



Critical raw materials as a driver of Finland's sustainable economic growth

– required measures

VTT, Aalto University and The Geological Survey of Finland (GTK)

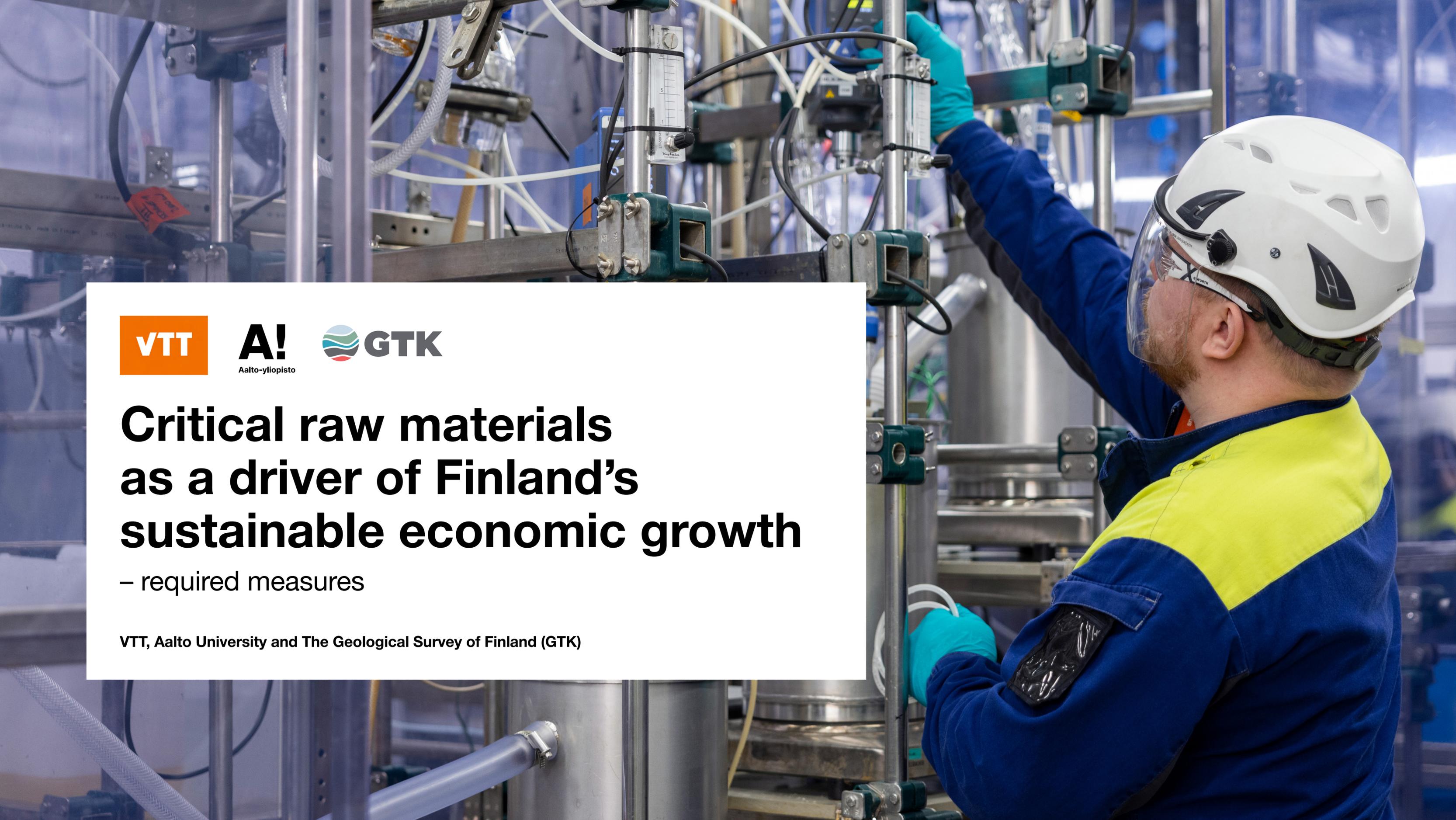


Table of contents

1. Introduction	3
2. Summary	4
3. Strong demand for minerals affects their availability	5
4. Finland's position as a European mineral producer	7
5. Strengthening Finland's competitiveness is essential	8
6. National mineral strategy	9
7. Measures to make Finland a pioneer in the mineral economy	10
Measure 1: Improving the competitiveness of the Finnish mineral sector	11
Measure 2: Cooperation to commercialise mineral-sector innovations	12
Measure 3: Developing multidisciplinary mineral expertise	13
Measure 4: Strengthening Fennoscandian raw-material and resilience cooperation	14
8. Closing Remarks: The need for comprehensive security is growing	15



1. Introduction

VTT, Aalto University and The Geological Survey of Finland (GTK) have prepared practical measures to enable Finland to become a pioneer in mineral economy in the field of critical raw materials, while advancing the national mineral strategy.

