Advancing Circularity and Responsibility in Mining: Geosciences for a Sustainable Future

The shift to sustainable energy technologies increases the demand for minerals and requires a more efficient and responsible use of mineral raw materials. Geosciences and minerals engineering are essential in solving these issues. Key areas to focus on include improving processing solutions, enhancing the traceability and recyclability of materials, and promoting design-driven circularity in mining projects. These innovations are essential for responsible stewardship of our finite mineral resources, reducing environmental impacts and securing the supply of critical materials.

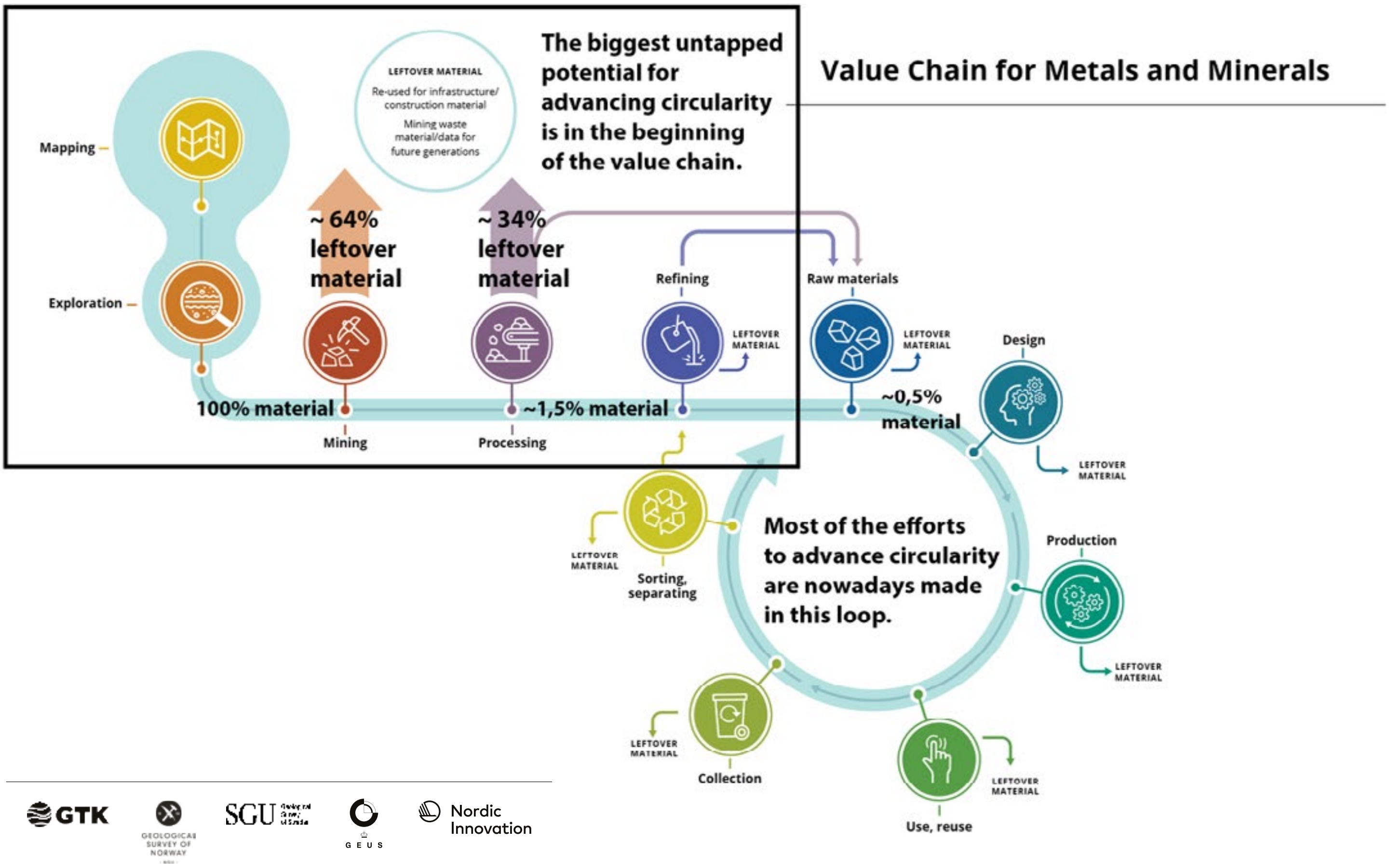
Designing circularity, and tracing minerals and materials

The circular economy of minerals plays a vital role in supporting the global energy transition. This approach involves:

- **Processing solutions:** Developing advanced methods for extracting valuable minerals from the mined materials, waste and industrial byproducts.
- **Traceability and recyclability:** Implementing advanced characterisation and fingerprinting methods to trace the origin of minerals and enhancing the recyclability of secondary materials through increased material knowledge.
- **Design-driven circularity:** Promoting the use of mining waste through innovative project designs and the development of co-products that reduce waste, support sustainability and enhance resource recovery.

