts compared to mining virgin material. Nevertheless, improper recycling and recovery procedures can lead to exposure to carcinogenic and toxic materials, which often occur in developing nations where recycling regulations to limit worker exposure are lax or nonexistent.[12]

Rare Earth Mining Damage in China[13]



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.[3]
- Buy refurbished rather than new products. Rent products from companies with extensive take-back laws that require material recycling.[5]
- Support government programs like the Innovative Manufacturing Initiative, which funds projects related to reducing environmental impacts, lowering costs, and improving the process of renewable technology manufacturing. Approved projects include funding for gallium-nitride-based LED lights.[14]

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