The importance of critical minerals for Finland's economic growth and security of supply is increasing rapidly due to the green transition, electrification and the needs of the defence industry. Without nickel, cobalt, lithium and rare-earth elements, batteries and emission-free technologies cannot be produced.

Geopolitical tensions, technological shifts, climate risks and supply chain challenges are no longer exceptions but the new normal. This changing operational environment directly affects the availability of minerals and the self-sufficiency of the European mineral sector, which the EU seeks to strengthen through the Critical Raw Materials Act (CRMA). Evolving legislation influences companies' operations and needs, while also creating new opportunities for technological development.

Finland's mineral sector already boasts strong actors. This provides a solid foundation for the proposed measures to accelerate both the renewal of existing businesses and the creation of new products, start-ups and jobs. Together, these factors will have a direct impact on Finland's economic growth.

Research organisations and companies will play an increasingly central role in strengthening society's comprehensive security. Although Finland holds a strong position as a significant European producer and refiner of minerals, competitiveness and security of supply must be safeguarded in a changing environment. This requires long-term action and bold decisions.

We need innovations and practical steps to improve the resilience of entire value chains: from exploring ores and mining, through processing and refining minerals and metals, to manufacturing, distributing, using and maintaining devices and components, as well as recycling and the utilisation of side streams.

Minerals, metals and industries based on their use form a vital foundation for Europe's comprehensive security, security of supply and Finland's sustainable economic growth. The measures proposed by VTT, Aalto University and GTK strengthen this foundation.

2. Summary

VTT, Aalto University and the Geological Survey of Finland (GTK) have jointly developed practical measures that strengthen Finland's competitiveness and enhance Europe's security of supply and comprehensive security in line with the national mineral strategy.

Technological development in the mineral sector is often slow. New actors, such as small and medium-sized enterprises and startups, are needed for long-term cooperation to ensure new technologies are implemented and effectively integrated into the circular economy. At the same time, education must evolve to meet future skills needs. Therefore, advancing the mineral strategy requires national measures, cooperation, and long-term funding and commitment. The proposed measures are designed to address these needs.

Relevant ministries have an important guiding and enabling role. With proper resourcing, research institutes and universities generate solutions and support their scaling to markets, while also training experts for the mineral sector. International project work brings together commercial and other actors within and outside the EU, creating opportunities particularly for SMEs.

Improving the competitiveness of the Finnish mineral sector

- **Requires:** Producing new geodata, technologies, metals-refining processes and tools for the whole sector.
- **Solution:** A long-term research and innovation programme for the mineral economy and international research activities
- **Benefits:** Strengthening raw-material resilience and competitiveness and promoting development and commercialisation of new innovations.

Developing multidisciplinary mineral expertise

- **Requires:** Strong collaboration between research institutes and companies and combining technologies and expertise.
- **Solution:** Operation of strong technology hubs and utilisation of shared research infrastructures
- **Benefits:** Accelerating development, piloting and commercialisation of new technologies, tools and methods and combining expertise and infrastructures across actors.

Collaboration to commercialise mineral sector innovations

- **Requires:** Strong collaboration between research organisations and companies and combining technologies and expertise.
- **Solution:** Operation of strong technology hubs and utilisation of shared research infrastructures
- **Benefits:** Accelerating development, piloting and commercialisation of new technologies, tools and methods and combining expertise and infrastructures across actors.

Strengthening Fennoscandian raw-materials and resilience cooperation

- **Requires:** Identifying and exploiting regional synergies and cooperation spanning the whole Fennoscandian area.
- **Solution:** A joint synergy study on critical raw materials and a regional preparedness and supply-chain model.
- **Benefits:** Stronger defence-related capabilities and industrial resilience across Fennoscandia. A Nordic reserves database. A strategic whole greater than the sum of its parts.



