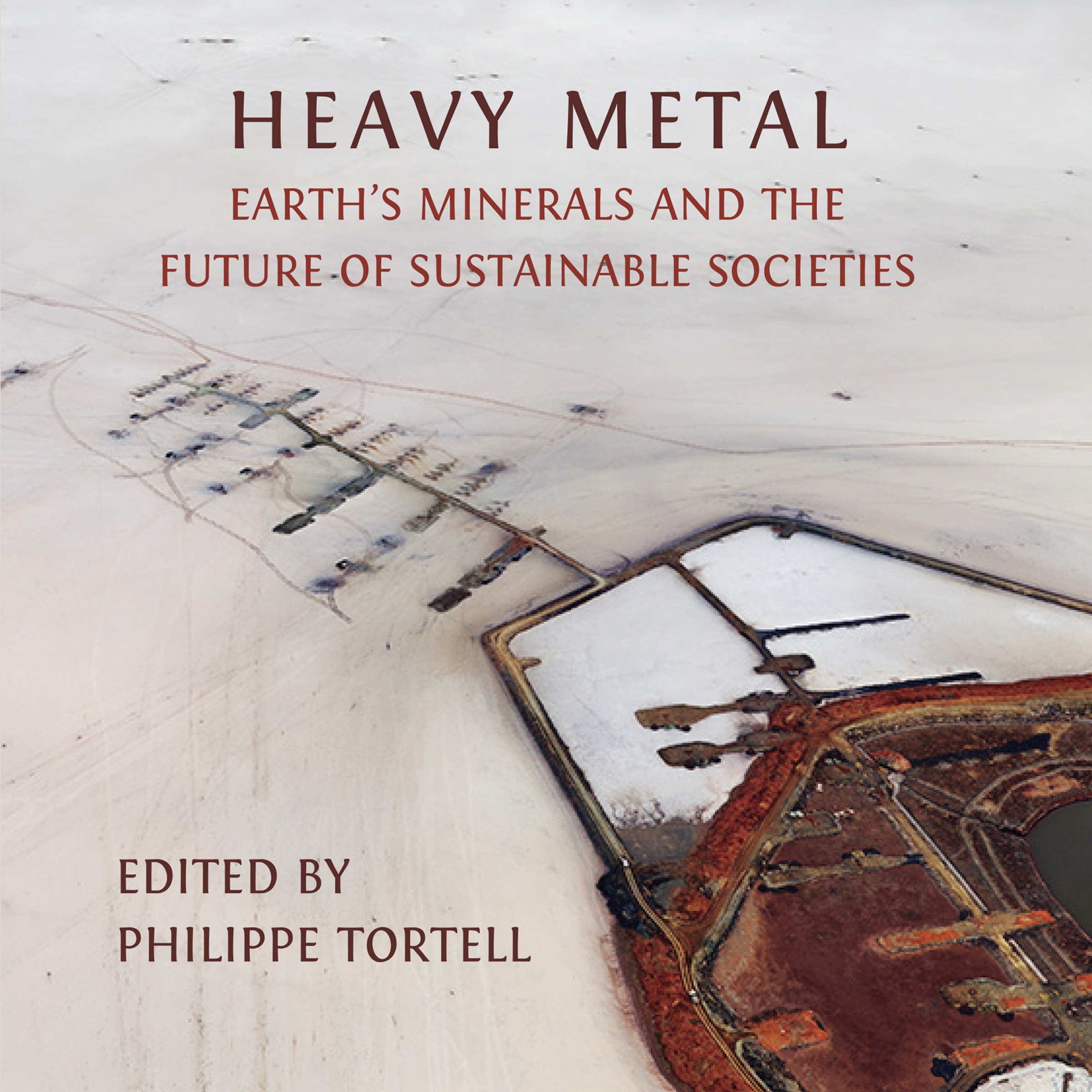

HEAVY METAL

EARTH'S MINERALS AND THE FUTURE OF SUSTAINABLE SOCIETIES

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Digital material and resources associated with this volume are available at https://doi.org/10.11647/OBP.0373#resources

ISBN Paperback: 978-1-78374-956-0
ISBN Hardback: 978-1-78374-958-4
ISBN Digital (PDF): 978-1-80064-977-4
ISBN Digital eBook (EPUB): 978-1-80064-390-1
ISBN HTML: 978-1-80511-043-9

