ETP SMR Strategic Research and Innovation Agenda

European Technology Platform
on Sustainable Mineral Resources

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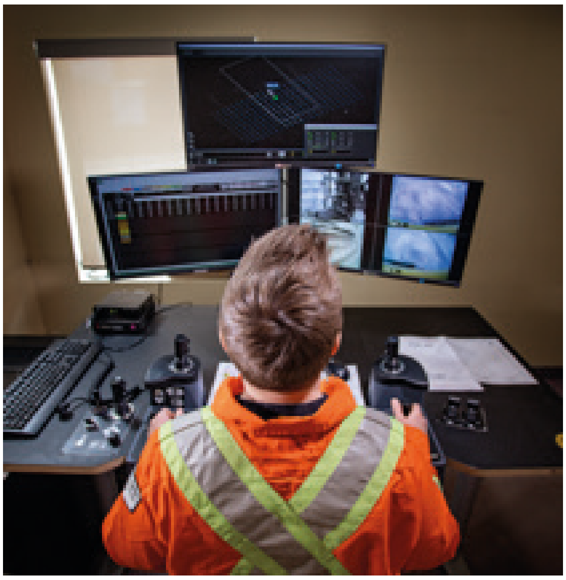

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FOREWORD

Overcoming the great socio-economic challenges of our time, such as access to clean energy, mobility, digital transition as well as securing raw materials for emerging technologies in an environment of increasing global competition requires secure supply chains and a strong European raw materials sector. Answering such challenges requires innovative solutions based on sustainable materials resources, the core ambition of the European Technology Platform on Sustainable Minerals Resources (ETP SMR).

Officially recognized by the European Commission in 2008, ETP SMR successfully combines interdisciplinarity and deep commitment from its members. Its significance is underlined by the increasing political and strategic importance placed on the development of secure and sustainable raw materials supply. ETP SMR aims to build education, research, and innovation to form the basis of economically successful, self-confident, independent actions that are committed to sustainability for our future raw material supply through this Strategic Research and Innovation Agenda (SRIA).

This SRIA supports a number of key areas in line with European Commission priorities for achieving the overarching socio-economic transition goals and technological leadership affecting the raw materials sector:

- Raising the competitiveness of the European Raw Materials Sector through innovation.
- Stimulating the commercialization of research results.
- Improving self-sufficiency in European raw materials supply.
- Enabling supply chain diversification through deployment of new technologies.
- Gaining industrial and technological leadership in core segments of the raw materials value chain.
- Raising resource and energy efficiency.
- Strengthening the mineral resource research and innovation sector from its existing small, fragmented base.
- Updating and expanding the knowledge base.
- Maintaining and strengthening university research, education, and training.
- Increasing the attractiveness of jobs in the raw materials sector and securing skilled workers.
- Raising awareness of raw materials and supporting research and development in school education.
- Maintaining natural sciences as a priority subject in curricula.

This SRIA outlines key areas of action which the ETP SMR believes should be included in the design of future European and national research programmes. The Strategic Ambitions within the SRIA are the result of a collaborative process conducted with our stakeholders, defining specific needs for action in relation to research and innovation. These ambitions also aim at increasing raw materials awareness within society, academia, industry, and policy.

ETP SMR Executive Committee,
Brussels, November 2023

EXECUTIVE SUMMARY

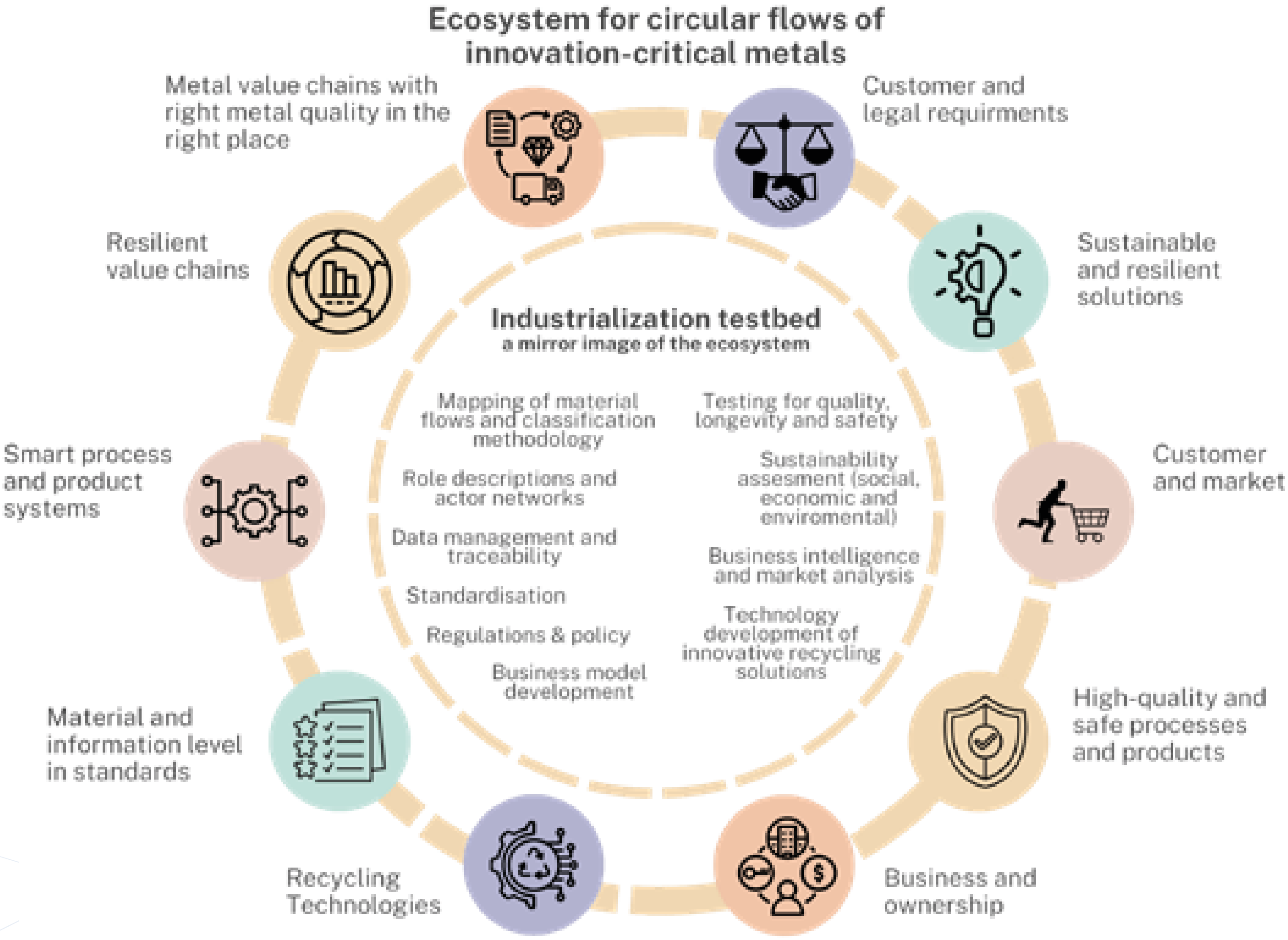
In the wake of decades of declining exploration and mining activity on the continent, Europe's minerals and metals raw materials research and innovation community has suffered from low funding and loss of talent abroad, leaving the European knowledge base fragmented and ill able to support a strong European raw materials sector. EU-funding, through Horizon 2020, Horizon Europe, EIT Raw Materials, and ERA-MIN, has been fundamental to start the journey, but must be scaled up dramatically if the European Union wants to increase its self-sufficiency in raw materials. The resulting vulnerability of the EU's raw materials supply chains have been starkly revealed in recent years, particularly in the wake of the energy crisis and the Russian war of aggression on Ukraine. In response, the EU has built a powerhouse of Green Deal policy and supporting legislation, including the Critical Raw Materials (CRM) Act. The research and innovation actions implemented to support this Act will be crucial in rebuilding strength in Europe's ability to retake a position as a global leader in mineral and metals raw materials research, technology, and innovation to support industry and to pave the way for meeting the ambitions of the Green Deal. To facilitate the change needed, an ecosystem perspective will be required also from a research point of view, as well as innovation support on a system level.

Here we outline the Strategic Research and Innovation Agenda (SRIA) of the European Technology Platform for Sustainable Mineral Resources (ETP SMR) a consortium spanning industry, academia, and government organisations, all active in mineral raw materials research and innovation. Through this SRIA, ETP SMR will contribute by defining the way to securing the supply of primary and secondary mineral raw materials and adapting mineral products to the needs of the EU, strengthening the supply chain, and fostering resource efficiency, while addressing related environmental and social impacts. ETP-SMR aligns with the EU vision on the definition of raw materials, which encompasses all parts of the raw materials value chain (including recycling).

By 2040, our vision is a European minerals and metals industry that is recognised as instrumental in achieving European climate targets as the backbone of the EU's industrial ecosystem and a fundamental component of the circular economy. Europe's mineral resources knowledge base will be strengthened, along with the ability to efficiently extract and refine metals including CRMs. The European mineral and metals industry will be recognised as an attractive and safe employment sector, a global leader in technological development, automation, digitalization, and minimisation of environmental and climate impact, giving Europe a market edge. A rebuilt minerals and metals research and innovation sector, has in turn supported new vigour into the education sector, with strong collaborations between industry, academia, and governments. These strong collaborations have led to an ecosystem in which sound raw materials policy is informed by high quality science.

To reach the ambitious targets set for Europe´s increased self-sustainability, a systemic shift is needed along with a new ecosystem focus on sustainability, circularity, and resilience. The full effect of the actions taken within each of the domains shown in the next picture and described below, will only be achieved when working on them in an integrated way (e.g., resource efficiency, environment, and social acceptance benefit from characterization and utilization plans, also for the expected waste streams, already in the exploration, resource characterisation, feasibility study, and permitting phases). An ecosystem perspective thus integrates other dimensions than technology and processes, such as infrastructure, business models, culture, behaviour, work routines, regulations, standards, and policy. This includes aspects such as technologies for traceability and information exchange, sustainability assessment, and material flow and value-chain analysis. In addition, test and demonstration environments to increase TRL and MRL could be an efficient instrument to catalyse technical innovations, from idea to market.

Left picture credit: Istock



Ecosystem for critical raw materials.

The ETP SMR's strategic ambitions for research and innovation in the raw materials sector will be key to the EU reaching the raw materials benchmarks of the CRM Act—crucial in the short to medium term to implement the Green Deal and meet its strategic goals in building resilience in raw material supply chains.

By 2040, ETP SMR has the following strategic ambitions

ETP SMR strategic ambitions (Credits: terratec, Nickelhütte Aue, GKZ Freiberg and EPIROC)

Exploration and resource characterisation: Knowledge of Europe's mineral potential is significantly improved, attracting exploration investment. There is a high level of social acceptance for exploration and mining. Integration of geodata is improved and predictive mineral potential maps indicate new target areas. Improved exploration technologies lead to new discoveries of deep deposits and deep sea and extraterrestrial exploration are under development. Improved drilling technologies increase efficiency and reduce costs. Research, national programmes, and exploration results are gathered in national and European databases and support new studies, policy decisions, and attract further investments in exploration and mining.

Mining. The majority of mining and quarrying operations are climate-neutral. Increased knowledge has improved ore recovery and minimized waste. Interoperability and improved systems and system integration enable process optimization, mining efficiency and their interlinks upstream and downstream. Autonomous and manual machines interact efficiently. The industry is regarded as high-tech and safe, with high climate and environmental standards, attracting talented personnel and increasing social acceptance. World-class European mining technology is exported worldwide.

Mineral processing. Resource and energy efficiency is significantly improved. New or improved processing techniques reduce losses. Smart and intelligent process design optimizes comminution and separation processes, while reducing mill wear. Environmental footprint is minimized, including reduced emissions to air, land, and water. Processing residues are valorised in the construction material industry.

Metallurgy/ Metals recovery and recycling. Europe's metal extraction and refining capacity have increased, reducing vulnerability to international trade disturbances. Sustainable, resource-efficient, carbon-neutral technologies increase ore yields, and technology has been implemented to extract additional elements from material processing streams. New technical solutions result in metals recovered and refined from secondary resources including mining waste, waste streams from other industries, and electronic scrap. The industry is moving toward a vision of "zero waste".

Decarbonization of operations in highly intensive process chains. In mining and processing as well as in refining and recycling, greenhouse gases have been reduced in line with the Glasgow Climate Pact by raising operational efficiency, electrification, and renewable-energy use and by introduction of new kiln technology and optimization of electrolysis processes. The cement industry has commissioned larger installations of carbon capture and storage (CCS) in Europe. The EU taxonomy has raised capital investments to achieve most of the decarbonization potential, as well as competitiveness and acceptance of the European Raw Materials sector.

Forecast and substitution of raw materials. Material substitution has substantially reduced CRM and SRM product criticality, contributing to mass reduction, enhanced durability, and reduced machining/process time at a cheaper raw materials price. Substitution of cement constituents and replacement of limestone by non-carbonate bound calcium have significantly reduced CO_2 emissions from cement production. Novel anodes and cathode materials from European research and development and commercialization have sustainably increased the competitiveness of European battery manufacturers. European smelters have made important technology leaps, contributing to the raw material security of CRMs and SRMs.

Environmental performance. The environmental and climate impact of the industry, throughout the value chain, has substantially decreased. The EU has been a forerunner in implementing climate neutral technologies. Mining technologies are climate-neutral, and subsequent mineral processing is well on its way to climate neutrality and fossil-free energy use by 2045. Waste has been substantially reduced and environmental monitoring shows little or no impact from existing or closed mine sites and facilities. Open pit mine sites experience a renewal of biodiversity, and the industry actively works towards reducing and compensating biodiversity impacts and restoring habitats with the aim of reaching a net-positive biodiversity impact of mineral and metal production.

Social performance. The industry is widely accepted as a key enabler for the energy transition and the path to a climate neutral society. Tools to integrate stakeholders have been developed and are widely used to build Social License to Operate. The industry is regarded as an attractive workplace, at the forefront of new technology and sustainability.

Raw Materials policy and monitoring. Implementation of the CRM Act has significantly increased knowledge of European mineral potential, attracting investment and boosting research and innovation. Member State mineral strategies support a pan-European strategic direction for Raw Materials policy, high industry standards, and increased social acceptance. A sustainable Geological Service for Europe and a well-developed mineral and metals research and innovation community provides ongoing strong science-informed policy support.

Global partnerships. The EU will provide strengthened support for international collaboration with the EU research and innovation community, including in relation to EU bilateral strategic partnerships. These international partnerships will strengthen EU's international strategic relationships, and boost ESG standards, and commercialisation of innovation, building resilience in the EU raw materials supply chain.

1. INTRODUCTION

1.1 ETP SMR – a member of the European Technology Platforms

1.1.1 Origin, development and aim

European Technology Platforms (ETP) were the first type of public-priva te partnership established in the research field at European level. These industry-led stakeholders' fora define and implement a SRIA aimed at aligning research priorities in a technological area. The overall aim in establishing the ETPs was to create a European Research Area (ERA). The ERA concept is based on the idea that a gain in efficiency can be obtained if isolated national research systems become more interoperable, allowing for better flows of knowledge, technology, and people, creating a more integrated European system for research. The European Council's 2015 publication of an 'ERA Roadmap' aimed to increase Member State participation, as Member States were expected to implement the necessary reforms to establish the ERA but were considered to have been the least involved partners at that time. The activities developed at European level under the ERA concept led to more national research system integration, coordination, and interoperability in Europe, especially in relation to research infrastructures, researchers' careers and mobility, joint programming of research programmes, and public-private partnerships.

A total of 38 ETPs have been established. Being non-profit, autonomous organizations without dedicated funding, ETPs remain coordination and advisory structures, helping to define the topics of research programmes at European, national and regional level. ETPs bring together the main stakeholders—e.g., research organisations, industry, regulators, user groups—around key technologies, to devise and implement common strategy for their development, deployment, and use. Their objective is to provide major research and technological advances in strategically important areas, strengthening European industrial competitiveness and economic growth. ETPs also aim at creating pan-European partnerships to tackle complex and large-scale technological issues. ETPs have successfully contributed to creating and implementing the European Innovation Partnerships and assisted the establishment of the European industrial initiatives under the strategic energy technology plan (SET-P). The ETPs were also key to developing lead market initiatives in 2007 and to providing input in the preparation of the European Strategy Forum on Research Infrastructures roadmap.

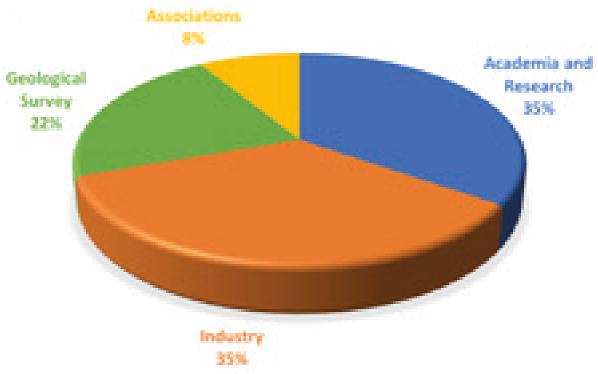
The main role of the ETPs lies in the capacity of their SRIA to influence research and innovation programmes at EU, national, and regional levels, having been jointly developed and regularly updated by private and public actors at EU level. The advisory role of the SRIA was integrated in the regulation of the priority-setting for the previous two European Research Programmes (FP7 and Horizon 2020). In this context, the ETPs are an important integral instrument alongside other institutional public-private-partnerships, such as the Joint Technology Initiatives or the contractual public-private partnerships1. The ETP SMR is a living platform which embraces manifold member activities in Brussels and in the regions as a Europe of the Regions. The regionalization of the platform aims at achieving increased synergies by taking advantage of the EU cohesion policy and Member States' national and regional raw materials policy and funding schemes.