3. Strong demand for minerals affects their availability

Minerals and the metals they contain are increasingly important in sectors such as energy production and storage, information and communication technologies and defence – sectors that are vital for society’s normal functioning and security.

Emission-free technologies and electrification depend on certain critical raw materials. These include nickel, cobalt and lithium, which are essential for battery manufacturing, as well as rare-earth elements (REEs, permanent magnets). Copper’s role in the green transition is also recognised by its classification as [a critical raw material for the EU](#).

The availability and sufficiency of minerals can be influenced through ore exploration, mining, metal refining, recycling, and by developing technologies for utilising side streams. Product design, extending service life and reducing consumption also play a significant role in ensuring sufficiency.

Demand is expected to grow rapidly

According to the International Energy Agency (IEA), demand for lithium doubled between 2021 and 2023, and climate targets could increase demand up to fortyfold by 2040. This highlights the importance of exploration and mining, and the need to invest in research and development in the sector in the coming years.

The benefits of recycling appear with a delay

Alongside primary production, recycling of metals and the development of substitute materials are central to meeting raw material demand. The IEA notes that recycling particularly reduces pressure on new production of nickel, cobalt, lithium and copper. The challenge is that recycling's positive effects on mineral availability will only become significant after 2040, when materials return to circulation at the end of their use cycles. Therefore, primary production of minerals and metals must also be increased.

Geopolitics challenge availability, and legislation aims to secure self-sufficiency

Production of certain strategic minerals and refined products is concentrated in a few countries, such as China. Undesirable dependencies and rapid growth in raw material demand from the defence sector have made self-sufficiency and supply chain reliability key values and competitiveness factors in industry. Finland's metal refining industry also relies heavily on imported raw materials. In recent years, concentrates valued at approximately €3 billion annually have been imported for refining in Finland.

The EU's Critical Raw Materials Act (CRMA) seeks to reduce dependence on third countries and increase raw material value added within the EU. It sets clear targets for mining, refining and recycling as well as for raising self-sufficiency. It also requires member states to implement national exploration programmes to increase the production and interpretation of geodata.



The EU Critical Raw Materials Act (CRMA) targets for 2030:

- **Mining:** at least 10% of annual EU consumption is produced within the Union
- **Refining:** at least 40% of annual EU consumption is refined within the Union
- **Recycling:** at least 25% of annual EU consumption is covered by recycled materials
- **Limiting dependence:** no more than 65% of any single critical raw material may come from one non-EU country

In addition, the EU Battery Regulation, introduced in 2023, sets requirements for recycling rates for battery materials and for the origin of new battery components. Eight years after entry into force, recycled material must account for at least 16% of the cobalt, 85% of the lead, and 6% of the lithium and nickel used.

4. Finland's position as a European mineral producer

Finland plays an important role as a European producer and refiner of minerals. The country is known for its ability to develop, innovate and apply new technologies to the mineral sector in a sustainable and responsible way.

More than half of global copper is produced using Finnish technology, and approximately 10% of the world's cobalt is refined in Finland. Finnish steel production is vital to the security of supply for energy and transport infrastructure and defence industries.

According to Technology Industries of Finland, electronics and electrical industry, machinery and metal products and metal refining generated a combined turnover of about €75 billion in 2023. Exploration activity is strong, with companies investing €94 million in 2023.

Exploration, mining and refining technologies and products in the mineral value chain present clear opportunities for Finland's economic growth. In the coming decade, strong growth is expected, particularly in the sustainable battery value chain and green steel. Boston Consulting Group has estimated their growth potential at €27–29 billion by 2035.

Competitiveness arises from mineral reserves and high expertise

Finland's bedrock contains reserves of rare-earth elements, lithium, cobalt, copper, nickel and platinum-group metals. Combined with technological expertise in refining, these are significant factors in Finland's competitiveness and the security of supply for Europe.

Finland has strong technological expertise in mining, mineral processing and metal refining, including leaching and separation processes to recover metals from ore or recycled materials, microbe-based bioleaching, precise electrolysis and purification methods and their control through real-time automation and process modelling.