DOI: 10.11647/OBP.0373

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Cover design: Jeevanjot Kaur Nagpal

A Closer Relationship with Our Metals

W. Scott Dunbar and Jocelyn Fraser

Why does society need metals and where do these metals come from? These questions are not likely top of mind for most people. Rather, the existence of metals is taken for granted, their sources unknown, but assumed to be reliable. This perception will be challenged over the coming years as growing metal demands and shifting geopolitics begin to threaten global metal supplies, with significant impacts on standards of living and economic development. In the face of such challenges, society will have to fundamentally alter its relationship with metals.

As a starting point, we need to understand how and why we use metals, and how our needs will evolve. At the most basic level, as income and population grow, so does the demand for metal-containing infrastructure and products—the 'stuff' we accumulate as our standard of living increases.[1] For example, the demand for various machines increases as people with growing incomes seek to do less manual labor. Urbanization and the concentration of populations in cities also increases the demand for metal-intensive transportation systems and other large-scale infrastructure. But the increase in metal consumption with income is not linear and can vary between countries. Assumptions about urbanization, industrial expansion and the corresponding demand for vehicles, electronic products and other equipment can be used to develop scenarios from which estimates of future metal demand can be made. These estimates

https://doi.org/10.11647/OBP.0373.13

vary, depending on the specific assumptions made in different scenarios. What is clear, however, is that the predicted demands are disturbingly large.

One scenario of particular importance is based on the Paris Agreement,[2] a treaty signed by 196 countries aimed at reducing greenhouse gas emissions to limit the global average temperature increase to 1.5°C above the pre-industrial (1880–1900) level. Achieving this target requires a net-zero emissions (NZE) scenario, where all human-derived carbon dioxide (CO2) emissions are matched by CO2 capture and removal from the atmosphere. In the NZE scenario, solar and wind power will have to supply 70% of global electricity demand by 2050.[3] This will lead to significant increases in the demands for several metals, most notably copper, which is a major component in solar and wind power generation technologies, and for the wiring connecting these (and all other) power sources to electrical distribution grids. Clean transportation systems will also increase metal demand. By 2050, the global number of electric vehicles (EVs) is expected to grow to two billion globally,[4] with each vehicle containing forty to eighty kilograms of copper.[5] Between renewable energy systems, electric vehicles and other copper-containing equipment, the copper demand associated with the NZE scenario is expected to be about forty million metric tons per year by 2040,[6] almost double the copper production from mines in 2022.[7] A similar argument can be made for nickel, which is used in solar and wind power systems, and, to a much greater extent, in EV batteries and in hydrogen technologies. By 2040, nickel demand for clean technologies is expected to reach seven million metric tons per year,[8] more than double the global nickel production from all mines in 2022.[9]

The projected metal demands will be exceedingly difficult, if not impossible, to achieve by 2040 within the current metal supply paradigm. Existing mines might be a source of additional supplies, but the concentrations (grades) of metals in these mines are decreasing, meaning that more rock must be extracted to yield the metals of interest. This results in the accumulation of larger amounts of mining waste,[10] with potentially significant environmental impacts. Increased metal demand could be satisfied by developing new mines, but economic factors, geopolitical complexities, together with social and environmental concerns can significantly limit the feasibility of new mining projects.[11] At present, only half of identified mineral resources are successfully turned into mines, and new mining projects typically take ten years or longer to begin operations. An additional consideration is that geology has placed large amounts of metal resources in developing countries that have limited capacity to regulate the social and environmental impacts of large industrial operations. The result is an inequitable global distribution of benefits and harms from mining. Unless transformational changes are made to the way minerals are extracted and metals are produced, issues related to the environmental and social footprints of mining will become unresolvable as demand increases. The problems cannot be easily mitigated, and they are projected to create a significant constraint on metal supply before 2040.