1. https://www.europarl.europa.eu/RegData/etudes/ATAG/2017/603937/EPRS_ATA(2017)603937_EN.pdf

Left picture credit: Boliden

1.1.2 Target groups

The ETP SMR assembles and targets stakeholders from the minerals industry and metallurgy, as well as related technology and machinery providers, the research community, regulators, consumers, associations, and civil society, centred around the major technological challenges to the minerals and metals raw materials sector. It comprises a strong network of experts who facilitate exchange of knowledge, proficiency, good practices, and lessons gained from many perspectives and areas of the raw materials sector, including public and private organisations.



ETP SMR members by stakeholder group (%).

1.1.3 Objectives

The objectives of the ETP SMR are aimed at meeting future demands and sustainable development goals by helping to increase and secure the supply of primary and secondary mineral resources, adapting mineral products to the needs of the EU economy, while dealing with related environmental and social impacts along the supply chain and fostering resource efficiency. The ETP SMRs´ objectives are to:

- Provide coherent business-focused analysis of research and innovation bottlenecks and opportunities related to societal challenges (strategic function).
- Mobilise and network innovation actors within the EU (mobilisation function).
- Share information and enable knowledge transfer (dissemination function).
- Encourage industry participation in EU research and innovation actions.
- Identify opportunities for international cooperation.
- Provide networking activities to address cross-sectoral challenges and facilitate new partnerships.

1.1.4 Commitment and Challenges

The ETP SMR is committed to the United Nations' 2030 Agenda and the European Commission's annual work programmes, which integrate the Sustainable Development Goals (SDGs) of the 2030 Agenda. In reference to the Report "Mapping Mining to the SDG: An Atlas", (prepared jointly by the United Nations Development Programme, the World Economic Forum, the Columbia Center on Sustainable Investments and the Sustainable Development Solutions Network), the platform complies with recommendations on the contribution of mining to the achievement of the SDGs.

Major Issue Areas for Mining and SGGs (Report "Mapping Mining to the SDG: An Atlas, 2016")

The most important current European economic policies for the ETP SMR are the European Green Deal, the EU Action Plan on Critical Raw Materials and the EU CRM Act.

Climate change and environmental degradation are a threat to our way of life in Europe and globally. To overcome these challenges, the European Green Deal will transform the EU into a modern, resource-efficient, and competitive economy, ensuring:

• No net emissions of greenhouse gases by 2050

• Economic growth decoupled from resource use

• No person and no place left behind

The Action Plan on CRMs addresses current and future challenges and proposes actions to reduce Europe's dependency on third countries. To achieve this, it proposes diversifying supply from both primary and secondary sources, improving resource efficiency and circularity, while promoting responsible sourcing worldwide. It aims to foster Europe's transition towards a green and digital economy and, at the same time, bolster Europe's resilience and open strategic autonomy in key technologies needed for such transition. The CRM Act takes this further in setting benchmarks for domestic extraction, processing, recycling, and limiting the extent of strategic raw material sourcing from single third countries, while also requiring Member States to conduct additional exploration and assessments of Europe's primary and secondary raw materials potential and streamline permitting.

The minerals and metals raw materials sector plays a crucial role in the implementation of this policy agenda, especially in accomplishing the major energy, mobility, and digitalisation transition processes, which are the greatest societal and economic challenges for Europe in the near- and mid-term. Overcoming these challenges and achieving leadership in emerging key technologies requires a highly competitive industry and a strong research base along the entire value chain, from upstream (exploration, extraction, processing) to downstream (refining, metallurgy/recycling). This will require a steady enhancement of research and a profound commercialization of research results in Europe of a new quality that finds its expression in the "Made in Europe" brand.

The enormous speed of development and market integration of emerging technologies as well as geopolitical developments determining Europe's economic policy have produced new challenges regarding sourcing and supply security. As a consequence, raw materials replacement (substitution), resource efficiency, and valorisation of domestic resources have raised the research and innovation demand in Europe. At the same time EU regulation and other industrial policies (such as REACH / ECHA Directives , Water Framework Directive, Corporate Sustainability Reporting, Supply-Chain-Act) and overregulation provoke challenges hindering industrial investment in European research and production. In this respect, research and innovation are always relevant in the political arena. It is therefore important—and a key focus of the ETP SMR—that research and innovation always have the best possible framework conditions in Europe.

1.1.5 Vision

The vision of the ETP SMR is to substantially meet the challenges in the given socio-economic transition processes and to meet the benchmarks of the CRM Act. Furthermore, to seek industrial and technological leadership and business field enlargement as preconditions and results of the transition, such as in resource efficiency, decarbonization, lowering exploration and mining costs, electricity storage and supply, to name only a few examples. This vision also encompasses further development of metallurgy as a key enabler in circular economy. The following basic principles are connected with this vision as conditions for its feasibility:

- Research and innovation in the raw materials sector are an ongoing focus of the political level of action and are taken into account in the budget of the EU and its Member States.
- Research and innovation are being carried out under competitive framework conditions.
- Examination of technological developments in the raw materials sector is performed free of ideology and based on facts.
- Technology development and production expansion are economically viable and socio-economically acceptable.
- There is a strong raw material awareness amongst political decision-makers.
- Academic research as well as industrial research are highly valued, have an international reputation, and are of high quality.
- Public and private research go hand in hand to benefit European society.

1.2 European Framework Conditions

1.2.1 Outlook and demand for action

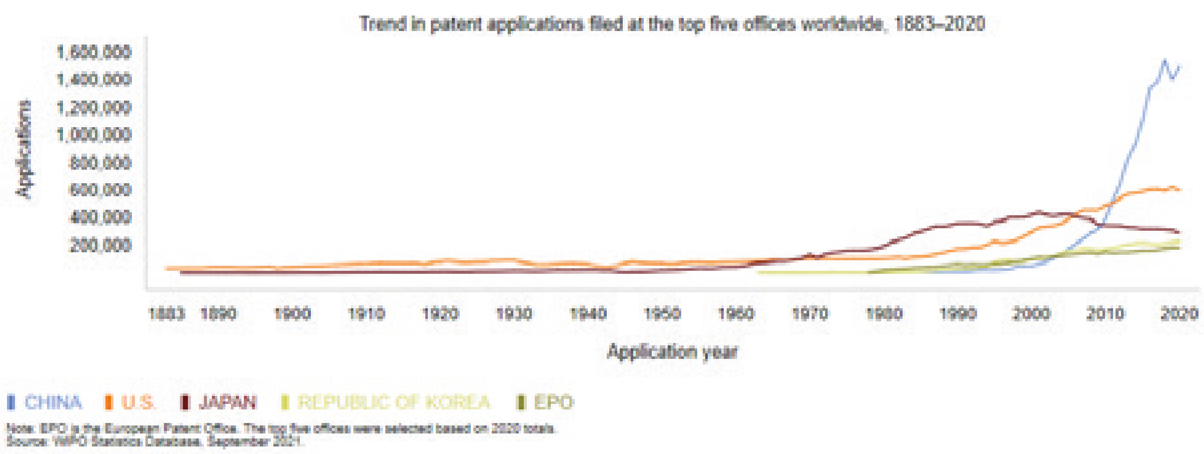
Achieving the UN Sustainable Development Goals by 2030 requires efficient, united, and rapid implementation of the European Green Deal agenda and a smart implementation of the measures contained within the EU CRM Act. European politics and the implementation of consequent legislation in the Member States interacts with global developments that also influence the framework conditions for research and innovation.

Dramatic increases in primary consumption of raw materials are being driven by increasing prosperity in the most populous countries and global climate protection, with its socio-economic transition processes and technological leaps. In addition, the importance of circular value creation will increase, and neo-ecology in particular will require new consumer behaviour. But Europe is in danger of being left behind the rest of the world regarding technical implementation of research and development in the raw materials sector, especially for large-scale projects, due to tight budgets and complex approval procedures. Added to this is the fact that Europe is becoming a more expensive investment location due to comparatively high energy prices, risks in the security of energy and raw materials supply, and very high regulatory requirements. It is therefore also an ambition of this SRIA to communicate, influence, and improve the framework conditions for the commercialization of research results at global level.

1.2.2 Geopolitical setting

Technology leadership is strategic both for nations and for global companies. However, Europe lags far behind in terms of filing patents and by 2021, was on a par with South Korea.

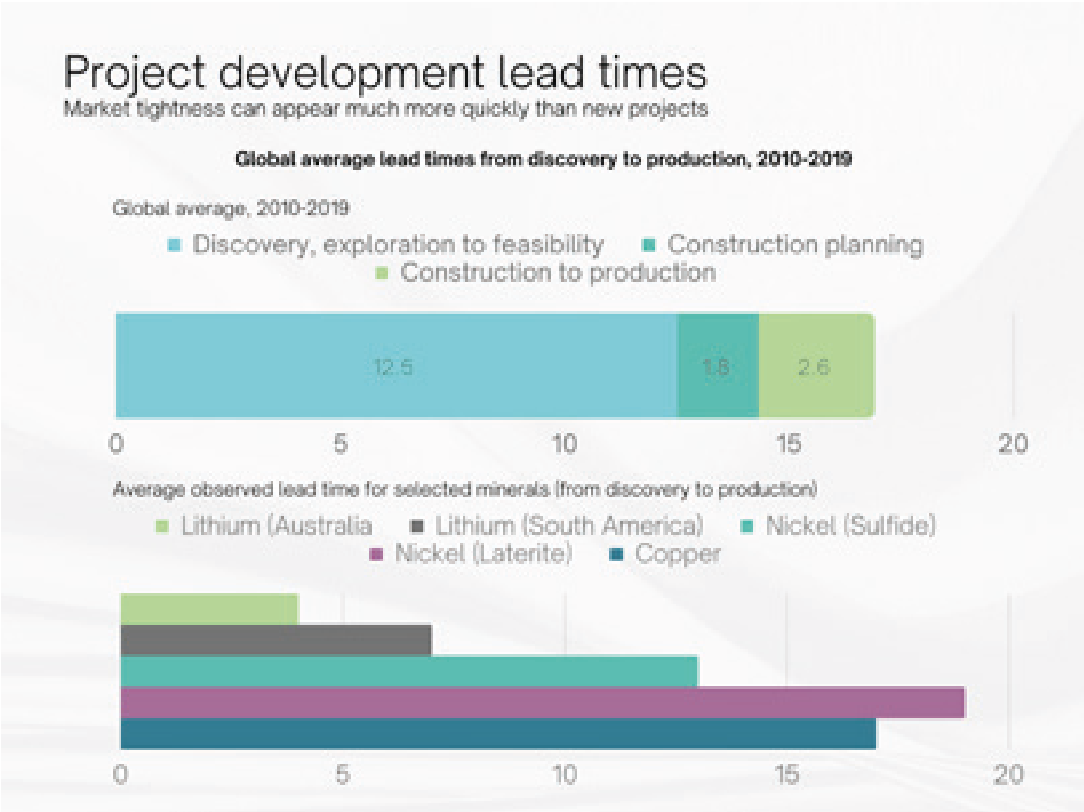
Over the past two decades, Europe has seen a >30% reduction in mining production[2], with concomitant lack of investment in exploration, mining, and processing. The resulting high dependence on imports of raw materials has weakened Europe's supply chains and negotiating position. Time lost due to the decl ine in mining and processing plants and, consequently, reindustrialisation cannot be rapidly recovered. The downstream raw materials sector and particularly metallurgical companies are similarly affected. The closure of numerous European smelters as a result of the recent energy crisis is a serious concern, since plant closure is faster than plant construction. Furthermore, the mining sector, by its nature, requires long project development lead times, which creates a bottleneck for access to materials used in European production, a situation of great concern to European industry. Increasingly long lead times for project development are also observed in other European research-related areas, e.g., pharmaceutical production and product development of important active ingredients and medicines, where there is a high dependency (up to 85%) on countries such as China and India. One key to the reindustrialization of Europe lies in prudent policy coupled with innovation and improved location conditions, which will counteract higher European location costs and assist the growth and capacity of European research.



Trend in patent applications for the top five patent offices, 1883-2021 (World intellectual property indicators, 2021 – World Intellectual Property Organization (WIPO), 2021).

2 Reichl C, Schatz M. World Mining Data 2023. Vienna: Federal Ministry of Finance; 2023. 265 p.

The National Intellectual Property Administration of the People's Republic of China (CNIPA) received 1.59 million patent applications in 2021, up 5.9% on 2020. The volume of applications received by CNIPA is similar in magnitude to the combined total of the next 12 offices ranked from second to thirteenth. The United States Patent and Trademark Office (USPTO)—with 591,473 applications—ranked second, followed by the Japan Patent Office (JPO) (289,200), the Korean Intellectual Property Office (KIPO) (237,998) and the European Patent Office (EPO) (188,778). Together, the top five offices accounted for 85.1% of the world total in 2021, 6.6 percentage points higher than their combined share a decade earlier in 2011. This is entirely due to an unprecedented growth in filings in China. China's share of the world total has almost doubled, from 24.4% in 2011 to 46.6% in 2021. By contrast, each of the other four offices in the top five experienced a decrease in their respective shares during the same period[3].



Average observed lead time for selected minerals (from discovery to production). It is a long way to sourcing and self-sufficiency. Research and innovation can help accelerate this development and making mining and metallurgy more competitive in Europe (IAE, 2020).

3. World Intellectual Property Indicators, 2022.

1.2.3 Europe's position in a world of change

Europe's current raw materials policy landscape has its origins in the recognition of its weakened strategic position and the 2008 implementation of the Raw Materials Initiative with, as its pillars, (i) access to raw materials on world markets at undistorted conditions, (ii) fostering sustainable supply of raw materials from European sources and (iii) reducing the EU's consumption of primary raw materials. This starting point has led to the European Innovation Partnership (EIP) on Raw Materials, the Raw Materials Alliance, Strategic Partnerships on Raw Materials, and the (at the time of publication, not yet adopted) CRM Act. The draft CRM Act sets benchmarks of:

- ≥10% of the EU's annual consumption for extraction
- ≥40% of the EU's annual consumption for processing,
- ≥15% of the EU's annual consumption for recycling,
- ≤65% of the Union's annual consumption of each strategic raw material at any relevant stage of processing from a single third country.

These ambitious European raw material-related goals, especially with regard to decarbonization, self-sufficiency, and technology leadership, require a consistent use of new technologies and new raw materials. The loss of the European industries' leading role in some key technologies underscores the importance of concerted research and innovation, consistent utilization of results, and less emphasis on cheaper production to the detriment of enhanced product development sustainability.

The Green Deal, as a set of policy initiatives, has already inspired a multitude of legislative actions, paving the way for a re-engineering of Europe's economy. Upfront investments will be needed to switch energy, industry, and transport to clean technologies. At a global level, industry may move business activities to other countries with similar opportunities but more attractive policy conditions. In this regard, the US Inflation Reduction Act, together with sustained high energy prices, could stimulate industry to implement their green ambitions outside of Europe. This would exert an immense effect on the domestic European commercialization of research and innovation. Hence, research and innovation policy will always be connected to the respective investment climate of market players.

1.2.4 Paradigm shift

As a consequence of the decline of mining in Europe during the end of the millennium, exploration, mining, and metallurgy decreased and, consequently, European industry now faces a lack of expertise in these sectors. With the advent of the European Innovation Partnership (EIP) on Raw Materials and its Strategic Implementation Plan to implement the 2008 EU Raw Materials Initiative there was a paradigm shift in EU policy making towards the raw materials sector. A new raw materials awareness entered political decision-making and research policy, and raw materials were—for the first time—assigned as a societal challenge, for consideration within Horizon research grant programmes. Horizon 2020, then the largest research program globally, came into force in 2014, offering a well-budgeted, important component of industry-related research. However, in the follow-up program, Horizon Europe, seven years later, the sector retained this position without being explicitly mentioned. It is therefore necessary for research to be steadily supported in the political sphere. This also requires a strong ETP SMR and high impact for the SRIA, since it goes far beyond the social sharpening of raw material awareness, especially in the political sphere, to conveying the relationship between research, technology leadership, and value creation.

1.3 Education, Research and Innovation

1.3.1 Knowledge triangle

The knowledge triangle is the integration of education, research, and innovation, working together as key drivers of the knowledge economy in delivering sustainable growth. It is useful as a tool for describing and understanding the interplay between education, research, and innovation. Today it is evident that education is stimulating research, and that there is a bi-directional relationship between research and innovation; however, return pathways from research, and particularly from innovation, into curriculum development and educational practice are much more difficult to trace.

Knowledge triangle.