Critical raw materials for the European Union

Primary commodity

- Antimony (Sb)
- Beryllium (Be)
- Phosphate (PO₄)
- Graphite (C)
- Cobalt (Co)
- Copper (Cu)
- Lithium (Li)
- Feldspar
- Nickel (Ni)
- Niobium (Nb)
- Platinum, palladium (Pt, Pd)
- Rare Earth Elements, REE
- Scandium (Sc)
- Titanium (Ti)
- Vanadium (V)
- Tungsten (W)

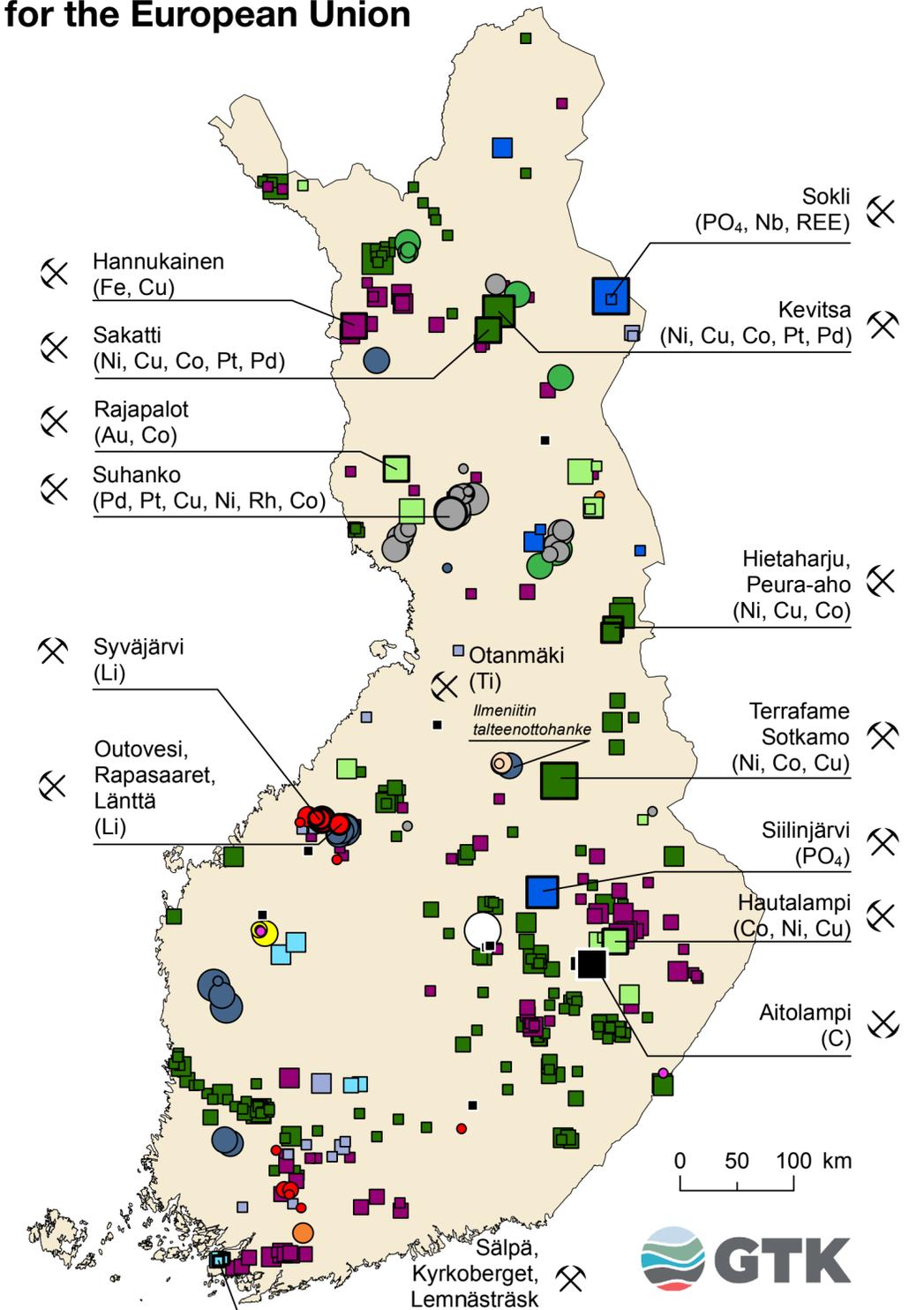
Size of deposit*

- Very large
- Large
- Medium
- Small
- Very small
- Unknown

*Remaining + extracted amount of the commodity

- ⌘ Mine
- ⌘ Mine project
- ⌘ Advanced exploration project

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5. Strengthening Finland's competitiveness is essential

To strengthen competitiveness, Finland must develop domestic value chains, increase the value added of raw materials and promote the development of precious, base and impurity metals from processes and side streams into marketable products.

