



Extracting energy transition metals from remining sources: A review of characterization and processing approaches, resource estimates, and potential environmental effects

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Executive Summary¹

The transition away from fossil-fuel-based energy and toward renewable energy sources will lead to a greater need for many metals, including those commonly used in construction and electrical wiring (e.g., copper and aluminum) and those primarily used in creating renewable energy technologies such as wind and solar (e.g., lithium and cobalt). The metals of relevance for different renewable energy technologies are shown in Figure ES-1.

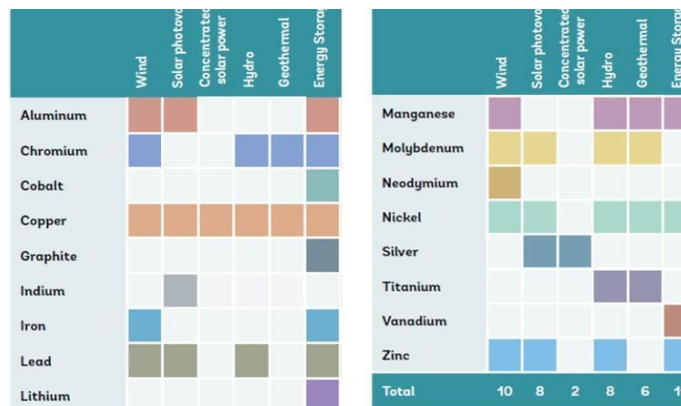


Figure ES-1. Overview of metals needed for renewable energy technologies
 Source: World Bank, 2020. Table 3.1 (modified to exclude nuclear, coal, gas, and carbon capture and storage technologies).²

¹ The technical report was published in an international peer-reviewed journal in 2023. Visit <https://www.mdpi.com/journal/minerals>.

² Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition. Prepared by K Hund, D La Porta, TP Fabregas, T Laing, J Drexhage. Available:

Renewable energy metals projected to have the largest increase in demand by 2040 varies, depending on the enacted climate change policies and changes in technologies and required materials over time. However, for solar PV, wind, concentrating solar, and geothermal, increasing demand is predicted for chromium, copper, lithium, manganese, molybdenum, nickel, rare earth elements, titanium, and lithium.³

The primary source of these metals, by far, is virgin extraction from existing large-scale metal mines around the world. Remining⁴ has been increasingly explored as an alternative or supplemental strategy to virgin extraction and recycling that could help address the increasing metal demand while potentially lowering environmental harm. However, more understanding is needed of the potential positive and negative consequences and the degree to which it can help supplement virgin extraction.

Metal ore grades in mined and proposed deposits have been decreasing over time,⁵ and the amount of waste produced per unit of final metal product has therefore increased. Remining sources include tailings, waste rock, acid mine drainage and associated treatment sludges, byproducts from ore processing, and coal ash. The most common mine waste with remining potential for renewable energy metals is tailings.⁶ The Global Tailings Review⁷ estimates there are 8,500 active, inactive, and closed tailings storage facilities worldwide. Using that estimate and extrapolating from the reported volume in a smaller number of facilities, roughly 217 cubic kilometers (km³) of tailings are in storage globally. While uncertainty exists about the total amount of tailings in storage globally, there is clearly no shortage of tailings at metal mine sites around the world – but the amount of renewable energy metals in the tailings and the economic and environmental feasibility of extracting them are largely unknown.

Because remining does not require blasting or extraction of ore from the earth and because some remined materials are partially processed, it uses less energy and has lower greenhouse gas emissions than virgin extraction for the same amount of product. Many questions remain, however, about the technical and economic viability of recovering these metals and the environmental and social costs and benefits of doing so. This review assesses what is known

<https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climat-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf>

³ IEA, 2022. The Role of Critical Minerals in Clean Energy Transitions. Available:

<https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions>. Hydropower has a relatively low mineral intensity compared to other renewable energy technologies, and it has the lowest projected future growth among all renewable sources.

⁴ Remining can be defined as the use of mine waste, including solid and liquid waste, as the source material from which to extract metals or create other materials with economic value.