The different roles and interplay between education, research, and innovation—and their respective weights—will vary depending on national or regional circumstances. However, in all circumstances, strengthening linkages between the three elements is crucial in ensuring that the full benefits are secured from investment in any of the three. In this way, multiplier and (often unexpected) spinoff, effects can be maximised.

The ETP SMR comprises all key players of the knowledge triangle so that targeted innovation activities are possible. However, innovation in the sense of developing and implementing new processes is complex and requires time, integrated research (from fundamental to applied research), and development in specific areas that converge towards concrete ambitions. If innovation is to thrive and build resilience in future European raw materials supply chains, research and innovation must be encouraged and supported along the entire value chain, from exploration to recycling, leaving behind no component of the whole ecosystem.

Education, skills, and training in vocations and professions relevant to implementing the Green Deal must receive strong near- to medium-term support to mitigate anticipated skills shortages in key areas. As an important example of a current challenge in this area, global geoscience student numbers have been in decline for almost a decade and employers report difficulty in recruiting suitably qualified geoscientific staff[4-5], despite growing demand from sectors encompassing the supply of minerals for low carbon technologies, development of renewable energies, and carbon capture and storage. Studies suggest that this skills shortage is significantly influenced by negative public perception of geoscience in relation to environment and climate change, and mining in particular, despite the key role of geoscience in delivering the required minerals and energy supply, and research, and innovation solutions. The crucial need to address poor public perception and acceptance of exploration and mining in Europe was highlighted in the negotiating mandate of the European Council to the CRM Act, in which the Council proposed a subgroup to the CRM Board "to discuss issues related to public knowledge and acceptance of CRM projects."

Students training at Leoben University (Credit: Leoben University (RGP))

1.3.2 Positioning Requirements for Research & Innovation

One of the core tasks of the ETP SMR is to pinpoint research priorities for the minerals and metals raw materials sector in close consultation with members, affected economies, research communities, and education providers. As such, if there is a particular need for action, the platform drafts position papers specifying the specific need for research and innovation in the raw materials sector to carry out its socio-economic tasks. Based on the framework conditions until 2022 and on the eve of the 2024 Horizon Europe Work Programme in 2023, the ETP SMR published a Position Paper about Raw Materials Research and Innovation to achieve the EU Green Deal[6]. In this paper, distinct research and innovation actions are listed in detail.

4. American Geosciences Institute, 2020
5. Cohen, 2022. Australian Geoscience Tertiary Education Profile 2003-2021.
6. https://www.etpsmr.org/wp-content/uploads/2023/01/ETP-SMR-Position-Paper_Raw-Materials-Research-and-Innovation-to-achieve-the-European-Green-Deal_08122022.pdf

Norwegian University of Science and Technology (Credit: NTNU)

Education and training in mineral resources is crucial to strengthening Europe's mineral raw materials resilience.

The Norwegian University of Science and Technology (NTNU) is Norway's largest university with a strong focus on technology, engineering, and science. NTNU collaborates with business and industry in education and research (10,000 projects with national and international companies) and works with SINTEF[7], one of Europe's largest independent research organisations. Mining and minerals production education aims to produce versatile candidates with a clear understanding of their technical, economical, social, and environmental responsibilities. A master's degree in georesources and geotechnology spans the production chain from exploration, resource modelling, mining, mineral processing, and waste management.

To facilitate knowledge transfer along the production chain, all the students are given a foundation in mining, mineral processing, and mineral resource management. NTNU is a core partner in the EIT RM Knowledge Information Community with several specialist centres (ECCSEL-ERIC[8], MiMaC[9], Nanolab[10]) and national infrastructure NORFAB[11]. The Mineral processing Laboratory - IGP - NTNU is a nationally important resource and is integral to education, research, and innovation. Through increased opportunities to collaborate with more universities and research institutes in the EU and internationally, cross-fertilisation can take place that accelerates the EU's ability to ensure sustainable raw material supply and build up the necessary skills for the sector.

7. https://www.sintef.no/en/
8. https://www.eccsel.org/
9. https://www.ntnu.edu/mimac/facilities
10. https://www.ntnu.edu/nano/nanolab
11. https://norfab.no/

1.4 Collaboration

1.4.1 European Partnerships

As one of 38 European Technology Platforms, the ETP SMR is embedded in a network of organisations in Brussels. Achieving the aim of the ETP SMR depends on vital partnerships with Member States to provide information on national strategies and priorities with European and national public authorities in addition to identifying overarching Key Technology Priorities to address EU and global challenges that require a coordinated and collaborative approach.

Interfaces to other platforms exist, e.g., i n the areas of:

- Advanced materials and technologies for energy storage.
- Advanced materials for sustainable production of renewable electricity.
- Measures to foster breakthrough innovations in the wind energy sector.
- Advanced engineering materials and technologies.

1.4.2 International co-operation

Several countries outside Europe have recently enacted critical minerals strategies combined with financial tools that also consider investments in research and innovation. The EU has also been active in developing bilateral strategic partnerships in raw materials to strengthen and diversify its raw materials supply chains. Since 2021, the EU has established such partnerships with Canada, Ukraine, Namibia, Kazakhstan, and Chile, and negotiations continue for many others including the DRC, Zambia, Kazakhstan, Greenland, and Australia, amongst others. These partnerships will benefit from streamlined access to finance and, in regard to research and innovation, will allow access to Horizon Europe funding. The ERA-MIN research programme, which aligns the natio al EU research programmes and includes strategic international partners, helps cover some of the research needs through smaller and more specialized projects, while also providing a platform for skills development and student participation across the sector. ERA-MIN has proven its success by securing co-funding from its member countries and the EU since 2011 and across two framework programmes (FP7 and Horizon 2020).

Geophysicist and geologists from SGU, Uppsala University, and Hellas Gold during the field campaign in Chalkidiki Greece - Hellas Gold core shed in Mavres Petres (Credit: Ronald Arvidsson)

International collaboration in Mozambique (Credit: GKZ Freiberg)

ERA-NET Co-fund on Raw Materials (ERA-MIN3) is a global, innovative and flexible pan-European network of 24 research funding organisations, supported by EU Horizon 2020[12]. It builds on the experience of the FP7 ERA-NET ERA-MIN (2011 to 2015) and ERA-MIN 2 (2016-2022). ERA-MIN3 addresses 5 key objectives:

- **Support and promote R&I cooperation in Europe**, contributing to the objectives and the implementation of both the Raw Materials Initiative and the EIP RM Strategies, maximising the impact of the Technology Pillar of the Strategic Implementation Plan;
- **Reduce fragmentation of R&I funding** in the area of non-fuel, non-food raw materials, across Europe and globally;
- **Provide a pan-European support network and financial resources** to improve synergies, coordination, and collaboration;
- **Improve the efficiency and impact of human and financial investment** in R&I activities in the area of Raw Materials;
- **Improve the competitiveness and the environmental, health and safety performance** of non-fuel, non-food RM operations.

Over the past 12 years ERA-MIN substantially contributed to the implementation of the Strategic Implementation Plan of Raw Materials of EIP[13-14]. Like Horizon, the key objectives are based on a SRIA. A revision of the ERA-NET SRIA is currently taking place, considering new insights towards innovating the innovation system beyond 2030. Its aims are two-fold:

- **Identifying critical technological and structural challenges** within the EU relating to raw material supply for the green and digital transition
- **Addressing needs for research and innovation** to tackle the challenges, as well as prioritizing among strategically important core targets.

ERA-MIN's new SRIA focuses on six thematic areas:

- Resilient primary and secondary raw materials supply
- Efficient use of raw materials in design and production
- Sustainable use and reuse of products
- Effective policy development and governance
- Maximizing societal benefits
- World-class innovation capacity

Synergy between ETP SMR and ERA-MIN Strategic Research and Innovation Agendas.

The ETP SMR SRIA is aligned with the responsible institutions of the ERA-MIN SRIA update through a consultation process, as well as through public workshops and events. Synergistic development of the two SRIAs allows for a better definit ion of topics that consider the regional innovation priorities of the Member States and their partners outside the EU. It thus not only promotes synergies, but also influences the European Commission policy making and raises impact. In the development of the ETP SMR SRIA there were condensations with priority towards the European Commission, but also additions that guarantee a holistic approach and consider input from regional research project owners. In the future, institutionalized cooperation will be sought between the two institutions, which will contribute to learning from the experiences of both networks and to avoid duplications in the preparation of calls.

12. https://www.era-min.eu/about-era-min-3
13. https://single-market-economy.ec.europa.eu/sectors/raw-materials/eip/strategic-implementation-plan-sip_en
14. https://www.era-min.eu/dashboard

1.4.3 Regionalisation

ERA MIN, as well as the Cohesion funds such as INTERREG programs, show which resources are hidden within the regions of the European Union. A considerable number of Member States have developed their own raw material policies, as analysed by the EU INTERREG Europe project REMIX Smart and green mining regions, and derived best practices for all European regions. This also affects research priorities and the linking of research with entrepreneurial valorisation in each region.

The European Committee of the Regions[15], an advisory body to the European Commission representing Europe's regional and local authorities, is increasingly concerned with raw materials issues. The implementation of the CRM Act will impact the regional level and private and public research infrastructures will be faced with new opportunities.

Regional, closed value creation plays a major role in driving cooperation potential between the regions and using it for stronger cooperation, as identified and used, e.g., by the Horizon 2020 project MIREU - Network of Mining and Metallurgy European Regions. It is common knowledge that Europe´s prosperity and the life of the European spirit are grounded in the regions with the local people. This is also the case regarding education, research, and innovation.

The Member State exploration programs will lead to new knowledge about the EU's mineral deposits. To accelerate knowledge building and skills, instruments should be developed to increase collaboration between these programmes and university education and research.

Field mapping work carried out by GeoSphere Austria (Credit: GeoSphere Austria, Hans-Georg Krenmayr)

Cross-European consortium of an HORIZON 2020 research project at Panasqueira tungsten mine, Portugal (Credit GKZ Freiberg)

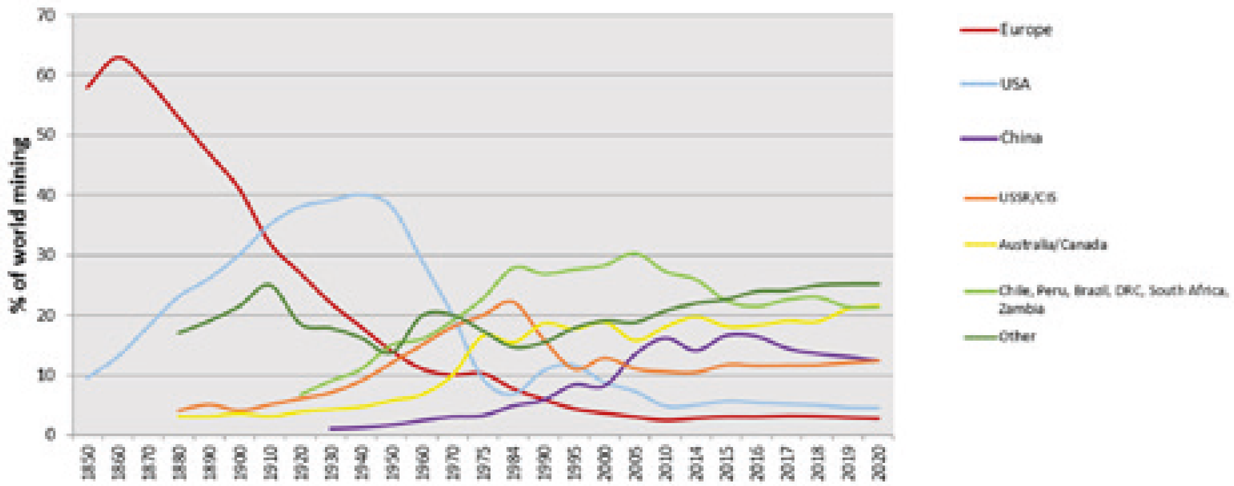
15. https://european-union.europa.eu/institutions-law-budget/institutions-and-bodies/search-all-eu-institutions-and-bodies/european-committee-regions-cor_en

2. VISION

2.1. Key to Europe's future: long-term commitment to building knowledge, capacity, and innovation

Within a variety of initiatives under the umbrella of the European Innovation Partnership on Raw Materials, a network of actors has come together to strengthen the EU's ability to secure internal EU raw materials supplies. An important tool has been the Strategic Implementation Plan launched by the European Commission in 2013, which has been the basis for actions and calls under the EU framework programme Horizon 2020. The ETP SMR Strategic Agenda was an important input to the work of the European Commission and was instrumental in bringing industrial stakeholders together towards a common vision. At the start of the journey to fulfil this vision, Europe's raw materials sector was highly fragmented. However, the European Commission has been successful in establishing new networks and bolstering existing ones. It is important that this work continues and is reinforced. However, rebuilding a European industry in decline for the last century takes time and requires long-term commitment from the European Commission and EU Member States. It is also important that other policies do not create barriers to the development of the sector. In some areas, Europe has remained a global leader, exporting novel mining and processing technology innovations globally.

This is also, in part, owed to the strong innovation system built up where much of the development takes place in collaboration between technology and equipment providers, mining, and metallurgical industry. In other areas, the challenges are greater and fundamental action is needed if the EU is to achieve its security of supply objectives. One such element would be to build knowledge about the EU's domestic mineral deposits—how they have been formed geologically and how they can be exploited to also access CRMs in an economically viable way. With new endeavours under the auspices of Horizon Europe or other initiatives, industry, together with a growing network of stakeholders, can continue the journey towards achieving the mining and minerals industry's 2040 vision.



Share of world's metal mining (1850-2020). Europe dominated global metals production in the mid-19th century. Rebuilding a European industry in decline for the last century requires long-term commitment from the European Commission and EU Member States (RMG Consulting, 2021).

Left picture credit: Boliden

2.2 Vision 2040

By 2040, the European minerals- and metals industry is seen as a vital pre-requisite, and instrumental in achieving European climate targets and securing a reliable, environmentally sound supply of minerals and metals required by European industries—not only by policy makers but also by the general public, individual communities, and society as a whole.

The minerals and metals industry is seen as the backbone of the EU's industrial ecosystem and as a forerunner (and participant) of the circular economy, where an increasing proportion of metals mined are also recycled with high quality. Europe's mineral resources knowledge base has been strengthened and the ability to extract and refine more metals, including CRMs, has increased significantly. The European minerals and metals industry is considered an attractive and safe place to work, leading in developing and implementing technology and automation, extracting and processing in an economically viable way, and yielding the lowest environmental and climate footprints in the world. This gives the industry a competitive market advantage since low environmental impact production metal products and safe working environments are seen as desirable by downstream industries and end users. European mining equipment is in global demand, contributing to increased mine safety, energy efficiency, and reduced emissions. Research and innovation, together with industrial leadership, has led to:

- European mines contributing to the EU's self-sufficiency in critical and strategic minerals and metals with low environmental and climate footprints, while being competitive on the global market.
- A significant increase in fully automated or remote-controlled mines in the EU.
- A wide social acceptance of mines.
- New and attractive workplaces where automation, digitalization, and high environmental standards have contributed to enhancing the appeal of the industry.
- A minerals and metals industry that has developed into a hub and integral part of the circular economy.
- European mining technologies and mining equipment that are in global demand and that enhance climate and environmental performance to meet the UN SDGs.
- Policy making and decisions affecting the minerals and metals industry are based on scientific evidence and barriers to industrial development caused by other policies are addressed.

Tailings pond under recultivation (Credit: GKZ Freiberg).