New kinds of business and new operators, especially small and medium-sized enterprises, are needed to create innovations across the mining and mineral sector value chain. Competitive and innovative use of data related to mineral value chains is also key to development.

We also need more decisive measures to prevent carbon leakage from Europe and the harm of unfair competition. Strengthening demand for sustainably produced European products involves preventing

circumvention of the Carbon Border Adjustment Mechanism and applying anti-dumping duties more readily.

To ensure the success of sustainability-driven investments, the competitive edge of the mineral sector pioneers must be safeguarded. Comprehensive and sustainable use of raw materials benefits future generations. Finnish added value can only be created through sustainable solutions.

Mapping mineral potential and geodata provides a long-term foundation for competitiveness

Securing sustainable domestic raw material reserves and raising self-sufficiency for refining requires continuous identification of new exploitable ore deposits.

Finland has long experience in producing, maintaining and interpreting geodata to support continuity in exploration and mining. Mapping mineral potential is essential, as companies do not carry out this work. The national exploration programme required by CRMA also addresses this need.



6. National mineral strategy

The national mineral strategy launched by the Ministry of Economic Affairs and Employment was completed at the end of 2024. The mineral strategy implements industrial policy in part and supports the development of Finland's strengths.

The strategy highlights nearly 30 measures across different areas. Through cooperation between the research community and industry, it is possible to advance the conceptualisation, development and scaling of new technologies for mineral processing, exploration and mining, as well as the development of new products and information management. The research community also has an important role in education and skills development.

Technological development in the mineral sector is often slow, and companies and other actors are needed for long-term cooperation to ensure new concepts are implemented and effectively integrated into the circular economy. Developing the mineral strategy, therefore, requires national measures, cooperation, long-term funding and commitment.

Relevant ministries have an important guiding and enabling role. With proper resourcing, research institutes and universities generate these solutions, support their scaling to markets and train experts for the sector. International project work also brings together commercial and other actors within and outside the EU, opening discussions particularly for small and medium-sized enterprises.

The mineral strategy identifies measures related to the above objectives:

- Ensuring sufficient mapping of bedrock and mineral potential
- Designing incentives for the adoption of best technologies and circular economy solutions
- Conducting scenario work on future technologies and raw material needs
- Establishing a network for doctoral training in the mineral sector
- Developing new solutions in mineral sector value chains
- Promoting exports and integration of Finnish actors into the international projects
- Exerting influence by participating in international forums and fostering partnerships



7. Measures to make Finland a pioneer in the mineral economy



VTT, Aalto University and The Geological Survey of Finland (GTK) have prepared practical measures to enable Finland to become a future leader in the field of critical raw materials, advancing the national mineral strategy.

In implementing and executing the national mineral strategy, new knowledge and expertise, as well as the utilisation, further development and

scaling of modern technologies, are key. Research institutes and universities play a central role in this implementation.

We propose the following measures:

1. Improving the competitiveness of the Finnish mineral sector

- A long-term research and innovation programme for the mineral economy and international research activities

2. Cooperation to commercialise mineral-sector innovations

- Operation of strong technology hubs and utilisation of shared research infrastructures

3. Developing multidisciplinary mineral expertise

- Establishing a new multidisciplinary doctoral school for critical minerals

4. Strengthening Fennoscandian raw-materials and resilience cooperation

- Developing a joint synergy study on critical raw materials among Fennoscandian countries and a regional preparedness and supply chain model

Measure 1:

Improving the competitiveness of the Finnish mineral sector

Advances in technology have enabled new and more efficient ways of collecting and processing data. This potential should be harnessed to produce new geodata, technologies, processes and tools for the needs of the mineral sector.

Current short-term campaigns are insufficient to support renewal in the sector, including developing expertise, geodata collection and interpretation, digital capabilities and method development, practical solution development across value chains and scaling technology to the market.

The research and innovation programme should be structured so that participating companies can benefit from R&D tax deductions. Funding should enable EU Innovation Action-type development work at the national level. Business Finland's funding criteria should include the possibility of making project decisions based not only on export potential but also on indicators of self-sufficiency and waste-free or circular economy practices.

