A competitive and sustainable mineral and mining industry

2022

Strategic research and innovation roadmap for
the Swedish mining, mineral and metal producing industry

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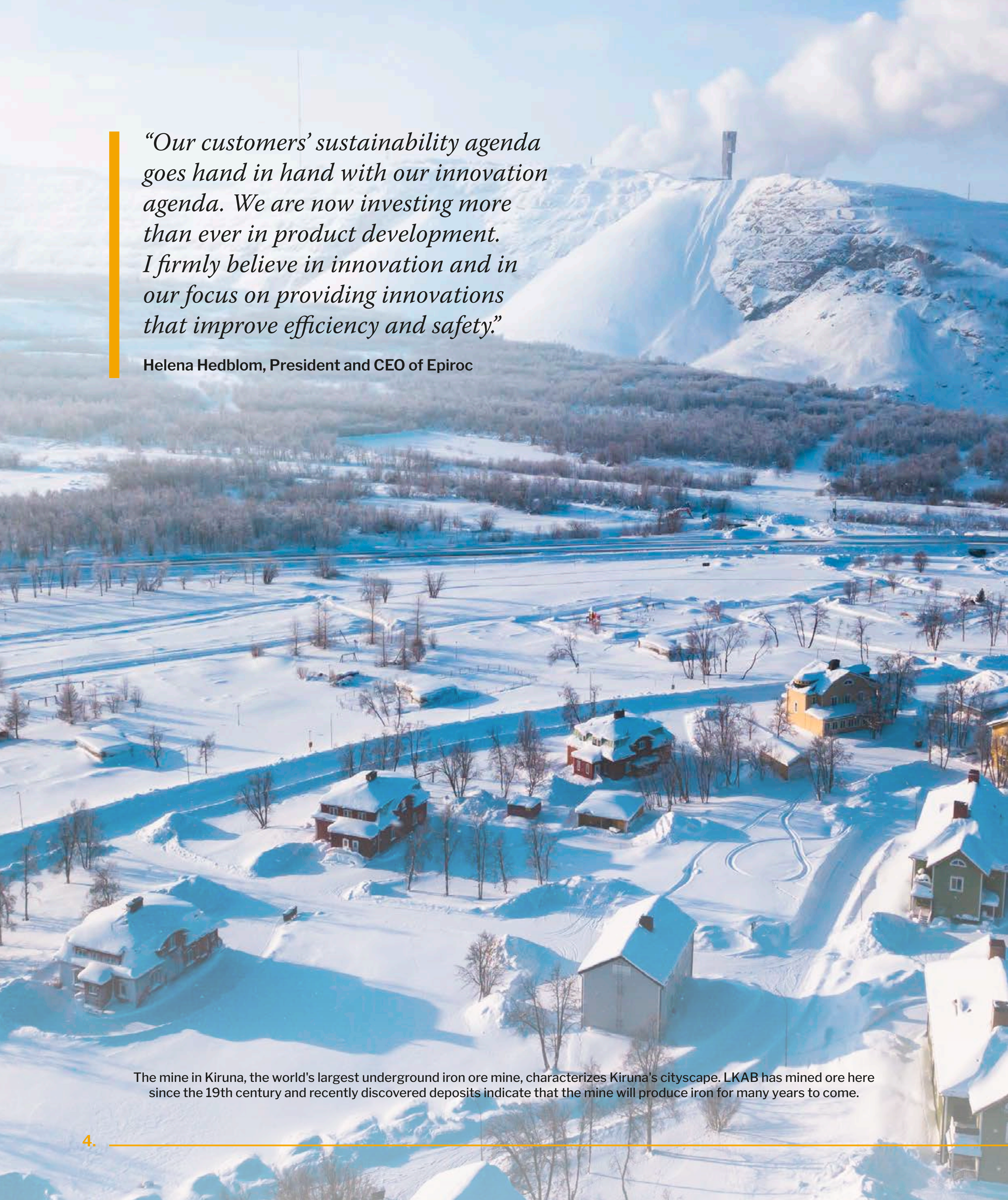


> *"Our customers' sustainability agenda goes hand in hand with our innovation agenda. We are now investing more than ever in product development. I firmly believe in innovation and in our focus on providing innovations that improve efficiency and safety."*
>
> **Helena Hedblom, President and CEO of Epiroc**

The mine in Kiruna, the world's largest underground iron ore mine, characterizes Kiruna's cityscape. LKAB has mined ore here since the 19th century and recently discovered deposits indicate that the mine will produce iron for many years to come.