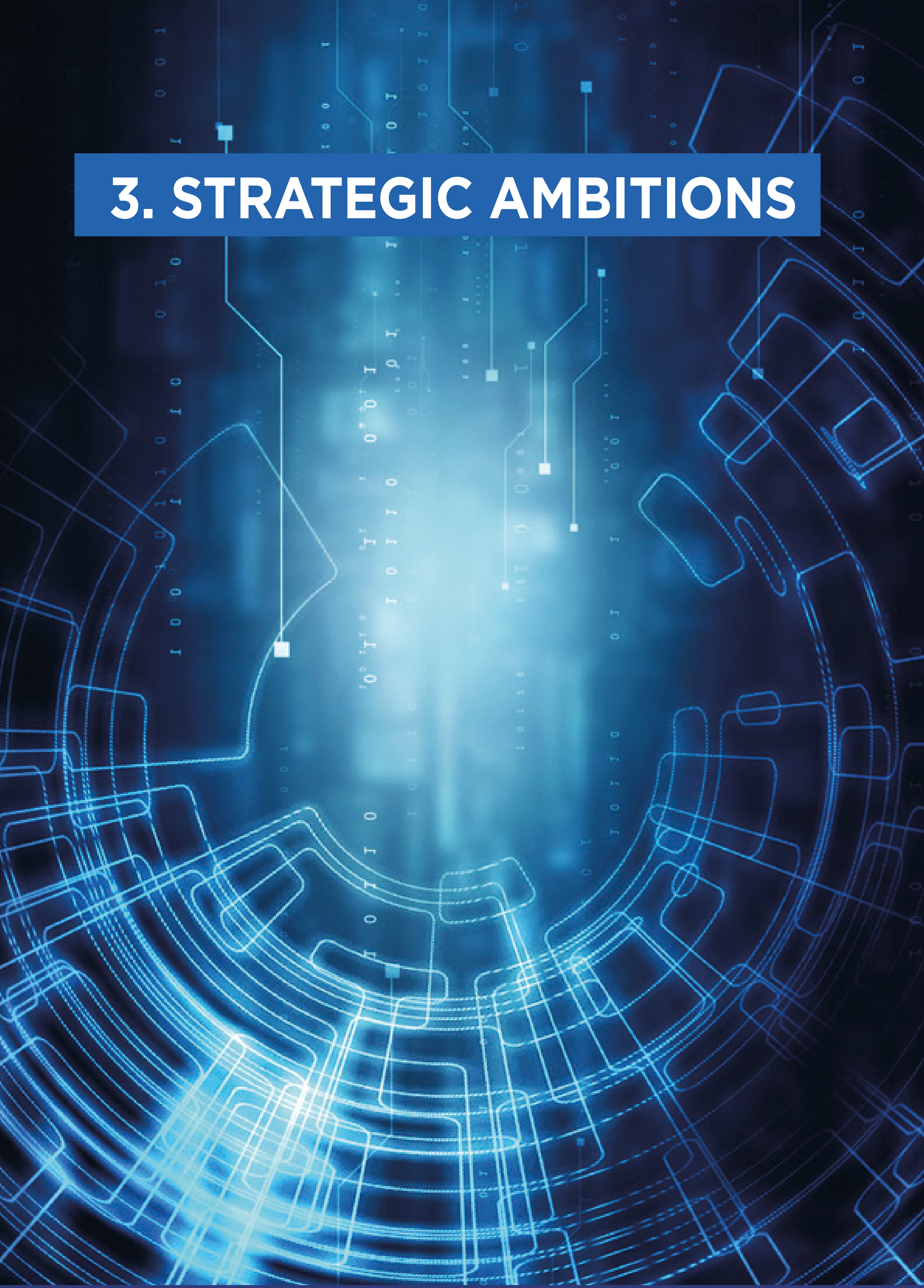
The following key objectives will be targeted:

- At least 10% of the EU's annual strategic raw material consumption domestically produced by 2030[16]
- At least 15% of the EU's annual consumption from secondary sources by 2030[17].
- Mineral processing capacity of at least 40% of the EU's annual consumption of strategic raw materials[18].
- Net-zero GHG emissions in mining by 2035 and processing by 2045
- Net-positive biodiversity impact of mineral and metal production by 2030
- Tenfold the number of advanced level graduates by 2035

To fulfil this vision, a long-term political commitment is needed and a policy framework and understanding of the industry's fundamental needs (see 2.3). To make this vision a reality, the following strategic ambitions, covering all commodities and based on a value chain approach, need to be pursued.

16. To be modified according to CRM Act
17. To be modified according to CRM Act
18. To be modified according to CRM Act

3. STRATEGIC AMBITIONS



The ETP SMR has defined a set of Strategic Ambitions focusing on technology development and innovation to gain industrial leadership in resource sustainability and efficiency as well as climate-and environmental goals, while at the same time increasing global market competitiveness. Each Strategic Ambition outlined below lists the identified focus areas for research and innovation as well as expected impacts if objectives are met.

Mineral exploration REE in Greenland (Credit: GKZ Freiberg)

3.1 Exploration and resource characterizations

Despite the significant potential for locating new mineral deposits in many parts of the EU, large areas are still under-explored. The EU's share of global exploration expenditure accounts for only 3%. Mineral production in EU Member States is equally low (3%), making the EU vulnerable to supply disruptions as the EU consumes 25–30% of metals produced globally[19]. Investment decisions in exploration are often substantially based on the mineral potential of a jurisdiction, although policy factors are of importance (accounting for approximately 40%)[20]. Europe's research in ore geology has long been limited, leaving the knowledge base fragmented. However, increased geological knowledge of mineral deposits and districts with geological potential will increase the attractiveness of future exploration investment, which is important if the EU is to obtain a secure raw materials supply and is a fundamental requirement if we want to increase our self-sufficiency in mineral and metal raw materials. Important to achieving this increased knowledge are the requirements, under the CRM Act, for Member States to carry out national geoscientific exploration or surveying programs, where the European Geological Survey Organisations will play a key role. Under the Act, these national programmes will increase knowledge of the Union's CRMs via new acquisition and processing of existing geoscientific data including, e.g., mineral mapping, geochemical campaigns, geophysical surveys, and predictive mapping. In addition, the Act requires assessments of the CRM potential of extractive waste.

These activities would further benefit from collaboration between the European Geological Survey Organisations, who are the mandated authorities for conducting such work at national level, with academic institutions and industry to build a broader community of applied research and innovation expertise on raw materials within Europe.

New technology is also needed to efficiently locate and explore deep deposits. To reach deeper mineral deposits

19. Hinde, C. & Farooki, M., 2018. STRADE - Promoting Investor Interest in the EU Mining Sector.
20. Fraser Institute 2022. Annual Survey of Mining Companies, 2021.

Left picture credit: Boliden

containing both base metals and CRMs, geological, geochemical, geophysical, drilling and mineral-chemical methods need to be developed and improved. The aim of research in this area is to improve knowledge of how ores have been formed, about the structure of ore bodies, quality of the rock, and how the rock is affected by mining. Thereby, more resource-efficient mining will be achieved with smaller environmental impact. There have been several successful FP7 and Horizon 2020 projects in this field, including PROMINE[21], NEXT[22], SMARTEXPLORATION[23], GREENPEG[14] a.o., that have paved the way to better implement and focus research efforts.

Exploration (Credit: Boliden)

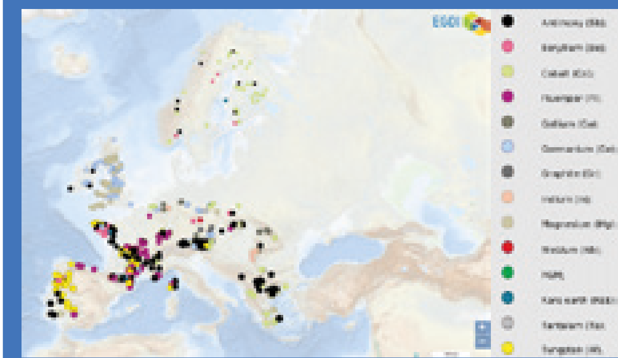
Our Strategic Ambition is therefore:

By 2040, the knowledge base of Europe's mineral potential, along with deposit types, is significantly improved, including for critical and strategic raw materials. Knowledge of society's need for metals is widespread, creating a high level of acceptance for exploration and mining project development. Accurate and applicable ore genetic, geometallurgical, and mineral system models for a variety of different European mineral deposit types, as well as methods to explore and validate mineral reserves from mine wastes have been developed. Improved integration of geodata and the development of predictive mineral potential maps indicates new target areas for further investigation and validation. New and improved exploration technologies lead to new discoveries of deep deposits, while methods focusing on deep sea and extraterrestrial exploration are also under development. New, improved drilling technologies increase efficiency and reduce exploration costs. Systems and techniques for gathering down-hole data while drilling have been established.

The increased knowledge of Europe's mineral potential attracts significant exploration investments. Information gained by research, the Member States' own national programmes (e.g., as mandated by the CRM Act), and exploration activity (taken with due consideration for corporate confidentiality and intellectual property rights) is gathered in national and European databases and publications that can be used for further studies, policy decisions, and to attract investments to the sector.

International cooperation is the key to a self-sufficient Europe in terms of Raw Materials.

PROMINE[24] (FP7) project provided the first pan-European maps and georesources database that includes primary and secondary raw materials of anthropogenic origin and 3D, 4D and predictive models of major mineral belts in Europe[25]. In 2014, PROMINE was awarded the best project launched under the EU Framework Programmes in the field of Industrial Technologies.



ProMine map of anthropogenic concentration of CRM in Europe [26-27]

NEXT (New Exploration Technologies)[28] Horizon 2020 project (GA n°776804) further developed predictive mapping and mineral prospectivity analysis and stepped from regional-scale predictions to target-scale detections by means of advanced statistical and machine learning methods. These geomodels can be used to target areas with high mining potential and therefore reduce the exploration cost and the environmental impact.

A list of relevant concluded projects can be found at www.europe-geology.eu/mineral-resources/

21. https://www.europe-geology.eu/promine/
22. https://new-exploration.tech
23. https://smartexploration.eu
24. https://www.europe-geology.eu/promine
25. Weihed, P. (Ed.), 2015. 3D, 4D and Predictive Modelling of Major Mineral Belts in Europe, Mineral Resource Reviews. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-17428-0
26. https://www.europe-geology.eu/promine/
27. https://data.geus.dk/egdi/?mapname=egdi_new_structure#baslay=baseEMODnet&extent=-3657890,145480,10081150,5845040
28. https://www.new-exploration.tech/

3.1.1 Focus areas for strategic research and innovation

Strengt hen efforts to improve EU's exploration capabilities by linking R&I actions to the Member State Exploration Programs.

Collaboration should not focus solely on CRMs, but also on other identified key deposit types where there is a strong potential to extract SRMs/CRMs as by-products. The toolset to locate such deposits needs to be improved, along with our knowledge base on the vast variety of European ore types, particularly with deposits rich in CRMs and their characteristics. There is a need to accelerate the development of projects on improving exploration, with predictive maps of mineral potential and new technologies that can locate various types of mineralisation at depth, and much more cost-effective drilling technology that can provide real time data while drilling. There will be no new mines in Europe without exploration. Without a continued and strengthened effort on R&I is this area, the target of 10 percent domestic production of strategic raw materials will not be reached.

* This section covers new topics or those still relevant in this new SRIA considering current actions at European and national levels. The other subjects are not any less relevant and the actions undertaken must be continued.

Mapping and modelling

- Geoscientific mapping and data collection, including from exploration activities, when possible, to enable quantification of mineral resources at Member State and EU-level.

- Integration of geodata (petrophysical, geophysical, geochemical, geological) to develop predictive mineral potential maps and 3D/4D models on deposit and regional scales, incorporating application of big data, machine learning, and AI technologies.

- Mineral systems analysis and development of ore genetic models and geometallurgical models to build a broad understanding of Europe's deposit types including for CRMs.

Resource Characterisation

- Resource characterization to improve resource efficiency by reducing waste masses and improving geometallurgical models and resource management systems.
- Development of methods to explore and validate mineral resources from mine waste.

Exploration technology

- Geophysical and geochemical technologies, methods, and instruments to locate deep deposits.

- Integration of technology from other sectors and non-destructive technologies, e.g., drone-borne measurements and satellite data collection.

- Cost effective drilling technology and systems and techniques for gathering down-hole geodata while drilling.

- The new plasma drilling technology currently being developed will certainly reduce the cost and the time of drilling, but much of the more essential information required for mineral processing can only by obtained through coring. For example, this technique will not provide the structure and the texture of the host rock, the mineralization distribution (2D/3D model), etc.

Drilling machine (Credit: EPIROC)

Automatic Bit Changer ABC (Credit: EPIROC)

3.1.2 Expected impacts

- Increased knowledge of Europe's mineral deposits including critical and strategic raw materials.
- Increased understanding of mineralizing processes in different environments.
- Provision of technology and knowledge required to discover and characterize new mineral deposits.
- Increased attractiveness of exploration investments.
- Reduced ore losses through improved mineral deposit models.
- Reduced mining waste through increased resource efficiency.
- Efficient use of old mining waste as a secondary raw material.
- Improved European resilience and self-sufficiency regarding strategic and CRMs, providing responsibly produced minerals and metals to European industries.

To increase EU's domestic supply, we need to focus on research and innovation needs that allow us to find and use Europe's mineral resources.

New innovative exploration technologies are needed to find deep-seated mineral deposits in different geological settings. EU-funded projects have already led to good results. However, we are still at the starting point of our journey: we need a suite of diverse innovative and cost-efficient exploration technologies to locate different deposit types in Europe's distinct geological settings. For example, new geophysical exploration technology has been tested at different mine sites in the ***Smart Exploration project***[29] (Horizon 2020, GA n°775971). The technology has shown a possible deep mineralization located at an old mine site in Sweden. The exploration company that has seen the research project's results, expanded their exploration license area and will use the technology in their exploration work. Their GPS-time transmitter is now used at deep mines in South Africa to allow synchronized surveys in denied GPS environments such as exploration and production tunnels.

Mineral resources have been mined in Europe for centuries and many deposits are known, so to some, exploration might seem unnecessary. But the commodities sought in the past are not the same as those needed today for the energy transition or our daily life (e.g., Li, Be, Ga, Ge), and advances in exploration technology may lead to the discovery of new ore deposits and attract new investors.

GREENPEG[30] Horizon 2020 project (GA n°869274) aims to improve domestic exploration for LCT and NYF pegmatites (sources of CRMs such as Li, Ta, Cs, Be). The researchers developed first toolsets for its exploration which are based on the specific properties of the ores, e.g., low density and conductivity, in some cases elevated gamma-ray emissions and magnetic signature, small ore body size and distinctive mineral geochemistry and diversity, depending on the nature of the pegmatite. The delivered toolsets – including an easy-to-use piezoelectric spectrometer - will lower exploration costs by improving non-destructive ore body targeting and reducing exploration time. Moreover, the project constructed a certified demonstration of the first European nose stinger with magnetometer which will make it possible for small and medium-sized enterprises in Europe and abroad to fly airborne surveys, using light European helicopters.

First ESA certified nose beam for airborne surveys (Credit: terratec)

29. Smart Exploration new ways to explore the subsurface. Exploitation Tour Canada, February – March 2020. Flyer2. https://smartexploration.eu/
30. https://www.greenpeg.eu/

Sandvik automine concept (Credit: Sandvik)

3.2 Mining

Even today, some of the world´s smartest and most energy- and resource-efficient mines and quarries are operating in Europe. However, mining faces growing challenges. To make mining and quarrying processes increasingly sustainable, extensive reduction of emissions is needed throughout the entire process without reducing economic sustainability. The mines and quarries of the future must be climate neutral, digitalized, and automated. At the same time, new deposits are being found at greater depths, which require new approaches regarding safe mining methods, climate neutrality and higher energy efficiency. To achieve safe and sustainable mining, new innovations and technical solutions must be developed, new innovations and technical solutions must be developed, validated in upscaling activities and implemented. Due to automation, digitalisation, and interoperability the complexity of development and need of interoperability is increasing. One area of development is smart, connected control systems that enable machines to communicate both with each other and with the overall process system to optimize and increase the efficiency of mining. To attract skilled staff, mines must also be attractive and safe places to work. Mining operations must also reduce their environmental footprint. For example, Sweden's mining industry has agreed on the goal of making a net-positive contribution to biodiversity by the year 2030 in all regions of operation[31]. Our Strategic Ambition is therefore:

By 2040, the majority of mining operations are climate neutral. Increased knowledge of the ore composition has improved ore recovery and minimized waste. Interoperability of mining equipment and other systems enable machines to communicate both with each other and with overall process systems to optimize and increase mining efficiency. The systems can also handle mixed traffic scenarios, e.g., interaction of autonomous machines with manually-driven machines and/or people. The industry is regarded as a high-tech industry and a safe working place attracting talented personnel. High climate- and environmental standards also make the industry more attractive to employees and increase social acceptance. World-class mining technology from Europe is sought after and exported worldwide.

The technology shift and mindset also demand new research, education and training for the digital mine and their miners. Research areas in system innovation and integration is essential for reducing CO_2-emissions, environmental footprint, and product environmental footprint.

31. Mining with nature. https://www.svemin.se/en/project-mining-with-nature/

System Innovation and Integration.

To reach the full potential of technology innovation in digitalization and automation, the opportunity to accelerate development with a system integration approach in all levels of technology matureness is essential. The technical shift in digitalization and automation is expected to have continuously development for several years ahead on both technology solution level and system level and their system interlinks levels. The complexity grows by adding the different processes needs of integration (drilling / blasting cycle processes, material logistic etc.) and interlinks between exploration/ mining and material handling processes to reach full potential in operation, economic f easibility, and a safer and better working environment.

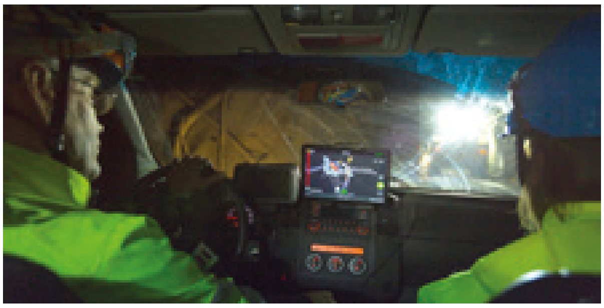
Control room, Garpenberg mine, Sweden (Credit: Boliden)

3.2.1 Focus areas for strategic research and innovation

Energy & Electrification

Innovation and development in electrification is a key enabler for lowering CO_2 emissions. In underground mining, this will also hav e a positive impact on lower energy costs for ventilation and better working environments.

- Energy- and cost-efficient mining and quarrying processes.
- Energy- and cost-efficient transportation in the mine/ quarry.
- Development of climate-neutral mining, quarrying technology, and processes.
- Mechanical excavation methods for hard rock conditions to enable continuous mining.
- Improving and developing ventilation, air quality control, and on-demand temperature control.



Mobilaris Onboard (Credit: EPIROC)

Decarbonisation and evolution of the mining sector in the digital age.