How can we address our metal supply dilemma? One goal would be a fully circular economy, where future metal demand is secured from recycling and reuse of metals.[12] The question is, how do we get there? An approach that has not yet been explored is an innovative change to the global metal supply system. The current system can be represented as an assemblage of mining companies, equipment and service suppliers, metal processors, metal exchanges and traders, and manufacturers and recyclers; each of these plays a distinct and quite separate role in the supply of metals and metal-containing products. Governments, communities and financial institutions also contribute through regulations, and the supply of labor or capital. The current supply system evolved during the early twentieth century to accommodate the metal demands of a rapidly growing global economy. It is rigid, inflexible and cumbersome, based on the extraction of metal from large mineral deposits, and dominated by large corporations with enormous capital resources. Over the past one hundred years, the system has not undergone any notable change, even though the availability and quality of large mineral deposits have decreased significantly around the world. Moreover, the system has created a strong disconnect between society and the metals it requires. Closing this gap is an important first step towards addressing our future metal demands.

In the typical case, mining companies are responsible for extracting primary ore and its initial processing to a concentrate, which is shipped (often over long distances) to smelters and refineries that produce useful forms of the metals that are traded on international markets. The refined metals are then distributed throughout the economy, embedded into all manner of useful products, from cars and cell phones to wind turbines. Once these products reach the end of their life, they are often discarded in landfills, resulting in significant amounts of unrecovered metals.[13] Efforts to extract or recover these metals—like gathering breadcrumbs on a kitchen table—have not been considered economically viable. Soon, however, these 'crumbs', if collected efficiently, will become increasingly important in overall metal supply.

Many opportunities exist along the supply assemblage to access more sources of metal, while also providing economic benefits to more companies, communities, and individuals. Such opportunities can give rise to new businesses that operate alongside the traditional supply assemblage to produce metal that would otherwise be lost. The key to success is actually a form of innovation—finding new points of entry to the metal supply assemblage, identifying and removing barriers to entry, introducing necessary (possibly new) technologies, and organizing more efficient business models.

The concept of a supplier (or a group of suppliers) providing distributed services to mining companies offers several avenues for broader participation in metal supply. Such distributed service providers are already present in the mineral resources industry, particularly in equipment maintenance, and new models of Mining as a Service (MaaS) are under development. In these new economic models, a wide range of suppliers and service providers, both existing and new, become more dominant participants in various stages of metal production, each working in one or more parts of the metal supply assemblage.

Small ore deposits provide one example of an innovative approach to metal supply assemblages. Collectively, these small-scale deposits could provide a significant source of metals, and their limited size leads to a reduced mining footprint. But the ore bodies can be widely dispersed, with variable geometry and mineral properties over short distances, making them difficult to access with conventional mining equipment and techniques. An additional barrier is the perception of financial risk associated with high capital and operating costs relative to the small size (and thus anticipated profits) of the deposits. A novel approach to accessing small deposits involves the use of small-scale mining (SSM), based on mobile and modular machinery for mineral extraction and processing.[14] (These small-scale operations should not be confused with artisanal mining practices, which rely on manual labor with little technology.)[15] The use of mobile and modular equipment provides the flexibility needed to adapt to changes within a small-scale deposit, and the ability to quickly change location. The modular equipment also makes smaller-scale mining operations easier to manage, allowing them to be developed in stages, with options to reduce financial risk.[16] Globally, there are many examples of small-scale mining, but two examples illustrate the importance of flexibility and adaptability in this approach.

Mineco,[17] a company based in the United Kingdom, operates a portfolio of small, underground mines in south-eastern Europe. Each of the deposits is composed of irregularly shaped, high-grade ore bodies containing various metals. These mines produce about 1,000 metric tons per day or less, which is about 10% of the amount extracted from a typical large underground mine. The scale of the mine is small enough to enable almost continuous adaptation to local changes in ore body geometry or geotechnical conditions. Extracted ore is processed locally to produce a mineral concentrate that is shipped to smelters in Europe, where it is refined into a pure metal product.

Vital Metals[18] provides another example of a small-scale, flexible and adaptable operation. The company mined a rare-earth deposit in the Northwest Territories, Canada, generating a metal concentrate from the ore by separating heavy rare-earth minerals from the lighter silicate minerals. The company employed a portable X-ray density separator to sort the material on-site, without the use of water. Mining and operation of the density separator involved members of the local Indigenous community. The concentrate was initially processed at a plant in Saskatchewan, prior to final refining in Norway into rare-earth oxides that were sent to an automotive plant in Germany. The contract terms of the supply chain, from mined ore to a final product, were developed and negotiated by the mining company. The small scale of the mining operation allowed it to adjust and operate in 'switch on-switch off' mode, depending on short-term market requirements. Such flexibility is a hallmark of small-scale mining operations.