By focusing on these areas, the circular economy of minerals can reduce environmental impacts, increase resource efficiency, diversify our sources of materials and contribute to a more responsible mining industry.

GTK research presented in this Policy Brief contributes to these United Nations Sustainable Development Goals



Are we putting our efforts to advance the circular economy in the right place? Of the entire volume of what is mined, only a small percentage enters the product loop. Yet, we concentrate most of our efforts on this part of the value chain. Visualisation of the value chain is a joint effort of GTK, NGU, SGU, GEUS and Nordic Innovation.

Building a sustainable mineral supply for the energy transition

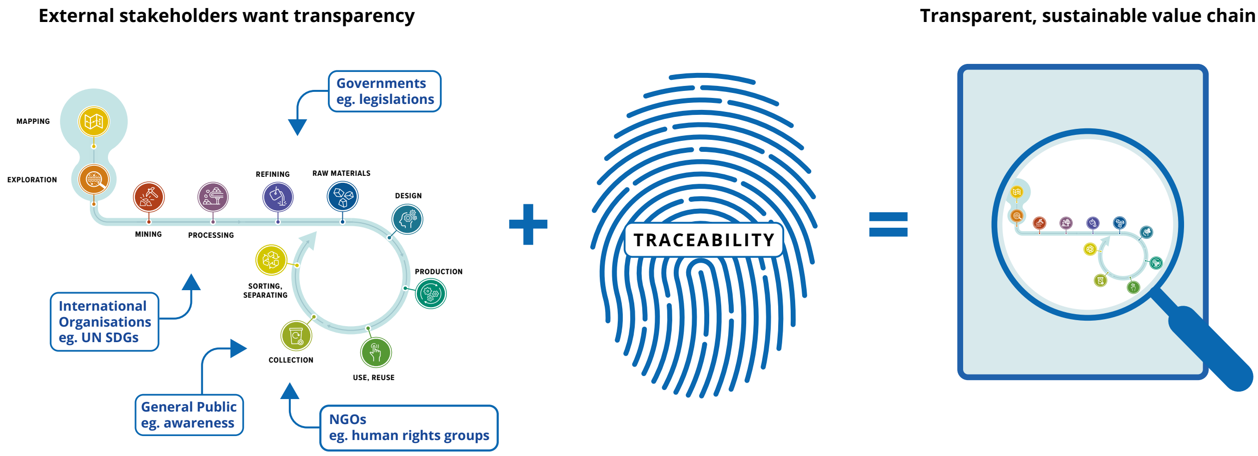
Societies are currently facing the need to phase out fossil fuels and shift into renewable energy production and use. This shift involves minerals-based solutions as new energy technologies require considerable amounts of raw materials including novel technology metals derived from minerals.

This step-change increase in metal demand will be met with an increase in mining production as the increase cannot initially come from recycling alone. At the moment, as little as 33% of the Cu, 31% of the Ni, 26% of the Al, 10% of the Co and 3% of the Li we use are derived from secondary sources. Of the rare earth metals, only around 1% make it to recycling in the first place.

The European Union set ambitious targets for Europe in the Critical Raw Materials Act: by 2030 25% of strategic raw materials should come from recycled materials.

Because the demand for critical raw materials (CRM) increases as we strive to curb climate change, the mining sector faces new challenges in balancing resource extraction with environmental and social responsibilities. The circular economy of minerals seeks to address these challenges by focusing on resource-efficient processing and mining, responsible sourcing and sustainable waste management. This includes using advanced technologies to recover valuable materials from industrial waste and improving recycling methods to reduce dependency on primary mining operations.

A sustainable value chain for metals and minerals needs the transparency that traceability techniques provide



Traceability techniques are the tools to make the metals and minerals value chain transparent. However, making the chain transparent is not enough. We also need mechanisms such as legislation, agreements, and voluntary commitments to ensure sustainability at all steps of the value chain we are tracing.