⁵ Baker E, Davies M, Fourie A, Mudd G, Thygesen K. 2020. Mine tailings facilities: Overview and industry trends. Chapter II. In: Global Tailings Review. Toward Zero Harm. A compendium of papers prepared for the Global Tailings Review. August. Available:

<https://globaltailingsreview.org/wp-content/uploads/2020/09/GTR-TZH-compendium.pdf>

⁶ Tailings are the wastes remaining after the metals of interest are removed from the ore using a process called flotation.

⁷ Baker E, Davies M, Fourie A, Mudd G, Thygesen K. 2020. Mine tailings facilities: Overview and industry trends. Chapter II. In: Global Tailings Review. Towards Zero Harm. A compendium of papers prepared for the Global Tailings Review. August. 135 pgs. Available:

<https://globaltailingsreview.org/wp-content/uploads/2020/09/GTR-TZH-compendium.pdf>

and unknown about remining sources, how renewable energy metals can be recovered from the materials, the potential benefits and risks of remining, and how the risks could be reduced through best practices. The gaps in our knowledge and research needs are also assessed. The major findings of the review are as follows.

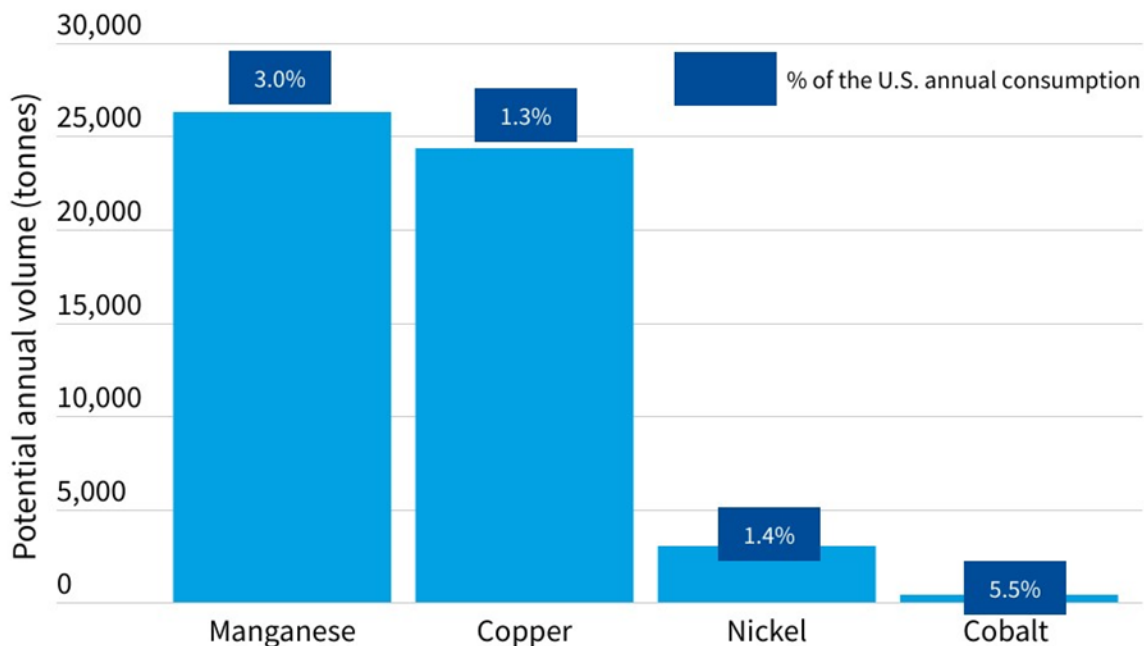
Key characterization and processing approaches