Faced with climate challenges, the mining sector has initiated decarbonisation by switching to electrical equipment and has carried out significant work on reducing its carbon footprint. The Russian invasion of Ukraine has further stressed the need of cost-effective technology that can move industry away from dependence on fossil fuels. Electrification plays a major role. Less energy-intensive extraction methods will also be key. Research and innovation on new technologies that enable mines to remain profitable in a changing climate is now even more urgent, such as techniques being investigated to improve recovery rates and reduce waste and water consumption. Research and innovation to develop cost-effective solutions for both new and old mines is needed.

In the era of artificial intelligence, machine learning and digital twins, the raw materials sector will need to adapt and evolve with the times to improve its competitiveness, efficiency, and safety. Research and development into the integration and automation of systems with autonomous or remote-controlled operations up and down the value chain is only just beginning in many parts of Europe and will be critical to the industry's future operations.

Production & processes

The trend that mines grow deeper will drive new research and technology concerning process and production methods including safety, efficient production, and water usage. Many new uncertainties will need to be addressed with research and new technology to become sustainable and economically feasible.

- Resource-efficient mining, e.g., improved ore recovery and selective mining to reduce waste.

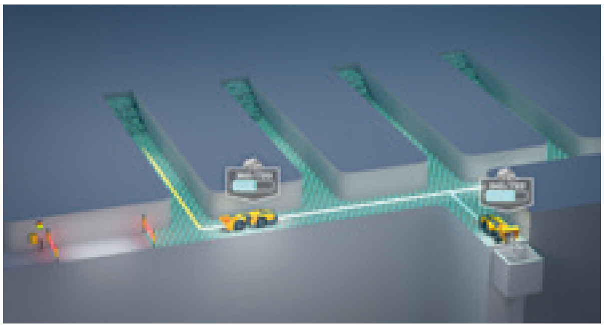
- Sustainable resource management for reduced water and energy consumption.

- Deep mining solutions for high rock stress environments.
- Alternative materials for backfill, rock support, and explosives to reduce emissions.

- Efficient backfilling techniques with increased use of waste (including in shotcrete) while addressing challenges with properties, stability, and subsidence.

Automation

Automation is a key enabler of operational safety and efficiency. Development of autonomous features in the mine are many and complex due to demand on system integration on several levels. Automation is directly correlated to increased safety and will increase opportunities to broaden the workforce, enabling remote and teleworking.



Deep Automation (Credit: EPIROC)

Automatic Bit Changer ABC (Credit: EPIROC)

- Reliable communication networks with real-time capabilities, including localization, and navigation systems in mines.

- Automation features enabling closed process cycles with interaction remotely or totally adaptive optimization. Driving aim for "zero persons at face" and remote inspections and features.

- Development and optimisation of predictive maintenance from supply chain to recycling with green, sustainable focus, securing robustness and 24/7 operations. By AR simplify Service operations.

- Technology development and support by digital test simulation environments, AI, and on-edge technology.

Digitalisation

Implementation and development of digitalisation on all levels is necessary due to the demands of system integration to achieve efficient and safer environments. It is essential to connect different processes in different production areas from upstream to downstream: a focus on end-to-end processes creating interoperability.

- Explore digital technology possibilities, including digital twins, to provide the best possible conditions for deep mining.

- Use of AI in the mining and quarrying environment and its processes.

- Create digital environments from technology development, system integration, to cybersecurity.

- Use digitalisation technology for creating and connecting value in and between process areas.

- Interoperability allowing communication man2machine/ machine2machine/ machine2process systems to optimize and increase mining efficiency and safety.
- On-line analysis for agile decision-making e.g., monitoring tools for rock reinforcement.

- Continued development of autonomous or remote-controlled operations.

3.2.2 Expected impacts

- Minimized environmental and climate impacts of mining.
- Minimized dilution and maximized ore recovery.
- Reduced total energy consumption per tonne of produced ore.
- Reduced waste rock.
- Cost-efficient mining.
- Safe mining operations.
- More attractive working environments.
- Increased social acceptance.
- Increased European export of world-class mining and environmental technology.

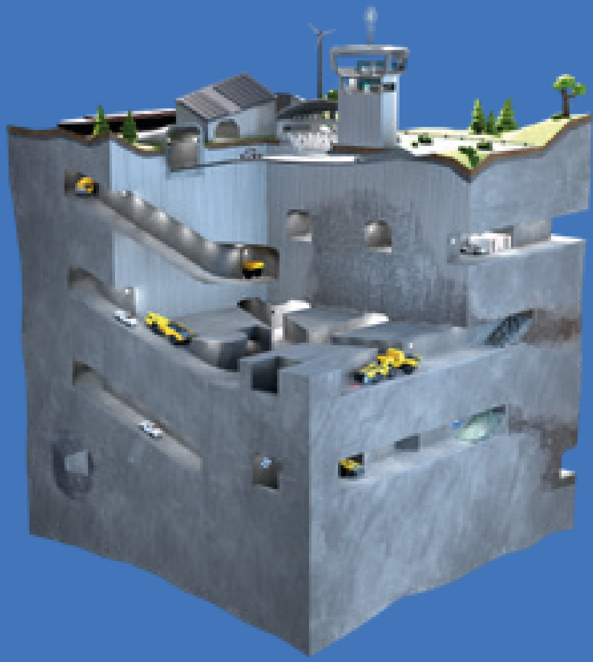
During the last couple of years the digital transition has made mining production more efficient and secure (Credit: Sandvik)

Mining evolution for the future

Horizon EU funded Innovation Action, NEXGEN SIMS is an example of a project that supports acceleration of innovation by target focus on technology development in combination with system integration.

NEXGEN SIMS[32] project develops new technologies, methods, and processes that will enable a more sustainable and efficient carbon neutral mining operation. This includes the use of battery-electric mining equipment, full utilization of 5G for optimal connectivity and positioning, autonomous material handling, AI-powered traffic and fleet control, and collaboration among machines. The project is also focusing on the mine worker of the future—'the modern miner'—and safe ty, e.g., by developing autonomous mine inspection technology. The core of the project is collaboration, with thirteen partners cross the value chain from EU to Australia.

"*NEXGEN SIMS is a powerful example of innovation by collaboration. This project allows us to rapidly scale technology, innovation nd system integration simultaneously,*" Sami Niiranen President Underground Division, Epiroc.



3D block representation of what the mine of the future could be according to NEXGEN project (Credit: NEXGEN SIMS)

Scooptram ST14 Battery (Credit: EPIROC)

32. https://nexgeneurope.eu/

To ensure Europe's independence and resilience in CRM supply, we need to develop new technologies for mining, while considering social and environmental impacts.

ROBOMINERS[33] is a project funded under Horizon 2020 (GA n°820971) with the strategic objective to facilitate EU access to raw materials, including those considered as strategic or critical for the energy transition. The aim is to use bio-inspired robots to develop new mining methods with a low environmental impact and making the mining of small and complex mineral deposits profitable. The ambition is to consider reopening old mines in Europe and reduce dependence on imported mineral resources, with reduced energy consumption.

Robot miner prototype tested in Estonia (Credit: ROBOMINERS project).

33. Policy Brief: September 2023. https://robominers.eu/2023/09/19/policy-brief-september-2023/

Underground processing Mittersill tungsten (Credit: GKZ Freiberg)

3.3 Mineral processing

In mineral processing, the mined rock is treated to produce an ore concentrate for subsequent metallurgical extraction, industrial minerals, or aggregate products. Mineral processing operations need to be optimized for resource and energy efficiency, and for environmental performance. Comminution is usually the most energy-intensive step, where particle sizes are reduced by breaking, crushing, or grinding of ore, rock, or other materials. An optimized comminution, in terms of particle size and size distribution, is crucial for all subsequent beneficiations and requires knowledge of ore properties for optimal parameter settings. The purpose of the separation processes is to concentrate the valuable compounds of the raw material stream by rejection of unwanted components. The efficiency of these processes needs to be optimized for the specific mine commodities to reduce ore losses, remove impurities, and make them more sustainable. Economically viable recovery of additional metals from polymetallic ores, including CRMs, is challenging. New, environmentally friendly, and safe reagents may need to be introduced and tested for more metals to be recovered sustainably. At the same time, technologies to reduce climate emissions and environmental impact for all mineral processing steps must be developed. Smart process design, novel flowsheets, and unit operations can further optimize comminution and separation processes and lead to intelligent production systems.

Finally, the residues from mining and mineral processing operations show significant potential as construction materials, e.g., as filler or supplementary cementitious material. The challenges in realizing this potential are both technical and regulatory. To increase circularity, climate and resource efficiency in society, technologies must be developed to treat these residues and efforts made to adapt policies, legislation, and construction material standards to these new input materials. Our Strategic Ambition is therefore:

By 2040, resource- and energy efficiency is significantly improved. Energy and cost-efficient comminution equipment is available and innovative measurement solutions and mill modelling substantially enhances mill control while reducing wear. New or improved mineral processing techniques result in reduced losses of valuable minerals, including CRMs, improving EU's security of supply. The utilization of smart and intelligent process design optimizes comminution and separation processes. The environmental footprint is minimized as emissions to air, land, and water are minimized. A significant amount of processing residues, e.g., tailings, are largely valorised in the construction material industry.

3.3.1 Focus areas for strategic research and innovation

Growing environmental considerations in the face of climate change – implementing a systemic approach.

In recent years, resource efficiency has been at the heart of environmental considerations in the raw materials sector. Actions have been taken to reduce the quantity of water used and the toxicity of reagents, while increasing their performance. The need to develop new water treatment technologies is becoming a major challenge but a prerequisite for meeting regulatory requirements for water discharges, and continuing research in this field is essential to achieving the goals set at national and European level.

It is also necessary to consider process optimisation regarding energy efficient comminution technologies and product optimization for highly efficient downstream processing. Likewise, improving our capabilities to recover low-grade CRMs. It is clear that we have only partially harnessed the power of digitalisation and AI. Extensive research and innovation are needed. Digitalized processing plants with integrated systems upstream and downstream can increase mineral yields, while reducing waste, energy consumption and costs.

Traceability and industry integration

- Global Passport (traceability through the value chain) and internationally accepted standardisation in terms of harmonisation of the feed (primary/secondary).

Process optimisation

- Improved and new comminution technologies, with regard to energy efficiency, wear characteristics, and product optimization for highly efficient downstream processing.
- Measurement technology and models for optimizing design and control of comminution and separation circuits.
- Improvements in separation technology especially for coarse and very fine particle sizes.
- Geometallurgical modelling, process mineralogy and analytics for resources characterization, economical optimisation, and ore traceability.
- Efficient wet and dry separation processes for treating polymetallic and complex ores, removing impurities, and improving recovery of low-grade CRMs.
- New and smart process design and methods.
- Model-predictive control concepts and data-driven models (digital twins).

Concentrator Boliden Aitik (Credit: Boliden)

Environmental performance

- New, efficient flotation reagents including consideration of effects on downstream processing, water recirculation, and health and safety.

- Efficient water treatment methods and purification of process water.

- Environmentally friendly and safe reagents with high performance.

Recycling and secondary feed streams

- Design for end-of-life products.

- Automation of the identification of the source (in terms of design/dismantling).
- Automation of dismantling and separation.

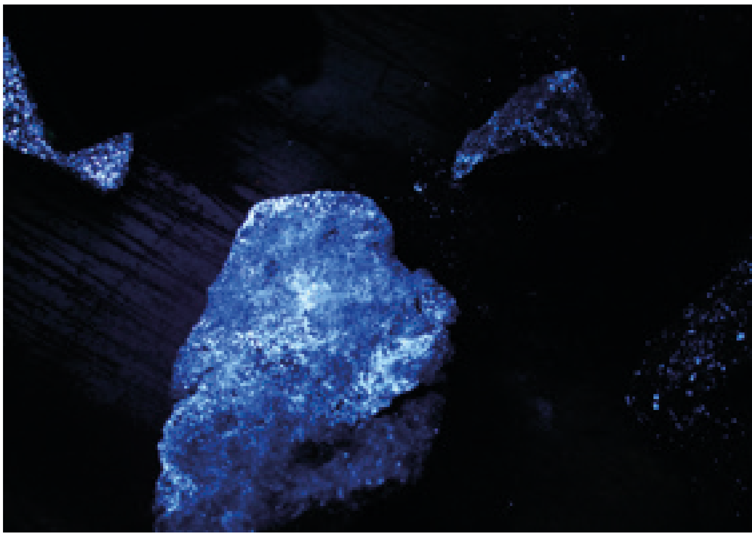
System integration

- Digitised processing plants with further advanced online characterization, sensor technology, and data analytics.

- Integration with upstream and downstream processes (geology/mining and smelter processes), e.g., optimized fragmentation chain from mine to mill.

- Coupling of business sectors and development of new business models.

Tungsten processing in Panasqueira - Portugal (Credit: GKZ Freiberg)



Fluorescent Scheelite (Spain) (Credit: GKZ Freiberg)

3.3.2 Expected impacts

- Reduced energy consumption.

- Reduced losses of valuable minerals, including CRMs.

- Intelligent production systems.

- Reduced cost (less energy consumption and wear) and increased revenue through cost-effective production of by-products.

- Improved environmental performance (related climate impact, water management, emissions, tailings).

- Improved social acceptance of mineral processing plants due to higher resource efficiency, lower emissions, and less waste.

- Increased security of supply of raw materials, addressing EU's dependencies on raw materials for strategic technologies.

Development of mineral processing technologies to increase recovery rates, reduce energy consumption, and limit mining waste are among the major challenges for the future of the mining sector.

FAME Horizon 2020 project (GA n°641650) aimed to improve technology and increase efficiency in extraction and processing of complex low-grade ore deposits. Low-grade deposits are common in Europe and include reserves of tin, tungsten, and other important secondary elements in skarn, greisen, and pegmatite ore types. This project provided preprocessing studies to optimize flotation processes and the valorisation of a Sn-Zn-In-Fe skarn mineralisation by elaborating flowsheets that allow the economically viable processing of a tin concentrate fit for smelting at a local smelter. It also targeted enhancing metal recovery and valorisation of residues.

FAME LNEG Pilot Plant Testing[34] (Credit: WAI)

34. https://cordis.europa.eu/project/id/641650/reporting

Smelter Saxony (Credit: Nickelhütte Aue)

3.4 Metallurgy/Metals recovery & recycling

Metal production relies on both primary and secondary raw materials. Both streams face challenges regarding cost-efficiency, technology, and environmental performance. The demand for metals will increase with the transition to climate neutral technologies and many of the metals needed are not yet produced in the EU. To strengthen Europe's capacity to recover metals from both ores and secondary resources, new innovative technologies and refining capacities must be developed. A key challenge is to increase recovery yields and extract additional elements contained in the materials streams that are not extracted today. New hydrometallurgical processes to extract critical raw materials need to be developed. Adaption of raw materials processing to carbon-neutral operations is also a challenge as fossil coal and reagents with a carbon footprint are commonly used for metal extraction. Research is needed to ensure efficient CO_2-neutral processes and required product quality. Our Strategic Ambition is therefore:

By 2040, Europe's metal extraction and refining capacity for several metals, including CRMs, have increased making EU less sensitive to trade disturbances/barriers. New, sustainable and resource efficient, carbon neutral technologies to increase process yield from ores have been developed and technology to extract more elements from material streams already progressed. The development of new technical solutions has meant that metals are also economically recovered and refined from a variety of secondary resources including mining waste, waste streams from other industries, and electronic scrap. Knowledge and technology is in use to extract by-products, such as slag in new applications, moving the industry toward the vision of "zero waste".

Anode casting in Harjavalta foundry (Credit: Boliden)

Rönnskär recycling (Credit: Boliden)

3.4.1 Focus areas for strategic research and innovation

Limitation of the carbon footprint and secure and sustainable supply of CRMs.

Metal production is an energy-intensive industry. In order to achieve the benchmarks of the CRM Act, extensive research and innovation to accelerate technological developments is needed for the metal production to stay competitive while adopting to climate neutral processes, including utilization of Carbon Capture and Storage and CCU solutions. Development of bio-based, electricity-based, and hydrogen-based processes for producing iron, copper, and other metals and minerals is an urgent priority.

Increasing the production of CRM in Europe will require the development and improvement of techniques for extracting these elements. This also includes new technologies for extracting CRM as a by-product from ferrous and base metals and from recycling. Making the process economically and environmentally viable is a necessity to reach the CRM Act objectives and this cannot happen without further research and development.

- New materials for emerging technologies and their procurement, production, and recycling.

Traceability and industry integration

- Use of the EU's digital product passport in the recycling industry to support a circular economy.