Without a long-term research and innovation programme, many innovations critical for the future will not emerge. At the same time, research institutes and universities see the need to develop their own expertise, approaches, tools and processes to address challenges related to sustainability, responsibility and value creation, ensuring they are available to society when needed and in demand.

Long-term research and development of the mineral sector have immense national value

By harnessing new technologies such as artificial intelligence and utilising data, development work can be accelerated, new opportunities created and competitive advantage generated in the market. Conducting sustainability and ethical assessments alongside development work enables well-directed ore exploration, mining, beneficiation, refining and process and product design.

For example, increasingly precise geometallurgical data makes it possible to optimise exploration and mining throughout the value chain, from prospecting to metal recycling. Furthermore, by combining computational and experimental methods, it is possible to identify new optimised process solutions for the material and energy-efficient utilisation of mineral raw materials and recycled raw materials. Integrating computational materials science, data analytics, artificial intelligence and experimental materials technology makes it possible to design, for instance, data-driven material solutions to replace critical raw materials.



Measure 2:

Cooperation to commercialise mineral-sector innovations

Technology hubs provide a platform for commercialising research results and creating new business, as they enable the integration of technologies and expertise in new ways and accelerate the development cycle to market.

We propose funding technology hub operations and shared research equipment at a sufficient level so they can be utilised meaningfully and support the scaling of technologies to market. At the same time, it is important to promote collaboration between students and companies, for which technology hubs offer excellent channels.

Technology hubs are research, piloting and demonstration platforms and infrastructures that have been extensively developed in recent years, partly with public funding (Academy of Finland and Business Finland). Technology hubs often represent the forefront of digitalisation, enabling the collection of up-to-date and diverse data on the phenomena, devices and processes under study, as well as interconnections between technologies.

It is in society's interest that high-level equipment is used as efficiently and widely as possible in shared use. This increases, in particular, the opportunities for SMEs to develop technologies from laboratory scale to demonstrations and piloting.



Measure 3:

Developing multidisciplinary mineral expertise

The availability of a skilled workforce is essential for the sector's competitiveness and for attracting investment to Finland. According to Technology Industries of Finland (TIF), up to 74% of the technology industry's need for skilled workers is focused on those with higher education.

We propose meeting future needs through a multidisciplinary doctoral school for critical minerals, covering the entire value chain of the mineral economy. In addition, every researcher in the doctoral school should be trained in strong data and artificial intelligence capabilities.

The research fields of the multidisciplinary doctoral school would span the entire value chain, from geodata management, exploration and mining to mineral beneficiation technologies, metallurgical refining and metal production and processing. Research is also needed on the utilisation of metal-containing side streams as well as on assessing the environmental impacts of existing and new processes.



New-generation experts are building a sustainable raw materials sector for the digital age

In the future, value creation in the resource-intensive raw materials sector will rely increasingly on new sustainable solutions, digitalisation and the integration of technologies. To maintain Finland's competitiveness, we need highly educated professionals who can flexibly combine knowledge and disciplines.

Education can meet future needs by further strengthening the foundation of basic scientific expertise, linking teaching to societal sustainability and interdisciplinarity and providing opportunities for practical application already during studies. Education should promote data and artificial intelligence skills, as the digitalisation of processes and the intelligent utilisation of process flows across value chains play a decisive role in developing the mineral sector.

For example, comprehensive and system-level modelling and analysis of material flows can optimise the utilisation of mineral raw material resources. In addition, through AI development, the innovative use of data in the mineral industry can be enhanced, laying the foundation for new industrial process and product innovations.

Measure 4:

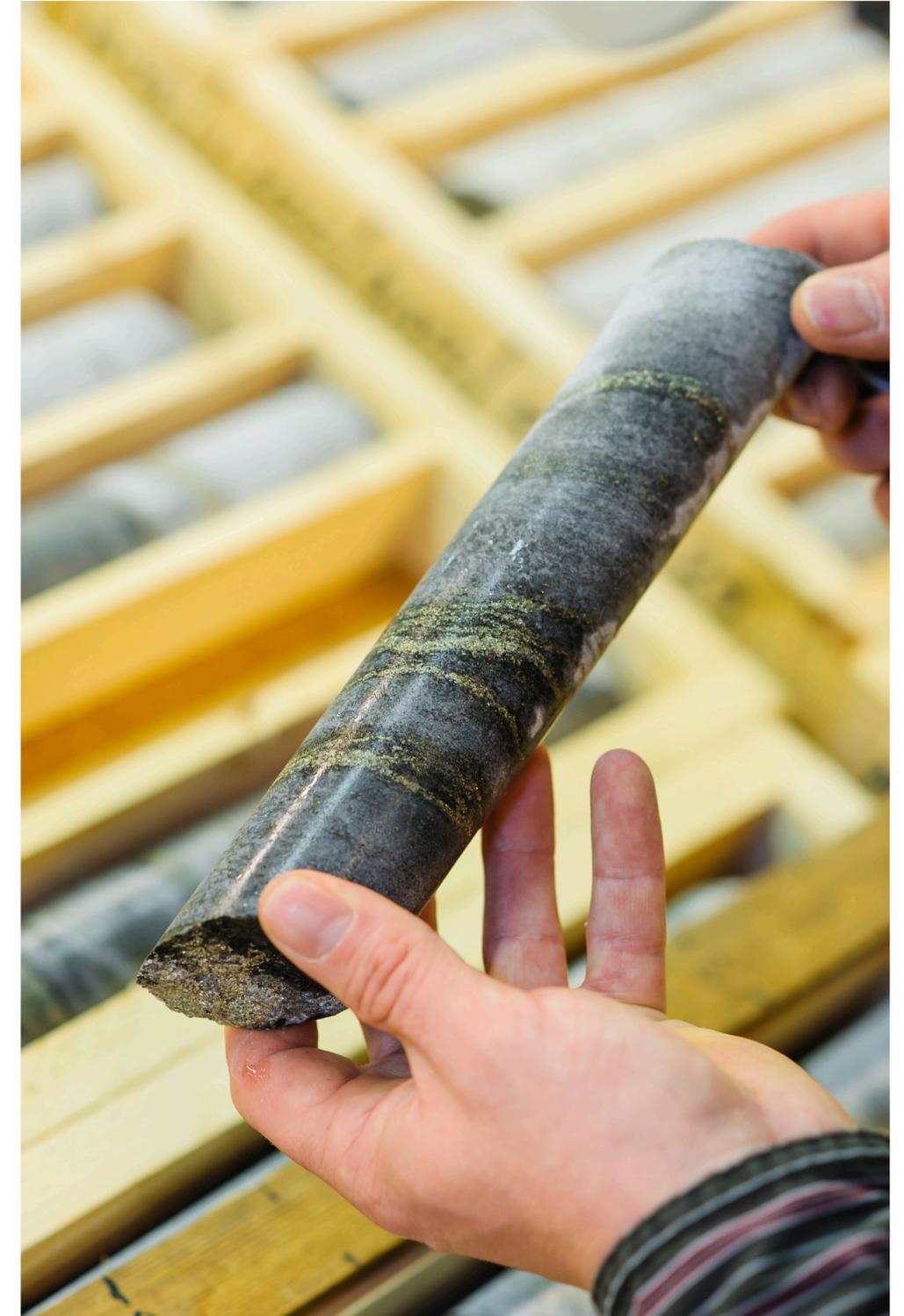
Strengthening Fennoscandian raw-material and resilience cooperation

The Fennoscandian countries (Finland, Sweden and Norway) together form an exceptional strategic resource, where raw material reserves, mineral potential, industrial value chains, energy infrastructure and technological expertise complement each other throughout the entire value chain.

We propose developing a joint synergy study on critical raw materials and a regional preparedness and supply chain model. In addition, we will continue building a shared database of Nordic primary and secondary reserves.

By deepening cooperation between the countries, it is possible to leverage significant regional synergies, strengthen resilience against both short-term supply disruptions and prolonged interruptions and create new business opportunities. Fennoscandia-wide collaboration enables scaling in recycling and refining technology development that individual countries cannot achieve alone.

From the perspective of Europe's key objectives – strengthening defence capabilities and industrial resilience – Fennoscandia forms a compact region that benefits from long-term preparedness and operational capacity based on shared values and NATO membership. The government and the Ministry of Economic Affairs and Employment are responsible for the study and the development of the preparedness and supply chain model. Projects that strengthen cooperation are funded, for example, through Business Finland.