- Knowing the total metal content of a mine waste is not enough to understand its value. The minerals that host the metals and the ease of separating those minerals will determine the most effective processing methods for extracting the metals. Bench and pilot scale extraction studies must also be conducted. These types of analyses are typical for virgin mining operations, and similar methods should be used for remined wastes. The characterization methods used for wastes at modern mines are insufficient to determine metal extractability.
- A full physical and chemical characterization of the waste is needed to understand the potential environmental, human health, and safety consequences of removing and reprocessing the waste. Characterization of potential wastes early in virgin mining projects for remining potential will improve circularity, minimize waste production, and create economic advantages.
- Large-scale mine waste characterization efforts are in the early stages in the United States, Europe, and Australia. Results from these studies may not be available for four to ten years.
- Technical, economic, and environmental challenges associated with remining methods include: the generally low concentration of metals in wastes, the use of strong acids and other toxic chemicals, decreasing efficiency if wastes must be reground, the amount of energy and water required, the safety and stability issues for remining wet tailings, and the disposal or use of wastes that remain after remining efforts.
- Technical and environmental advantages of remining include: the use of versatile and proven technologies; potential use of existing infrastructure at mine sites; reduced transportation costs; and generally lower cost, energy and water use, and greenhouse gas emissions compared to virgin extraction. Of the methods proposed and used, bioleaching, which uses microbes to dissolve metals from the wastes, appears to be among the most promising due to its lower cost, high selectivity, use of milder chemicals, and lower environmental impacts. Combinations of methods are also being proposed.

Potential for remining to meaningfully contribute to supplying renewable energy metals

- A comprehensive inventory of wastes disposed as tailings in Europe, released in 2019 but using older data, estimated the “stock” of certain critical raw materials in tailings and found that approximately 1,000 tonnes of cobalt, 2,000 tonnes of gallium, 200 tonnes of indium, and 100 tonnes of natural graphite are contained in existing EU tailings. These are rough total metal values based on mass balances and expert assumptions and do not consider economic or environmental considerations. An update on tailings and mine waste volumes and chemical compositions in the EU should be conducted as soon as possible.
- In general, the reprocessing of tailings or waste rock is more likely to be able to use existing infrastructure, especially at operating or recently closed mine sites.

- In the United States, currently operating metal mines are required to report the total amount of certain metals in their discharges and releases to the environment annually. In a single year (2021, the most recent year with approved data) 57,692 tons of manganese and manganese compounds, 53,696 tons of copper and copper compounds, 6,244 tons of nickel and nickel compounds, and 842 tons of cobalt and cobalt compounds were released from metal mines to the environment. Figure ES-2 shows the converted tonnes of these four renewable energy metals released from U.S. metal mines in 2021 and the percent of annual consumption for all uses (not limited to renewable energy) the metals could supply. Given the vastly larger total stock of U.S. tailings, which includes modern and legacy wastes, remining could be a substantial resource.



Note: The U.S. Environmental Protection Agency's Toxics Release Inventory (TRI) is not specifically designed for mineral characterization. The TRI reports metal and metal "compounds," where the exact amount of a metal is not known for compounds. The volume referenced here is an estimate calculated by combining the reported amount of metal and 50% of the metal compound amount.

Figure ES-2. U.S.'s remining potential for selected metals released from metal mines

Sources: U.S. EPA, 2023. TRI On-site and Off-site Reported Disposed of or Otherwise Released, for facilities in NAICS 2022 - Metal Mining. U.S. Geological Survey, 2023. Mineral Commodity Summaries 2023 (for manganese, copper, nickel, cobalt). Graph created by Transport & Environment.

- Historic tailings would likely have higher percentages of certain energy transition metals than tailings from active mines, depending on ore characteristics, concentrating methods, and the initial target minerals.
- The large amount of mine waste worldwide and the available estimates of the contained total metals in tailings point to a promising potential for recovery of renewable energy metals from these sources. More detailed characterization of the recovery potential from remined sources is needed to gain a more robust understanding of remining potential, to

prioritize wastes for remining, and to understand how the amounts compare to worldwide demand.

Potential benefits and risks of remining

- The potential benefits of remining include increased domestic supply of renewable energy metals; potential to supplement or reduce virgin extraction, including deep sea mining; lowering the acid-generation potential of wastes; cleanup of abandoned mine lands; minimizing wastes remaining on the land surface in perpetuity; improved land and water quality; reduced energy use and emission of greenhouse gases compared to virgin extraction; and potential reuse of water entrained in and overlying tailings impoundments.
- The potential risks of remining include reactivation of pollution from the wastes and releases to air, water, and land; potential for a tailings dam failure for rehandling of wet, slurried tailings in dammed impoundments; using remining as an excuse not to reclaim or close a mine; potential for reopening or adding metal smelters; and the large waste stream remaining after remining is complete. Indigenous and peasant communities are particularly vulnerable because of the proximity of metal extraction projects for renewable energy to their lands and because of the potential for damage to important cultural and spiritual sites.