Decarbonisation

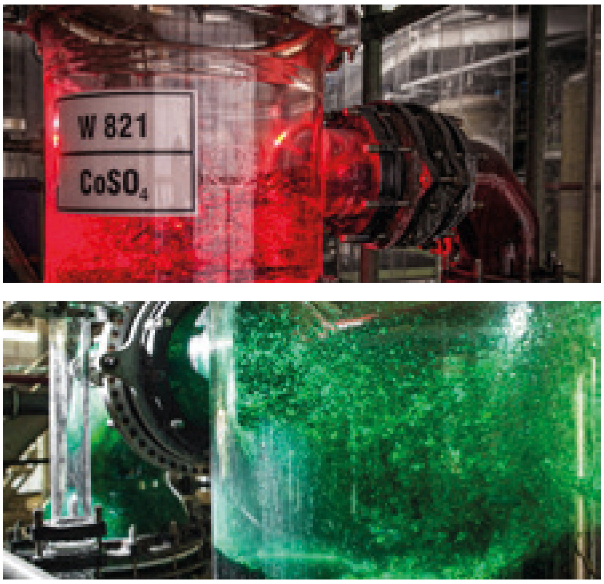
- Climate neutral processing and refining technologies, including the use of reagents with no carbon footprint.
- Alternative carbon free reduction agents that are technically and economically viable.

Process- and resource optimisation (primary- and secondary resources)

- Process design optimization using thermodynamic data and considering efficiency in the process route through new measurement technology, process modelling, and automation.
- Knowledge and technology to increase recovery yields and extract additional elements, including CRMs, from materials streams (primary and secondary).
- Technology, e.g., process control of slag properties and slag composition, to ensure the quality of by-products for use in new applications.
- Methods and business models to use secondary materials or side streams from internal processes or across business sectors to enhance efficiency and recovery of metals.
- Mechanical and chemical processing of complex products with minimal dissipation of CRMs.
- Reuse (compatibility; in terms of logistics, product optimisation, reintegration into life cycle, safety, efficiency)
- Setting up expert boards in knowledge building and identification of demand of action

Environmental performance

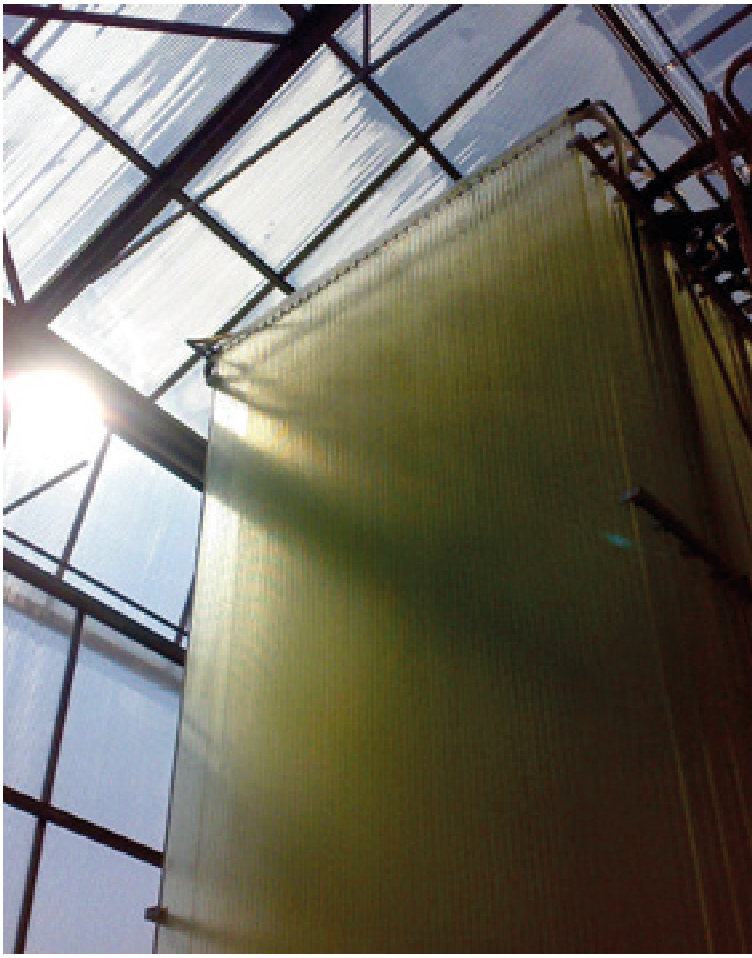
- Methods for optimized use of energy and water.
- Development of technologies with low atmospheric and water emissions with minimal impact on the environment.



Recycling Cobalt (Up) and Recycling Nickel (Bottom) (Credits: Nickelhütte Aue)

3.4.2 Expected impacts

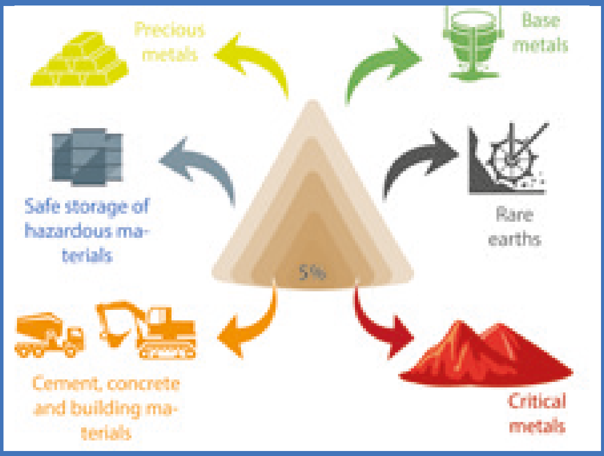
- Sustainable and climate neutral mineral and metal supply.
- Optimized processes for competitive and sustainable processing and refining capacity.
- Increased resource efficiency by increased minerals and metal recovery from primary and secondary resources.
- Efficient energy and water use.
- Development of a circular economy hub in the EU, using cross-sectoral process streams.
- Further development of markets for by-products.
- Reduced landfill/tailings.
- Increased security of supply of raw materials.
- Waste inventories of depositories and dumps (municipal landfills, domestic waste streams), improvement of waste use (redirection of waste streams).



Bioreactor in glass house (Credit: GKZ Freiberg).

Innovation in mineral processing and recovery techniques allows revaluation of ancient mining waste to recuperate precious and critical metals while reducing environmental impact.

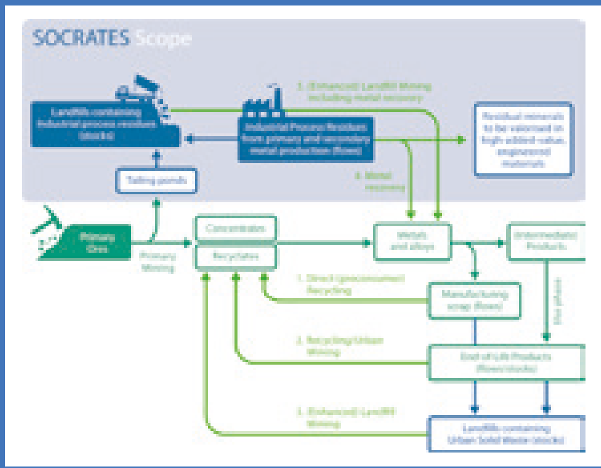
NEMO (Near- Zero – Waste recycling of low-grade sulphidic mining waste for critical-metal, mineral, and construction raw material production in a circular economy) Horizon 2020 project (GA n°776846) develops new methods to valorise sulphidic tailings with 95% of waste reduction. Two main objectives were achieved with the recovery of critical metals and the valorisation of mining waste thus cleaned for applications in construction.



NEMO concept[35] (Credit: NEMO project)

35. https://h2020-nemo.eu/outreach-communication/

SOCRATES (European Training Network for the Sustainable, zero-waste valorisation of critical-metal-containing industrial process residues) Horizon 2020 (GA n°721385) aims at an innovative metallurgical process that is environmentally friendly and can be integrated into a (nearly) waste-free valorisation flowsheet. By considering secondary raw materials, this project contributes to a more diversified and sustainable supply chain for critical metals.



SOCRATES Scope (Credit: SOCRATES project).

Trolleybanan Aitik (Credit: Boliden)

3.5 Decarbonization of operations in highly intensive process chains (smelting, refining/ hydrometallurgy)

The primary raw materials and the recycling industry substantially contribute to global CO_2 emissions and are facing increasing pressure from regulators, investors, and customers to decarbonize operations. While the upstream sector (mining with processing) accounts for 3% of global CO_2 emissions, aluminium production alone contributes this amount to total global emissions. To achieve a ≤1.5°C climate-change target by 2050, both sectors will need to reduce direct CO_2 emissions by breaking down the value chain with each share of current emissions, e.g., emissions from fuels, electricity as well as supply chain, transport including equipment (material), and process decarbonization.

Scooptram ST18 SG with operator and charging station (Credit: EPIROC)

3.5.1 Focus areas for strategic research and innovation

To further decarbonize the sector, CO_2-emissions from the entire raw material value chain need to be considered. Research and innovation will be necessary to optimize and introduce new energy systems as a heat source in energy intensive systems (processing, smelting, refining) and also utilize waste heat.

- Raising resource and energy efficiency.
- Improve operational efficiency.
- Sustainable drivetrains.
- Introduction of new energy systems as a heat source in energy intensive systems (processing, smelting, refining) and utilization of waste heat.
- H_2 production and utilisation technologies in the high-energy intensive sectors in refining and metallurgical operations.
- Optimization of electrolysis processes in hydro-metallurgy.
- Development of new production routes.

3.5.2 Expected impacts

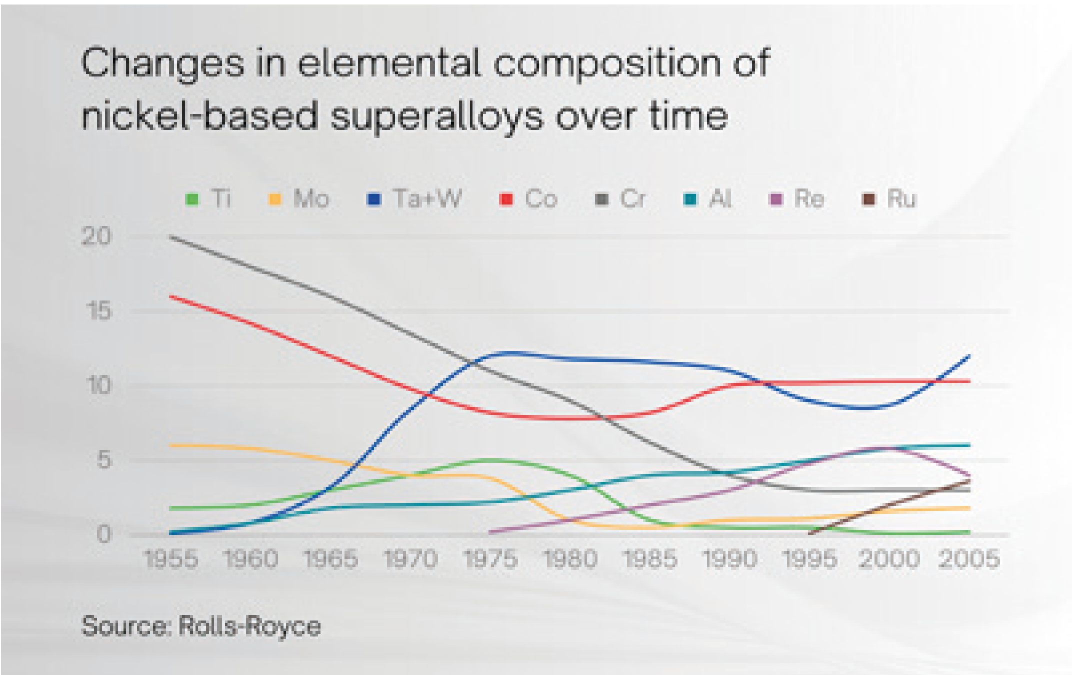
- Minimized CO_2 emissions.
- Reduction of operational costs.
- Improved social acceptance and increased investment attractiveness (following EU taxonomy).
- Raised competitiveness in the mid- and long-term.

3.6 Forecast and substitution of raw materials

Raw materials substitution implies effective and efficient use of raw materials to minimize losses along the process system as well as using different raw materials that will not generate waste during processing. More than this, substitution has become an important measure to especially the following three dimensions to mitigate: (1) supply risk, e.g., cobalt in lithium-ion batteries, (2) environmental implications, e.g., lead-free solders, and (3) strategic significance, e.g., alloying elements in superalloys used in defence technologies. This ultimately translates to reformulating and redesigning products that will be more environmentally friendly, less energy intensive, and which reduce the above impacts. The decarbonization of industry is another driver for the search for substitute raw materials. For example, a well-known industrial sector searching for substitution is cement production, searching for a raw material as a calcium supplier to replace limestone. This is because the calcination of limestone (conversion by thermal decomposition into lime CaO and CO2) is responsible for a large proportion of CO2 emissions. However, substitution is also an important part of material research in itself: recent developments in material science and engineering, metallurgy, polymer sc ience, chemistry, glass, and ceramic technologies, are continuously generating new structural and functional materials offering possibilities in a wide area of applications, including defence. A specific example, optimisation of the composition of a nickel-based alloy used in turbine blades, over time, is shown in the chart below.

Since materials research is not specifically anchored in the raw materials sector, it will not be discussed or considered further here. Nevertheless, quite a few CRM/SRMs originate from secondary raw material cycles, especially in the processing to refining part of the value chain, be it as primary- or by-product. This is where research comes in: to keep substitute raw materials in these process flows in terms of quality and quantity and to optimize them as required. This applies in particular to the backward integration of smelters in terms of feed composition and mix of primary and secondary raw materials.

By 2040, Material substitution has substantially reduced CRM and SRM product criticality, contributing to mass reduction and enhanced durability (such as in alloys for aeronautics and defence) and reduced machining/process time at a cheaper raw materials price. Substitution of cement constituents (e.g., clinker) and replacement of limestone by non-carbonate bound calcium has significantly reduced CO_2 emissions from cement production. Novel anodes and cathode materials from European research and development and commercialization have sustainably increased the competitiveness of European battery manufacturers. European smelters have achieved important technology leaps from research and development in metallurgical by-product extraction, contributing to the raw material security of CRMs and SRMs.



Changes in elemental composition of nickel-based superalloys over time (Source: Rolls-Royce36)

3.6.1 Focus areas for strategic research and innovation

- Identify CRMs that constitute limiting factors for production of the quantities of products required by foreseeable demands (e.g., new generations of energy storage systems) and forecasting under various scenario assumptions/dimensions.
- Investigate the substitutability in terms of technology development trends that determine, for the long term, the supply of specific CRM/SRM.
- Investigate metallurgical processes and determination of kiln parameters.
- Investigate reuse of waste and secondary waste streams for new raw materials in terms of raw materials substitution.

3.6.2 Expected impacts

- Reduction of waste and increased materials and energy efficiency.
- Reduction of environmental footprint.
- Reduction of supply risk and strategic significance.
- Contributions to materials research.
- Increased competitiveness of smelters and profitability of processing and refining.

Kaunis Iron, who operates an open pit mine in Pajala municipality carrying out Sweden's largest wetland restoration, in total about 700 hectares forest and wetlands until 2025. The aim is to promote biological diversity near the mining area. (Credit: Kaunis Iron).

3.7 Environmental performance

For successful environmental performance, a holistic and long-term perspective over the entire mine life—from exploration to mine closure and the following post-mining and remediation—is necessary. Environmental performance is a cross-disciplinary topic with links and dependencies to all parts of the value chain. Some relevant topics are therefore already covered under the chapters 3.1 to 3.6 Additional topics are addressed here.

National- and EU-legislation as well as operating permits require control of water and biodiversity status and waste management. Increasing understanding of the sector's environmental impact requires constant development of more environmentally neutral technologies. Mining, unlike most other industries, is not relocatable, which is a particular challenge. A mine can only be established where an ore deposit exists. This implies that the mine's operations must be adapted to meet the environmental requirements and reduce the impact on nearby areas and activities. For example, if the status of a nearby water body is not considered as sufficient according to objectives of the Water Framework[36] Directive, the "non-deterioration principle" essentially inhibits any mine development, even if the mine is considered critical for society. Acid and neutral mine drainage is the most prominent root cause of environmental issues in the mining industry and preventive measures and innovative solutions are required along with a reduction in emissions. Even though mines strive to minimize waste, there will be a need to safely store waste and improve waste management. The mine must also take into account the biodiversity present at the site to minimize and compensate for the impacts of mining. Global research shows that biodiversity loss is as substantial a threat to our planetary boundaries as climate change. Different methodologies to restore mine sites that take into consideration local biodiversity and climate must be developed. As new EU laws and regulations are developed to ensure the highest environmental performance, the science community must also contribute with research to ensure that new legislation is based on verified scientific data and knowledge.

By 2040, the environmental and climate impact of the minerals and metals industry, throughout the value chain, has substantially decreased. Mining technologies are climate neutral, and climate neutral processes and fossil-free energy use will be achieved by 2045. The EU minerals and metals industry has been a forerunner in implementing climate neutral technologies and processes for both primary and secondary resources. A strong focus on waste management has substantially reduced the amount of waste and accurate environmental monitoring shows little or no impact from existing or closed mine sites and related facilities, and open pit mine sites experience a renewal of biodiversity. The minerals and metals industry work actively towards reducing impacts on biodiversity, restoring habitats in compensation for any such effects.

36. https://environment.ec.europa.eu/topics/water/water-framework-directive_en

3.7.1 Focus areas for strategic research and innovation

Diversified approach towards the impact of climate change on the Raw Materials sector.