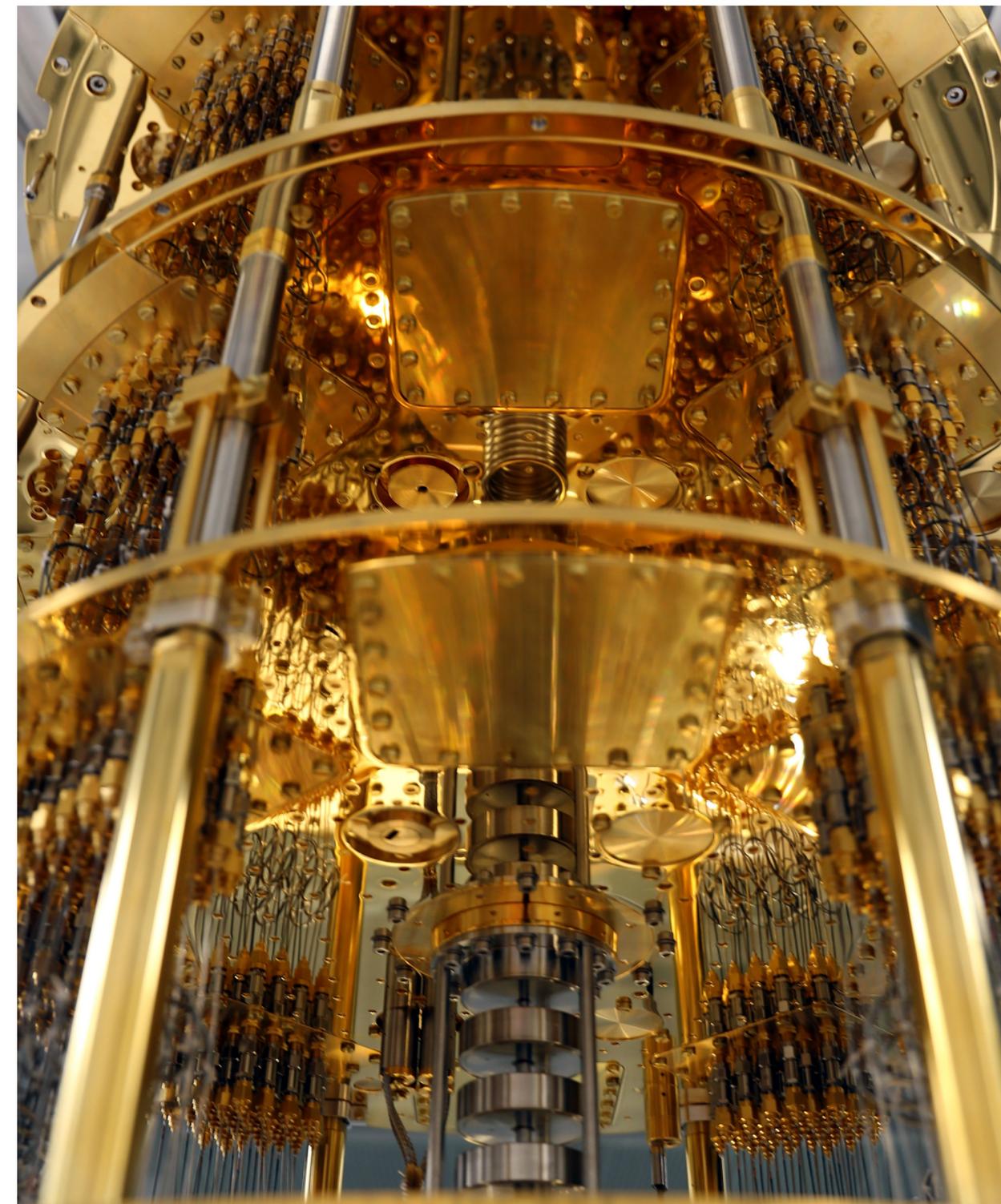


8. Closing Remarks: The need for comprehensive security is growing

Now is the right time to act. Amid geopolitical uncertainty, technological disruptions and climate risks, we need determined decisions that strengthen resilience across the entire value chain and secure Finland's position as a leader in security and sustainable growth.

We invite decision-makers and companies to work together to build new expertise and invest in research, innovation and broad-based collaboration. By strategically focusing on the mineral and metal sector and deepening cooperation among Fennoscandian countries, we can ensure that Finnish expertise supports not only society's comprehensive security but also a vibrant industry and future jobs.

Let us make Finland a success story of a responsible and sustainable value chain that endures crises and strengthens our shared future.





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