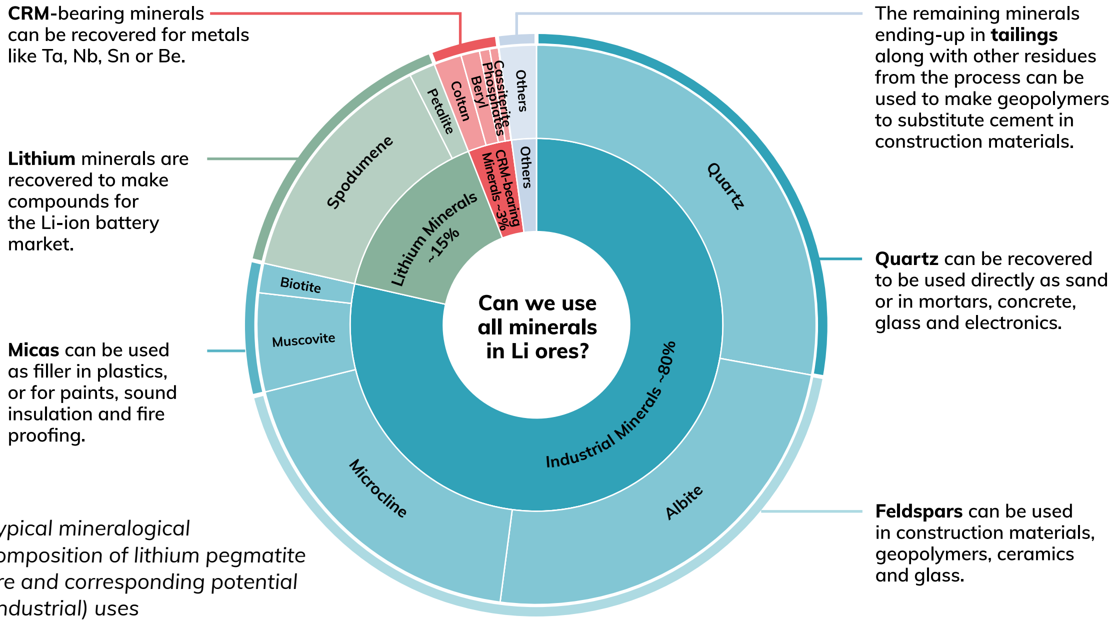
In addition to embracing circularity and producing mineral raw materials responsibly, traceability can be used as a tool for auditing and certification in order to verify sustainability claims. To ensure a material is responsibly sourced and meets the sustainability standards, we must know where it comes from. This is where geo-based fingerprinting of the material has a considerable role to play as a traceability method that complements digital ledger solutions and paper-based approaches. As the geological and elemental characteristics of a sample cannot be falsified, the method has unique potential as a complementary verification method for any certification system.

The current challenges, shortfalls and opportunities in the circular economy of minerals

Mineral deposits are unique, and we only have one chance of mining each deposit. Current mining practices generate significant waste and often fail to fully utilise the available resources. In fact, less than 3% of the rocks mined by metal mines ended up in the saleable mineral concentrates during recent years in Finland. Additionally, the need for traceable, responsibly sourced materials is growing due to increasing environmental regulations; social, environmental and human rights issues in some mineral producing countries; and consumer demand for ethical supply chains.

These challenges present an opportunity to innovate and enhance the sustainability of the mineral sector. The circular economy can help address these issues by improving the recyclability of materials, utilising secondary resources, increasing the co-products recovered in mining projects and developing responsible mining practices that can be traced to the final products and recycling. The design and feasibility assessment phases of new mining projects are crucial here because the economic and technical viability of circular production approaches is more likely when designed into the processes from the start.

Towards zero-waste mining through geometallurgy and advanced process designs: The case of lithium extraction from pegmatites in Finland



Typical mineralogical composition of lithium pegmatite ore and corresponding potential (industrial) uses

The mining of metals from hard-rock deposits has been – and still is – a major source of waste. Lithium is perhaps one the most critical metals for the energy transition. Currently, some of the main sources of lithium are hard-rock deposits such as lithium pegmatites and granites. In this type of deposits, the target minerals can make up to 10 to 20 wt% of the rock. This percentage is more than it is for many other mined metals, but still only a fraction of the processed ore.

At the Geological Survey of Finland (GTK), we are developing advanced processing routes to produce a high quality lithium concentrate and to maximize the use of the ore by recovering as much as possible of the other minerals in the ore into saleable by-products. These include industrial minerals like quartz, feldspar or micas, which can make up 70–80% of the ore, but also critical raw materials (CRM)-bearing minerals (~3%) which allow valorising up to 90% of the ore.

