ETM Supply Chain Deep Dive: Gadolinium

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Overarching Research Lens: The Expanded Supply Chain Approach

Energy Transition Mineral, Metal, and Material (ETMs) supply chains are generally represented as linear: from a mine, through a series of industrial processes, to a product and its subsequent disposal. Most circular economy research builds on this conception of supply chains, which reinforces the perception that mining geological deposits is the primary way to increase the ETM supply. This suggests that ETMs are lost through use. This is not the case. Unlike fossil fuels, most ETMs do not need to be combusted in order to perform their function. Rather, ETM supply chains relocate ETMs from their geologic deposits to the broader environment at every stage of processing, manufacture, application, and disposal. Research on the impacts of these "deposits", whether in ecosystems, human bodies, or waste sites, is extensive yet generally considered outside the scope of conventional supply chains. Our objective in reconceptualizing the ETM supply chain is to identify potential areas where environmental remediation and pollution reduction strategies to address negative environmental and health effects of ETM relocation can be used to grow the ETM supply while reducing the need to mine new geological deposits.

Element-by-Element Approach

The unique properties and applications of each ETM require an element-by-element research approach in order to identify:

- The losses that occur throughout the conventional supply chain to highlight areas where implementing best-available techniques to maximize efficiency and minimize waste-generation
- The proliferation of ETMs in environmental and biological systems that occurs as a result of their diverse applications, generally considered outside the scope of conventional supply chains, such as the accumulation of gadolinium or lithium in sewage as a result of their medical and pharmaceutical applications
- The unique elemental properties of each ETM that determines its interaction with environmental, chemical, and biological systems to better understand risks posed to human health – and to highlight priority areas for environmental remediation and ETM recovery.

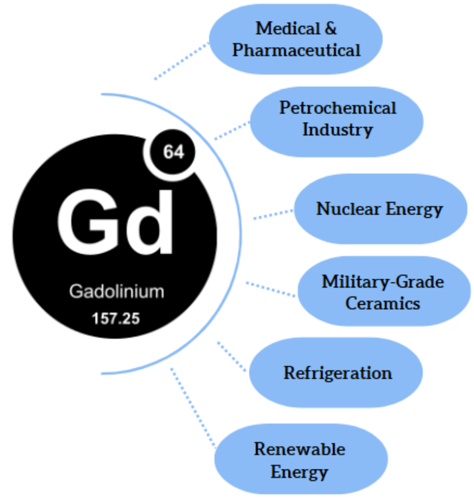
It is likely that element-specific findings will highlight new areas of inquiry for other ETMs, generating new insights into broader ETM supply chain dynamics and supporting further refinement of the expanded supply chain concept.

Example: Gadolinium

Gadolinium (Gd) is a heavy rare earth element (REE) with significant industrial, technological, and medical applications due to its ferromagnetism at room temperature and high neutron absorption capabilities, but it is less well-known compared to other REEs such as neodymium. Like other ETMs, it has many more applications besides renewable energy, including in healthcare, petrochemical and weapons industries. These diverse applications require specialized manufacturing processes, which means that they are subject to distinct economic and geopolitical dynamics. Both the diverse applications and specialized manufacturing processes generate specific forms of Gd wastes that interact with human and environmental systems in unique ways. It accumulates in locations as diverse as urban infrastructure and waterways, war zones, sewage facilities, and in the living tissues of plants, animals, and humans. There are currently no requirements to monitor or remove Gd from these locations, despite documented health impacts.

Supply Chain Insights: Scarcity & Competing Uses

Gd, like other ETMs, is subject to periodic supply and price fluctuations. This is not due to absolute scarcity. Instead, extremely low efficiency in Gd extraction is an important factor in the available supply. During the extraction and enrichment stages alone, 84% of the Gd extracted is lost as mining waste. These industrial inefficiencies weaken Gd supply security in the face of largely normal fluctuations in supply and demand driven by new applications. If current production inefficiencies do not change, a shortage of 830 tons of Gd is projected for 2030, driven in part by new applications, such as magnetic cooling systems, high-temperature superconductors, and military-grade ceramics.



Substitutability

Investigating the supply chain dimensions of elements promoted as substitutes for more prominent or controversial ETMs is important in order to evaluate whether substitutability presents a viable solution. Gd is used as a substitute for neodymium in neodymium-iron-boron (NdFeB) magnets: the most powerful permanent magnets. Adding Gd provides better thermal stability and can reduce production costs while maintaining the desired performance. When combined with other elements, such as iron and cobalt, Gd enhances magnet performance at high temperatures. This use is common in various industrial applications, including electric motors, electronic devices, and certain medical equipment. However, because it is also a REE, it is often sourced from the same mines as neodymium offering little difference in geopolitical, environmental, and labor conditions.

Deposit Locations: Above-Ground and Below-Ground

Many ETMs are sourced as byproducts from other mining operations because it is not economically feasible to mine for a single commodity. This also means that many Gd-bearing deposits are exploited for other materials, leaving the Gd as waste. The global incidence and availability of Gd in above-ground deposits generated by past and present mining activities has not been quantified, overlooking a potentially massive above-ground source of Gd. Like other rare earth elements, Gd is broadly distributed in Earth's crust. Production monopolies result from industrial and political decisions rather than geological scarcity.

Toxicity Concerns: Priority Areas for Waste Capture & Recovery

An important non-energy use of Gd is as a contrast agent to enhance the image quality and diagnostic effectiveness of Magnetic Resonance Imaging (MRI), with an estimated annual global consumption of 127 tonnes. It is ingested or injected into patients, and 95% is eliminated via urination in a few hours. Because most wastewater treatment systems do not capture Gd (or other ETMs), it enters surface waters, groundwater, and coastal waters, where it has been found to bioaccumulate in plants and animals. This poses potential risks of contamination in the human food chain through the irrigation of fields with contaminated surface water. Other studies show that Gd accumulates in the brain and organs of humans, with diverse health impacts. Improving wastewater treatment systems to filter Gd from hospital effluent would prevent broad ecosystemic contamination while generating a major non-mining source of Gd. Several other ETMs are directly consumed by humans, including lithium, copper and cobalt. This suggests comparable health and environmental concerns as well as unexplored opportunities for recovery.

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