Beyond the primary extraction and processing of mineral resources, there are also many opportunities to efficiently recover metals from various waste streams. Mining operations produce huge amounts of waste, in the form of tailings consisting of ground rock and effluent from the processing plant.[19] Tailings from active and 'legacy' mines can contain significant amounts of unrecovered primary metals, with typically higher concentrations in older mine sites where less efficient processing methods were used. The recovery of metal from mining wastes is usually found to be technically and economically unviable. Increasingly, however, improved technologies (including biological methods with bacteria)[20] are being used to extract metals from tailings and wastewater. As an example, waste material (slag) from steelmaking has been found to contain high concentrations of twenty-seven elements typically included in current lists of critical minerals,[21] while coal tailings and coal by-products contain significant amounts of rare-earth elements (REEs).[22] Feasible methods for recovery of metals from these waste streams are under development and could be offered as a service by specialized suppliers, working in partnership with communities, mining companies and manufacturers. This is one example of a creative assemblage of communities and businesses working together to increase metal supply.

End-of-life industrial and consumer products, such as cars, machinery, electronic waste and batteries also contain significant quantities of metals that can be recovered and recycled for further use.[23] However, end-of-life products are typically widely dispersed, and current collection methods are inefficient. In addition, some components of waste products are considered hazardous and subject to transport restrictions from collection points to a processing facility, especially across international boundaries. Contaminants in metal waste also include unwanted non-metallic materials that decrease value and make recovery less economical. One solution is to separate unwanted or hazardous materials from metal waste using combinations of shredding, dismantling and sorting in mobile plants located at or close to collection points. Mobile processing plants,[24] provided as a service, would offer the possibility of minimizing transport of waste and increasing the efficiency of metal recycling systems.

Several methods for recovery of metals from waste have been developed,[25] but separating metals from complex mixtures of materials remains a significant challenge. The organizational and regulatory systems in which metal recycling operates also cause barriers to efficient metal recovery and reuse—the key parts of a circular metal economy. For example, there are no regulations in place to ensure that metal waste is directed to a recycling operation, let alone to an operation that uses the best available technology. Policies to mitigate or remove these barriers are possible and would provide many opportunities for service suppliers who could recover metal from any location where metal waste is produced.[26]

The above examples demonstrate that innovative modifications to the metal supply assemblage can provide more access to the metals needed for the energy transition, while also creating broader opportunities for individuals, communities and businesses to participate in mineral supply. But more effort is needed to take full advantage of these opportunities, which are expected to increase. For example, when renewable energy systems, such as EV batteries and wind turbines, reach the end of their useful life, the metals within them will become available for recycling. Well-crafted policies should recognize and incentivize all types of organizations—national and international, public and private, non-governmental, academic and individual—to contribute their expertise, skills and ideas at the various stages of metal extraction, processing and recovery. Both local and regional initiatives would result, but it must be recognized that what works in one country or region may not work in another and may also change with time. Policies must therefore be flexible to adapt to local conditions and evolve as new opportunities and participants emerge.

Mining companies can play a vital role as owners or supporters of a metal supply assemblage, developing collaborative partnerships with entrepreneurs, innovators, and communities working across the industry.[27] Examples of such a collaborative approach could include joint ownership of mineral processing plants, tailings reprocessing plants or recycling facilities. Companies could also support 'intrapreneurship', where self-motivated employees are incentivized to pursue innovative projects, products or services within the organization. This could lead to spin-off endeavors led by employees with ideas for an alternative metal supply business. Such collaborative innovation sits at the heart of the various national critical mineral strategies,[28] highlighting the need for changes to the current metal supply assemblage.

To maintain economic prosperity and improve standards of living in developing countries, current barriers to entry into the metal supply system (legal, regulatory, financial and technical) must be identified and removed or mitigated. This will provide a path for anyone in society to become more engaged with the metal supply system and contribute to the supply of the metals needed for the energy transition. It is a daunting challenge, but also an exciting opportunity to embrace the social, technological and organizational changes that will transform the way we relate to and interact with metals.

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