But we do not stop there. Together with partner organisations, we also seek out applications for the remaining residues as construction materials, ceramics or geopolymers. This is made possible thanks to a mineral-centric integrated approach based on increased orebody knowledge via the application of geometallurgy relying on advanced mineral characterisation methods at our Espoo laboratory and the development of new mineral processing flowsheets that can be used to valorise the entire ore into multiple products at our GTK Mintec pilot plant (see other infobox for more details) and processing lab.

GTK Mintec helps design responsible mining projects

GTK Mintec is a unique service provider combining mineral research laboratories with an industrial-scale pilot plant. The facility also includes a GTK SMARTTEST test area for studying the long-term behaviour of tailings and extractive waste.

Located in Outokumpu, the GTK Mintec mineral processing industry pilot plant and research environment offer research and testing services throughout the value chain, ranging from ore deposits to the closing of mines and the reuse of materials. GTK Mintec studies and tests the beneficiation of minerals and mineral-based materials, as well as the recyclability of different types of side streams.

Critical areas of innovation in mineral circularity

Innovations in the following three key areas are crucial for advancing the circular economy of minerals:

Processing solutions. New technologies are needed to extract valuable metals and industrial by-products from increasingly complex (i.e. lower grade) ores and mine waste, with a focus on the materials critical for the energy transition, such as lithium, cobalt and alternative battery materials. In addition, the widespread adoption of circularity in mining projects requires processes that are capable of recovering multiple mineral fractions into separate, marketable products. Many of these will be similar in physical properties and thus difficult to separate. We should explore innovative processing methods, sophisticated analysis tools and sensors, and data-driven approaches to allow the full utilisation of the mined materials.

Traceability and recyclability. The development of geochemical fingerprinting techniques allows the tracking of metals and materials along supply chains, ensuring responsible sourcing and promoting better recycling processes. Understanding the origin of materials and their recyclability is critical in reducing the environmental footprint of mining, refining and manufacturing. Detailed material characterisation with sophisticated techniques can greatly enhance our recycling efforts when employed as a tool in developing waste-based products and new uses for minerals.

Design-driven circularity. Sustainable designs for mining and mineral processing are essential for reducing waste and promoting the reuse of materials. This involves identifying, developing and evaluating potential uses for minerals in the rocks to be mined, placing this information in deposit models for early-stage decision-making and investments in circularity. We need to learn to create and foster industrial ecosystems around mineral deposits, developing data-driven approaches to mining and processing operations that allow circularity, improving the management of water and other material flows at the mine site, creating new minerals-based products and extracting raw materials from other secondary sources.

Towards a circular and responsible mineral industry

Fostering a more sustainable, responsible and circular economy of minerals requires the following actions:

- **Adopt resource stewardship**. A mineral deposit can only be mined once. We must assume responsibility for all the materials we extract from the deposit, maximise sustainable benefits from the minerals we can use today and document the rest of the materials as deposits for future generations.
- **Promote circularity in mining**. Encourage policies that incentivise the co-productisation of the extracted minerals and reuse of mining waste through circular economy models, including the development of new products from waste streams and efficient water management systems.
- **Invest in processing innovation**. Support research and development for advanced processing and separation technologies and the utilisation of sensors and data-enabled approaches in order to recover valuable materials from industrial and mining wastes, tracing the separated streams throughout the processing chain.
- **Enhance traceability**. Establish methods for geochemical fingerprinting, standards and certification schemes to ensure responsible sourcing and improve recyclability across supply chains. Implement material traceability in all product chains and life cycles.
- **Observe circularity in legislative processes**. Resource stewardship and the uniqueness of the mineral sector and the non-renewable but highly recyclable and durable raw materials produced by mining should be observed in all legislative and administrative processes for sustainable outcomes. Legislation should promote comprehensive circularity and resource-efficiency to reduce waste.
- **Collaborate across sectors**. Strengthen partnerships between mineral-producing and mineral-using industry sectors, research institutions and governments to implement circular economy practices, ensuring that innovations in waste reduction and resource recovery are scaled effectively.

Sources and additional information

GTK's research areas, policy briefs and research projects

Circular Economy of Minerals - information and research projects

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GTK research news

- Mining Based on Circular Economy Has Many Advantages – Companies and Research Organisations Are Developing Ways for Its Implementation
- Designing and Testing the Beneficiation Process Is the Most Crucial Step for the Comprehensive Utilisation of Ores and the Safe Management of Tailings
- Study: Reliable Metal Traceability Takes Steps Forward
- Smart Field-Testing Platform and Concept Improves Management of the Long-Term Behaviour of Extractive Waste
- GTK Mintec in Finland is Important for Mineral Processing and Growth in the Circular Economy Globally

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