Approaches for reducing the risks

- Remined materials should be treated as a resource and evaluated in a similar manner as materials for virgin extraction with full transparency. Environmental and Social Impact Assessments (ESIAs) and economic evaluations should be required for all remining operations.
- Engagement with and involvement of stakeholders and rights holders should be initiated as soon as a proposed remining project is discovered. Community acceptance should be required.
- Currently, no best practices exist specifically for remining operations. Best practices for conducting remining operations are needed for baseline (pre-remining) characterization; economic assessment, evaluation of the most effective and safe processing methods; protection of cultural and spiritual uses and sites; environmental, human and ecological health, and worker safety evaluations; community engagement and emergency response; projected water and energy use and greenhouse gas emissions over the life of the project; and financial assurance and bonding. Two known major tailings dam failures have occurred at remining operations, and strict requirements are especially needed for remining that involves the use, handling, or disposal of tailings in wet impoundments.

Major knowledge and research gaps and recommendations for filling

To improve the reliability and understanding of remining resource potential, the following improvements are needed:

- More and better characterization of waste source materials, including mineralogy and metallurgical evaluations such as mineral liberation, as is more bench and pilot-scale testing of processing methods for remined materials
- Better estimates of resources and reserves for mining wastes, based on improved characterization and economic and environmental assessments
- Improvements in sampling approaches, especially for wet tailings

- More work on the potential for extraction of lithium and rare earth elements from mine wastes, especially tailings
- Full circularity examples and plans to evaluate the potential to more fully reclaim and make use of wastes remaining after reprocessing
- Best practices for remining from exploration through final disposal or reused.

To improve transparency and data availability and to understand potential positive and negative consequences of remining, the following improvements and studies are needed:

- More work is needed to predict, understand, and prevent the potential adverse effects of remining on the environment, ecological systems, communities, and workers. Water and energy use and greenhouse gas emissions should be estimated and reported for all remining operations.
- Examining and understanding the potential positive and negative effects of remining on the environment, ecological systems, communities, and workers is a data gap that needs to be filled as remining operations become more common. Although the potential positive effects of remining are often cited in the literature, few studies have attempted to quantify those effects. Careful baseline/background studies are needed to characterize environmental conditions before and after remining occurs.
- Life cycle impact assessments and other studies comparing energy and water use and environmental, social, and economic effects for virgin extraction and remining operations would help understand the advantages and drawbacks of remining.
- Remining should not proceed under the same license or permit used for virgin extraction at the same site. Financial assurance and emergency response plans should be developed in collaboration with local stakeholders and updated regularly.
- Due to the close association between renewable energy projects and Indigenous and peasant communities worldwide, the potential impacts of the remining projects must be evaluated, and free, prior, and informed consent must be gained before projects begin.
- The use of renewable energy sources for remining operations and related transportation will reduce greenhouse gas emissions associated with the projects.
- Adding traceability of metals in mine wastes and created products would allow for credit as “green” metals, if strict criteria are met.
- Improved accountability is needed by using Environmental and Social Impact Statements, NI 43-101 reports, and preliminary economic assessments as public-facing documents with adequate public review.
- The U.S. Toxics Release Inventory (TRI) and other waste or pollution reporting registers have not been designed to collect data for remining. Needed improvements to TRI include identification of the waste sources (e.g., tailings, waste rock) that the metal is contained in; total volume of waste and percent of metals of interest (to allow estimates of grade); basic metallurgical evaluation of wastes, especially mineral liberation and potential processing methods; expanding the TRI list to include lithium; REEs; aluminum, iron, and zinc (as metal releases to land and water); and other metals currently not included that are important for promoting renewable energy.