Europe has a very diverse range of climates, from the Mediterranean to the Arctic, and the changing climatic conditions are affecting these regions in a variety of ways. New technology and methodologies are required in face of these challenges, with an approach suitable to the wide range of environmental conditions. Dry stacking is a topic that could benefit from such R&I and would require pilot studies to test the different response of the residue under different climate conditions in Europe. Protecting biodiversity is a global challenge and interlinked with climate change. Tools and measures to preserve and develop good biodiversity status need to be developed.

Air and water

- Water management throughout mine life to after mine closure.
- Dam safety and tailings management.
- New technologies for air emissions management.

Waste

- Waste management for:
  - different ore types.
  - different climate settings (e.g., feasibility of dry stacking in wet climates).
  - optimisation in relation to climate change.
  - increased circularity.
  - development of new products from waste streams.
- Design of cost-efficient treatment, reclamation, and prevention technologies to reduce the release and mobilization of unwanted elements.

Models and assessment

- Improve characterization, prediction, modelling, and environmental impact tools for new and existing technologies.
- Traceability tools and business models for sustainably produced metals and minerals.
- Holistic assessment of environmental effects.
- Tools and measures to preserve and develop good biodiversity status in exploited areas.
- Mine closure processes for post-mining land-use and measures.

3.7.2 Expected impacts

- Minimised environmental footprint.
- Safe and climate-adapted waste management.
- Methods, technologies, and tools for assessment and improvement to secure good water and biodiversity status.
- Fewer land-use conflicts.
- Verified scientific data and knowledge to enable science-based policy development as well as adoption and implementation of directives, standards, and legislation.
- Improved social license to operate.

Zinkgruvan mine wind turbine fields (Credit: Zinkgruvan mine).

Supporting the energy transition in mining is essential to minimize environmental, economic and social impact

TRACER Horizon 2020 project[37] (GA n°836819) aims to support the transition from coal to a sustainable energy system in nine coal-intensive regions in Europe. Research and innovation strategies must be reviewed and include social, environmental, and technological challenges. The remediation of post-mining landscape is also an important topic of this project with a focus on ecological restoration.

Spontaneously overgrowen Hornojiřetínská spoil heap (Credit: Markéta Hendrychová[38]) .

Site-specific solutions

Site specific solutions are central in optimising operational practice, safety, benefit to society, and environmental impact, particularly in the selection and implementation of waste treatment and disposal techniques. Indeed, exploitation of non-renewable resources obligates optimal production solutions to avoid irreplaceable loss, requiring consideration of the entire value chain from exploration to reclamation.

Optimal solutions for mineral production will always be site specific because of the vast natural variability in ores and deposit types, complexity of production processes, and varied geographical settings of production. For example, considering tailings, a high-quality calcite concentrate can be produced from marble producing <10% of the mill feed as tailings. In contrast, tailings from processing of copper ore would usually exceed 98%. In the latter case, the bulk tailings volume would be considerably greater than the volumes excavated by the mining process, making deposition by backfilling alone inadequate.

Given the great natural variability in mineralogical and chemical tailings, waste materials will also vary greatly in their potential for pollution and valorisation. Since the environmental impact will depend on many factors (e.g., mineralogy, geology, topography, hydrology, biology, technology), the optimal solution becomes site specific and must be determined through a comprehensive impact assessment. Advocating certain alternatives as the only permissible solutions or imposing blanket bans on others will guarantee sub-optimal performance. Similarly, the site-specific conditions of mineral deposits need to be taken into account when granting authorisations, especially if mining is to be included in the Industrial Emissions Directive. Environmental Impact Assessment procedures will always be part of such procedural processes and guideline values employed by national environmental and regulatory authorities need to reflect local conditions in order to avoid misinterpretation of data and to achieve optimum results.

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37. https://tracer-h2020.eu/
38. https://tracer-h2020.eu/wp-content/uploads/2022/10/CZ04_Spontaneous-succession-North-Bohemian-post-mining-landscape.pdf

Staff in the Sandvick control room (Credit: Sandvick)

3.8 Social performance

Everywhere mining, quarrying, or refining and recycling activities occur, there is an impact on the local community. While the industries often provide jobs and economic benefits, operations can affect the surrounding area through competing land use, a changed environmental landscape, as well as impacting society at large through the need for new skills and for housing, schools, and services to avoid fly in fly out operations. Corporate social responsibility (CSR) is key for the operations to receive Social License to Operate (SLO). This involves, e.g., setting sustainability criteria and indicators recognised by key stakeholders, consultation processes, and addressing environmental and community values. Social science research addressing the industry's relationship with other stakeholders and its contribution to sustainable development must be initiated. Fact-based communication and information on industry impact from the research community and public authorities is needed to complement the industry's own communication and sustainability reporting. Achieving SLO is especially challenging in areas where no mining has been carried out for a long time and where common knowledge of its impact among stakeholders is low.

By 2040, the minerals and metals industry is widely accepted as a key enabler for the energy transition to a climate neutral society. Different tools to integrate stakeholder have been developed and are widely used by the industry to achieve Social License to Operate. The minerals and metals industry is regarded as an attractive workplace as it is at the forefront of new technology and sustainability.

Awareness building young careers Barracupuerdo Scheelite samples in UV light (Credit: GKZ Freiberg)

WHAT WE NEED?

Social acceptance has become a central element in the entire raw materials value chain, from exploration to recycling. Nowadays, social performance is closely studied for the approval of industrial projects. Lack of integration by the local community puts an end to a project before it starts. This factor is also a priority for attracting competent personnel and ensuring gender equality and diversity within the raw materials sector. The reopening or expansion of mines and mineral industries in Europe cannot happen without social acceptance and appropriate communication and education must be carried out upstream at different levels (European, national and regional).

3.8.1 Focus areas for strategic research and innovation

Corporate social responsibility and sustainable business

Corporate Social responsibility and sustainable business models require incorporation of social and environmental considerations into the companies decision-making processes, as well as accountability for the impacts of its decisions and activities on society. CSR can generate shared value by integration of sustainability considerations into the entire value chain and by identifying and involving stakeholders in the decision-making.

- Social science research addressing the industries' interaction with other stakeholders for mutual benefit and regional growth.
- Develop strategic tools and guidelines for improved stakeholder management, sustainable supply chain management, community development practices, and social innovations.
- Develop a toolset of sustainability criteria and measurable indicators addressing various environmental and community values.
- New business models addressing social or environmental problems or conflicts of interests.

Regional development and benefit-sharing instruments

Improved knowledge is needed about the impact of minerals and metals operations on regional development, migration and commuting patterns, job creation, and recruitment challenges. Identification and evaluation of different instruments that can be adopted to amplify positive impacts—benefit sharing—is also an important research field.

- Studies on regional economic impact on mining operations and the role of benefit sharing.
- The potential impact of the CRM Act on future labour recruitment needs, labour mobility, and labour migration impact on mining communities.
- Identify and evaluate strategies on how to promote economic and social cooperation between the industry and local communities and regions.

Management of land-use conflicts

It is often unclear how mineral interests interact with other land use interests and how the different interests are valued in relation to each other. Underlying many land use conflicts are different values and aspirations that should be addressed in ways recognised by all parties. This calls for research tools to evaluate impacts and how the regulatory frameworks address stakeholders, interests, goals and practices, including the role of communication and local participation in planning processes by all parties (industry, authorities and community stakeholders).

- Identify causes and challenges in land-use conflicts with respect to current institutions and practices and develop tools to enhance the quality of stakeholder interaction and relationships.
- Identify and evaluate strategies, practices, and regulations that could improve the legitimacy and efficiency of land use decision making with respect to permitting processes.
- Handbook for conducting cost-benefit analysis for minerals and metals industrial developments to support, e.g., legal processes and decision making.

Gender equality and diversity

To maintain competitiveness, the minerals and metals industry needs to be open to all. A report published by GENDERACTION states that the higher a country scores on gender equality, the higher its innovation potential. Moreover, research shows that companies with more gender-equal boards deliver more economic growth[39]. However, the mining industry has long been male-dominated and research and innovation are needed to find tools to broaden the recruitment base and make the mining industry attractive for all.

- Examine how diversity and gender in the minerals and metal industry connect to technological, organisational, and cultural development.
- Identify problematic patterns and consider how new diversity and gender equality in the sector can be constructed, implemented, and made productive (i.e., understanding the business effect of gender equality and diversity).
- Organization, learning, and leadership fostering gender equality and diversity.

3.8.2 Expected Impacts

- Improved Social Licence to Operate.
- Improved local community involvement.
- Improved recruitment base.
- Improved education, training, and employment opportunities for communities.
- Improved opportunities for local economic growth.

Boltec M Battery in workshop (Credit: EPIROC)

Student laboratory training (Credit: Leoben University)

39. https://h2020.genderaction.eu/wp-content/uploads/2020/06/D3.2._MonitoringERApriority4implementation.pdf

Towards Sustainable Mining (TSM) – an example of transparency standards development

A wide variety of standards and initiatives exist which are relevant to transparency within the mineral production value chain, health, safety, and environmental protection. There is considerable development within this sector, embracing new initiatives, adaptation, and extension of current initiatives, with work on harmonisation and equivalence between different initiatives and standards.

The Mining Association of Canada's TSM initiative is one such example. TSM is currently in use in 13 countries (Canada, Australia, Botswana, The Philippines, Argentina, Brazil, Columbia, Guatemala, Mexico, Finland, Spain, Norway). Finland was the first country to adopt TSM after its implementation in Canada. TSM consists of a set of protocols which mines self-assess annually, with independent external verification of ratings every third year. Information must be publicly available on a dedicated online platform. This system also utilises a Community of Interest Panel. Harmonisation with other initiatives and standards is in progress

INDIGENOUS

Individuals who represent the interests of Indigenous peoples

ENVIRONMENTAL NGO

Individuals with environmental expertise and experience in advocacy for environmental protection

ECONOMIC AND COMMUNITY DEVELOPMENT

Individuals with expertise in business development at the community level and knowledge of community interactions with mining facilities

SOCIAL, NGO, INCLUDING FAITH-BASED GROUPS

Individuals who represent civil society with knowledge of social justice issues

INTERNATIONAL DEVELOPMENT

Individuals with expertise in alleviating poverty and improving the standard of living through responsible development

FINANCE AND INVESTMENT

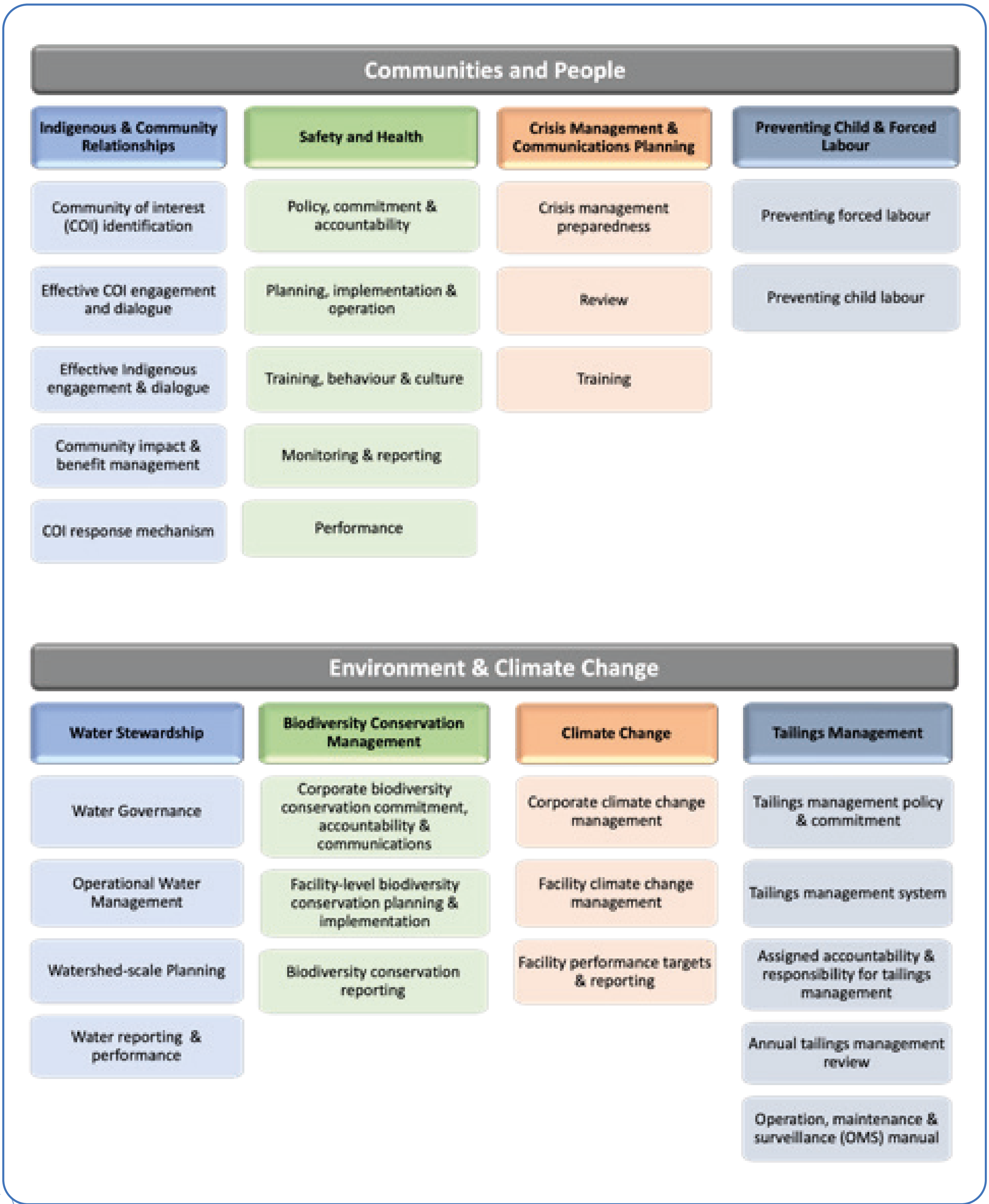
Individuals with financial expertise and knowledge of socially responsible investing

LABOUR AND WORKPLACE

Individuals with knowledge of the interests, safety and needs of workers

MINING COMPANY

Senior representatives of mining companies that are members of the national association

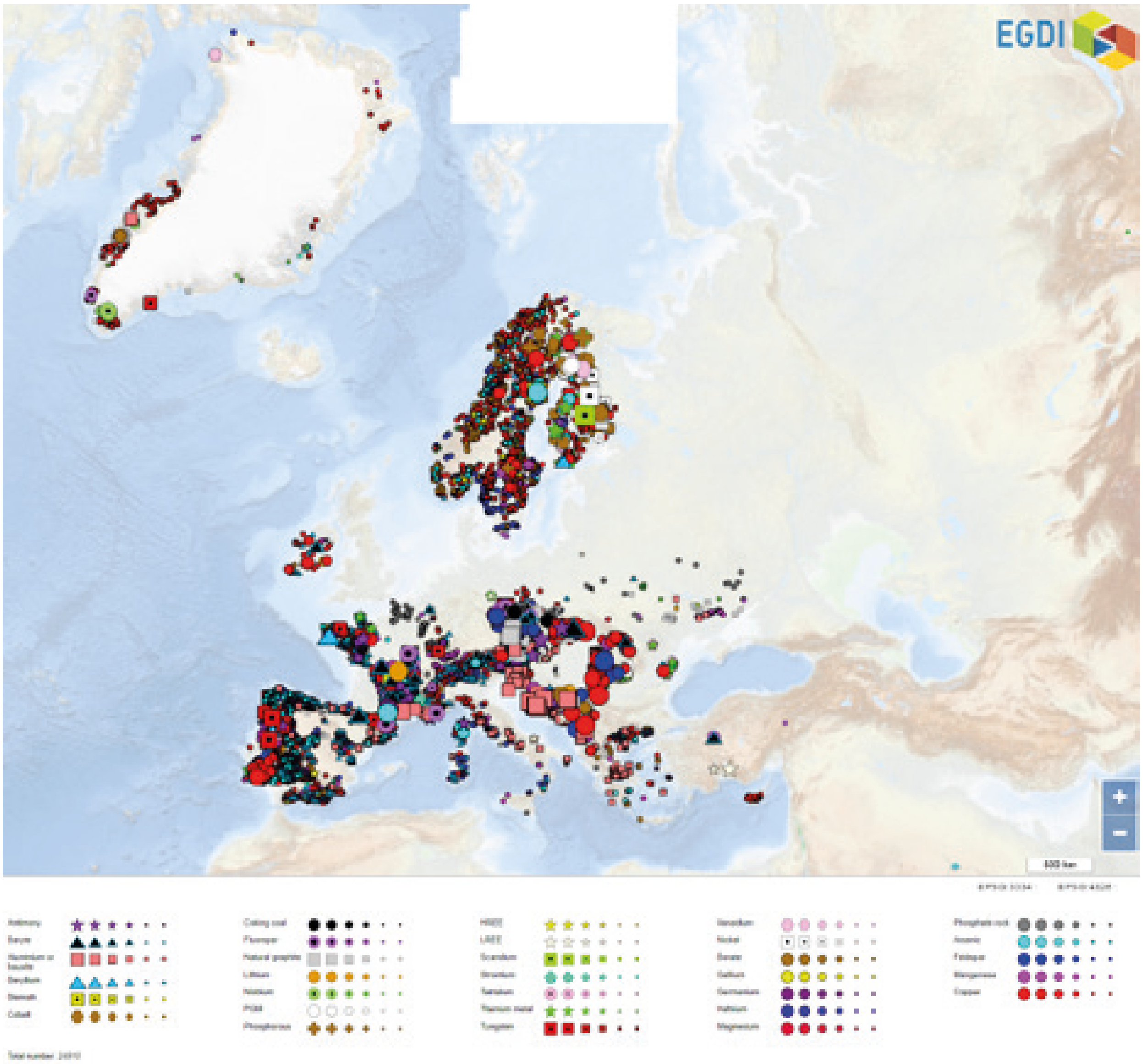

Communities and People
Indigenous & Community Relationships
Community of interest (COI) identification
Effective COI engagement and dialogue
Effective Indigenous engagement & dialogue
Community impact & benefit management
COI response mechanism
Safety and Health
Policy, commitment & accountability
Planning, implementation & operation
Training, behaviour & culture
Monitoring & reporting
Performance
Crisis Management & Communications Planning
Crisis management preparedness
Review
Training
Preventing Child & Forced Labour
Preventing forced labour
Preventing child labour
Environment & Climate Change
Water Stewardship
Water Governance
Operational Water Management
Watershed-scale Planning
Water reporting & performance
Biodiversity Conservation Management
Corporate biodiversity conservation commitment, accountability & communications
Facility-level biodiversity conservation planning & implementation
Biodiversity conservation reporting
Climate Change
Corporate climate change management
Facility climate change management
Facility performance targets & reporting
Tailings Management
Tailings management policy & commitment
Tailings management system
Assigned accountability & responsibility for tailings management
Annual tailings management review
Operation, maintenance & surveillance (OMS) manual

3.9 Raw Materials policy and monitoring

The CRM Act imposes challenging benchmarks for (near) future domestic raw materials consumption for extraction, processing, and recycling, as well as for sourcing of strategic raw materials from any single third countries (see section 1.2). Raw Materials policy on regional, national and EU- level will impact Europe´s ability to secure access to sustainably produced mineral resources. Well-functioning raw materials policy should also consider that viable mineral deposits are very difficult to find and cannot be relocated. Exploration and mining companies in Europe have pointed to the lack of flexibility in EU environmental legislation to take account of local conditions and the fact that a mine is not relocatable. Some European countries also face diverse obstacles such as the overlap between areas with high mineral potential and nature conservation areas and the difficulty in balancing different interests, water issues, climate conditions, and varying social acceptance. There may, therefore, be a case for examination of legislative barriers to the EU's ability to increase domestic production from both primary and secondary sources. Previous studies have mostly focused on Member States' implementation of legislation, best practices, and guidelines (for example MIN-GUIDE, MinLand, MIREU). These types of studies and projects are important, but there is a need to examine whether there are barriers based on the design of EU law and more, built in conflicts in EU regulations. The CRM Act goes some way to addressing some of these issues by potentially allowing the development of strategic projects to take precedence over EU environmental laws if they are of overriding public interest.

It is also important that new as well as current legislation and policy making is based on sound science. A European raw materials policy needs to consider the competitiveness of the minerals and metals industry and should not lead to an increased ecological debt in third countries. A modern, environmentally friendly, and economically viable raw materials industry is based on the highest standards. Investments in research and innovation will help the EU to set more global standards and improve the implementation of environmental, social and governance (ESG) standards. Involving the research community is vital to ensure that current EU-legislation is based on verified research findings, not the subject of an ideologically driven discourse. Again, in this regard, the CRM Act goes some way to addressing some of these issues, as it is founded on strong ESG standards enshrined in the UNFC for raw materials.

National geological surveys play a central role in providing new geological data and information on the mineral potential of each country. At the same time, to meet the ambition of >10% domestic (EU) CRM supply, more extensive mapping of the EU's overall potential regarding mineral resources and mineral flows is needed to promote commercial exploration activity. This is recognised in the CRM Act in the requirement for Member States to carry out national exploration programmes. Current groupings and functions such as EuroGeoSurveys (EGS) and the Raw Materials Information System (RMIS) are important but currently do not have enough capacity to meet the needs of policy makers, investors, or other users. Similarly, projects such as SCRREEN are central to building a network of experts and knowledge about CRM, future needs, and metal flows. There is a need for an office/mission or organization that takes on board information from Member States and from various EU projects to ensure an overall picture of the EU's mineral potential, metal needs and dependencies. Researchers, policy makers and any other interested stakeholders should be able to gain overviews of the state-of-the-art of knowledge and research with the possibility to filter and search according to certain criteria, such as materials, product groups, CRM markets and their characteristics (e.g., Herfindahl index, price volatility, key players etc.). In this respect, the installation of a Critical Minerals Intelligence Centre by the British Geological Survey, and similar initiatives in France and Germany, can be seen as an exemplary model for a similar initiative at EU level, which is being investigated by the Horizon Europe funded project "A Geological Service for Europe" (GA n°101075609), which aims to establish a sustainable Geological Service for Europe, which would draw on a permanent network of European GSO and their research partners, united in delivering harmonised pan-European data, information, and knowledge through the European Geological Data Infrastructure (EGDI).



Mineral occurrences and mines in Europe (onshore) (MIN4EU DB - The European Minerals Intelligence Database (2022)[40]. Category/Dataset: All Critical Raw Materials / All deposit importances/ All deposits/ All statuses. Retrieved from: https://data.geus.dk/egdi/?mapname=egdi_new_structure#baslay=baseEMODnet&extent=-4842030,693010,8897000,7068780&layers=egdi_mineraloccurr_critical_raw_materials_2023&filter_0=crm_2023.multi%3D%26commodity_importance.multi%3D%26has_oremeasures%3D%26mine_status.multi%3D (accessed on: 20/10/2023).

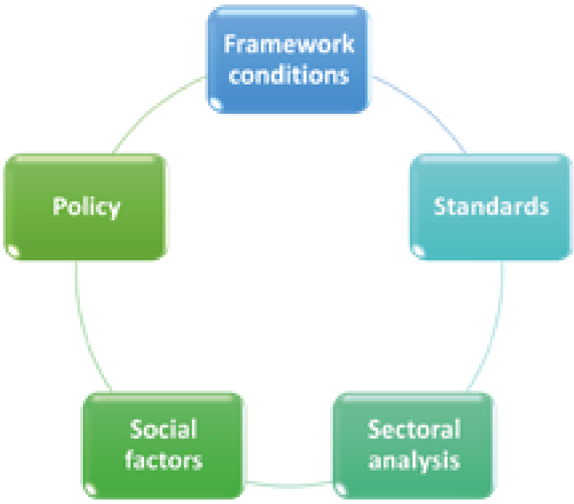
By 2040, effective implementation of the CRM Act has resulted in significantly increased knowledge of the geology and mineral potential of Europe, attracting exploration investment, and boosting associated basic and applied research and innovation. The establishment of mineral strategies in many Member States contributes to supporting a pan-European strategic direction for raw materials policy, boosts exploration and mining activity, supports high industry standards, and contributes to increased social acceptance. A sustainable Geological Service for Europe, grounded in a permanent network of European GSO and their research partners, provide ongoing strong science-informed policy support.

40. The data originates from European national repositories for mineral resource data and have been harmonised through several projects, partly funded by the EC, including Minerals4EU, EURare, ProSUM, ORAMA, MINTELL4EU and RESEERVE during the last 15 years. The data is provided by EuroGeoSurveys through the MIN4EU database of the European Geological Data Infrastructure, EGDI (https://url12.mailanyone.net/scanner?m=1qt4CM-00015H-5Z&d=4%7Cmail%2F90%2F1697626200%2F1qt4CM-00015H-5Z%7Cin12b%7C57e1b682%7C15209072%7C14343128%7C652FB9766854AF7E731612E911F5E20C&o=%2Fphtw%3A%2Fwtseuw.gop-erue.ygoloe&s=isKzRx8HtuTmYIrX34yQn0pRU70) and are available through CC BY 4.0 licence.

WHAT WE NEED?

In recent years, numerous regulations have been put in place to ensure a sustainable future (e.g., Nature Restoration Law, Water Framework Directive, CRM Act, etc.). These regulations significantly impact the Raw Materials sector and are not necessarily harmonized or adapted to this sector of activity. Research and development could be carried out to define suitable objectives for the Raw Materials sector, identify inconsistencies and obstacles in the EU regulatory framework and propose harmonized regulations at European and MS levels. Legislation must sufficiently take into account the climate variations, natural background levels, and the diversity of the natural environment in the EU.

3.9.1 Focus areas for strategic research and innovation



Framework conditions

- Research and analysis that identifies inconsistencies and obstacles in the EU regulatory framework that hinder domestic minerals supply (exploration, mining, and recycling) and suggests how to reduce institutional risks for investments that depend on the use of land and water.

- Framework conditions for financial aid to bridging "valley of death".

Standards

- Research and analysis to support the development of standards for a competitive mining and minerals industry with high ambitions for safety and environmental performance.

Sectoral analysis

- Research and analysis on total raw materials needs, comparing them to exploration findings, the evolution of mines and eco-settings at production sites.

- Identify CRMs that constitute limiting factors for production of the quantities of products as required by foreseeable demands (e.g., new generations of energy storage systems) and forecasting under various scenario assumptions.

- Research in chemicals needed in production of interim products.

- Research on business and social models including novel models involving commodities/raw materials / social contracts as part of new provision models.

Social factors

- Research on social behaviour towards waste as a resource (combined with new business models as a service)

- Harmonisation of MS regulation on waste.

- Social research on how to enforce restrictions on illegal exports combined with international collaboration.

Policy

- Cohesion policy on Member States' policy-making on strategic alliances in the secondary and primary raw materials life cycle (in terms of decision making and concerted actions).

- Policies on new financial incentives on high-risk investments in niche markets and emerging technologies.

- Policies on bringing in new stakeholder groups (expanding the expert groups on resource topics or engage "hidden" stakeholder groups).

3.9.2 Expected impacts

- Fact-based assessments for policy decisions and regulatory measures.

- Science based policy decisions.

- Mineral- and mining industry at the forefront of policy development of standards.

- Enhanced monitoring capacities.

Since 2010, Europe has determined a list of critical and strategic raw materials for its economy. To guide policies, it is crucial to have up-to-date and global data covering the entire value chain from production to the final use of materials.

SCRREEN H2020 project (GA n°958211) aims to produce an updated CRM list to guide the implementation of EU industrial policy, help prioritise action in trade agreements, research, and innovation to increase European competitiveness. This project produces reports and factsheets to facilitate decision making based on strategic knowledge and to disseminate knowledge to the general public.

SCRREEN Factsheets (Source: https://scrreen.eu/)

3.10 Global partnerships

The European minerals and metals community needs to strengthen its research partnerships with other resource-rich countries and increase our cooperation with technically advanced countries. Europe must look to other existing strong exploration and mining jurisdictions to learn how to build and sustain a mineral and metal ecosystem that fosters research and innovation capacity and succeeds in building a pipeline of new mineral projects and potentially new mines and refining capacities. ERA-MIN, the pan-European network of research funding organizations supported by EU Horizon 2020, has enabled such collaboration with, e.g., Canada, Brazil, and South Africa. It is important to support and strengthen such initiatives.

In the first pillar of the EU Raw Materials Strategy, the EU has committed to pursuing Raw Materials Diplomacy by reaching out to non-EU countries through strategic partnerships and policy dialogues. The focus for the dialogues has primarily been on access to raw materials in global markets, but also common interests in raw materials issues, e.g., the cooperation between the EU, Japan, and the US launched in 2011 to promote research cooperation in CRMs and several recent EU bilateral strategic partnerships. Other initiatives, such as the Minerals Security Partnership[41], also focuses mainly on catalysing investment from governments and the private sector to identified strategic projects. However, such initiatives could also potentially be used to boost research and innovation partnerships.

The geopolitical context has changed in a short period of time and there may be a need to identify key partner countries for different parts of the mineral value chain and for different types of mineral commodities. The EU efforts in establishing bilateral strategic partnerships on raw materials with countries in Europe, central Asia, Africa, and the Americas contributes to building future resilience in EU raw materials supply chains.

By 2040, the EU will provide strengthened support for international collaboration with the EU research and innovation community, including in relation to EU bilateral strategic partnerships. These international partnerships will strengthen EU's international strategic relationships, boost ESG standards and commercialisation of innovation related to the EU raw materials value chain, building resilience in the EU raw materials supply chain.

Key actions

- Strengthening current initiatives such as ERA-MIN and successor partnerships, connecting them with similar research funding initiatives from partner regions, giving access to a stronger research and innovation community, and strengthening strategic CRMs resilience.
- Build on existing strategic partnerships on raw materials to further strengthen research and innovation initiatives.
- Identify key partner countries for different commodities and different parts of the mineral value chain.

European and non-EU partnerships and joint research and innovation projects in the mineral resources sector are key to building a circular economy.

ERA-MIN Horizon 2020 funding programme (GA n°730238 (ERA-MIN 2); n°101003575 (ERA-MIN3)) was established to reinforce the EIP R M, the EU Raw Materials Initiative and further develop the raw materials sector in Europe through funding of transnational research and innovation activities. This project enabled collaboration with several non-European countries (e.g., Canada, Brazil, South Africa, Turkey, Argentina, and Chile) on raw materials for sustainable development and the circular economy[42].

41. https://www.state.gov/minerals-security-partnership/.
42. https://www.era-min.eu/dashboard

4. HOW TO HANDLE INNOVATION

Innovation is key to achieving the strategic ambitions of the ETP SMR, which in turn will contribute strongly to achieving the energy transition and the broader goals of the Green Deal. But innovation is not a switch that can be turned on. Not is it a linear process once underway. Innovation requires the right framework environment to flourish. In one sense, after decades of decline in exploration and mining activity, the EU is in a very challenging position regarding building a strong research and innovation environment to support the raw materials sector. Talent and experience have been lost abroad, and social acceptance has slipped away. But in another sense, the energy crisis, and the impact of war on Europe's weakened raw materials supply chains, and the requirements of the CRM Act to increase domestic resilience provide the ideal conditions for renewed innovation. Innovation is driven by demand, by problems and crises, and indeed also by new legislation[43]. If nurtured, the current geopolitical setting and drive toward increased resource independence and sustainability could move the EU into a new age of leadership in minerals and metals raw materials innovation.

However, innovation cannot be regarded as an isolated concept but is rather a combination of mindset, process, and outcome. To achieve innovation outcomes in the mineral and metals raw materials industry requires significant investment of time and resources, but also an innovation outlook, integrated into the framework in which research is funded and industry is regulated, supporting the required commitment to flexibility and risk. This is particularly the case in providing the right conditions for innovation to move from lab- to pilot-scale to commercial operation. A holistic, whole of value chain view is necessary. To achieve this strengthening of innovation in the European raw materials sector, requires a long-term and concerted commitment to funding research and innovation, to supporting collaboration and cross-sectoral knowledge sharing, and to building a supportive industrial framework while engaging broadly with stakeholders.

43. Taalbi, j., 2017. What dries innovation? Evidence from economic history. Research Policy, 46/8: 1437–1453.

Left picture credit: Epiroc

List of acronyms

CCS	Carbon Capture and Storage
AI	Artificial Intelligence
AR	Augmented Reality
CNIPA	National Intellectual Property Administration of the People's Republic of China
CRM	Critical Raw Materials
CSR	Corporate Social Responsibility
DRC	Democratic Republic of the Congo
ECHA	European Chemicals Agency
EGDI	European Geological Data Infrastructure
EGS	EuroGeoSurveys
EIP	European Innovation Partnership
EIT	European Institute of Innovation and Technology
EPO	European Patent Office
ERA	European Research Area
ESG	Environmental, Social, and Governance
ETP	European Technology Platforms
ETP SMR	European Technology Platform for Sustainable Mineral Resources
EU	European Union
GHG	Greenhouse Gas
GPS	Global Positioning System Geological Survey Organizations
GSE	Geological Service for Europe
GSO	Geological Survey Organisations
IEA	International Energy Agency
JPO	Japan Patent Office
KIPO	Korean Intellectual Property Office
LTC	Lithium-Cesium-Tantalum (pegmatite)
MRLs	Manufacturing Readiness Levels
NTNU	Norwegian University of Science and Technology
NYF	Niobium, Yttrium, Fluorine (pegmatite)
R&D	Research and Development
R&I	Research and Innovation
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
RMIS	Raw Materials Information System
SDGs	Sustainable Development Goals
SET-P	Strategic Energy Technology Pla
SLO	Social License to Operate
SRIA	Strategic Research and Innovation Agenda
SRM	Strategic Raw Materials
TRL	Technology Readiness Levels
TSM	Towards Sustainable Mining
UN	United Nations
UNFC	United Nations Framework Classification
US	United States
USPTO	United States Patent and Trademark Office
WIPO	World Intellectual Property Organization

Credit: Boliden

European Technology Platform
on Sustainable Mineral Resources

ETP SMR Secretariat
c/o EuroGeoSurveys, the Geological Surveys of Europe
36-38, Rue Joseph II - 1000 Brussels, Belgium
Tel: +32 2 888 75 53 - Fax: +32 2 503 50 25
info@eurogeosurveys.org

www.etpsmr.org