Foreword

Minerals and metals are fundamental components of a growing and sustainable future society. Without iron ore, zinc, lead and copper, modern society as we know it would not exist and a future sustainable supply of these commodities is crucial. Minerals and metals are also key to the green technology urgently needed to reduce the climate impact of our societies. Never before has the need to secure a sustainable supply of metals and minerals been more urgent.

Back in the 13th century Sweden was already making significant strides forward as a prominent mining nation. Hard, physical work combined with a knowledge of where ore was located, and how to mine and process ore were naturally crucial factors in this. Without a bedrock rich in minerals, however, this success would not have been achieved.

Our world-leading position today, hundreds of years after ore began to be exported, is to a large extent the result of development and innovation, and often the application of pioneering Swedish research. The Swedish mining cluster is considered to be the most sustainable in the world. Extensive investment in creating a good working environment, the continuous upgrading of production methods to make them more efficient, and technical achievements have ensured that emissions in Sweden are lower than in comparable countries.

Going forward, Sweden should show global leadership and demonstrate the potential for the industry to reduce its climate footprint as well as highlighting the important contribution of the mining industry to the climate transition. But there is no room for complacency; the international competition is tough and continued substantial investment in research and innovation is called for if we are to maintain a leading position.

Since the first edition was published in 2013, the national research and innovation roadmap has brought the Swedish mining cluster together and has become an unsurpassed source of knowledge regarding the industry's research and innovation needs. Our ambition now is that it shall also chart the path towards the future, both for the mining cluster and Sweden as a mining nation.

Luleå and Zinkgruvan, May 2022

Jenny Greberg, *programme director, Swedish Mining Innovation*

Staffan Sandström, *chairman of Svemin's research and innovation committee and CEO Zinkgruvan Mining*

"World-leading productivity and sustainability performance require investments in research and innovation. We will continue to develop our unique Swedish innovation system."

Mikael Staffas,
President and CEO of Boliden

A world-leading mining cluster thanks to research and innovation

A THOUSAND-YEAR-OLD INDUSTRY WITH THE FUTURE AHEAD OF IT

The prosperity of Sweden has its origins in the bedrock. A thousand years ago, mining was already underway in Bergslagen to access the valuable iron ore located there, and since the middle of the 13th century Sweden has been one of the world's foremost iron ore producers. Swedish mines, some of which are considered the most productive in the world, now account for over 90 percent of overall iron ore production in the EU. Sweden is also important for its mining of the base metals copper, zinc and lead and precious metals gold and silver.

Over time, an extensive cluster of industries, universities, expert authorities and IT and telecom companies has grown up around the value chain that starts in the rock. These provide the mining industry with novel technical solutions, contributing to it with their curiosity, research and innovation and ensuring that the industry can benefit from the opportunities that digitalisation and automation bring.

Today Sweden is a world-leading mining nation, with sustainable and productive mineral extraction and an outstanding manufacturing base for underground equipment in particular. Swedish suppliers of mining equipment enjoy a global market share of around 60 percent for underground mines.[1] The level of digitalisation and automation in the Swedish mining industry is among the highest in the world. The collective strength in climate transition and the digital transformation of society, sometimes termed the twin transitions, will enhance productivity and profitability and safeguard competitiveness; but they will also mean a smaller ecological impact and greater safety for those who work in the industry.

COOPERATION IS THE KEY TO THE SUCCESS OF THE MINING CLUSTER

From the beginning the mining industry has created employment in large parts of the country, contributing to Sweden's economic development. The mining cluster now accounts for three percent of Sweden's gross national product and around 13–20 percent of annual industrial investment in Sweden.[2]

There are many reasons for the rapid development of the industry and its current position. A functioning market economy and free competition have been fundamental to this, along with the understanding that aging technologies, processes and products are continuously being replaced by new, better solutions.

Sweden's long tradition of cooperation between public sector and industry should also be highlighted. The collaboration between Asea and Vattenfall, for example, brought about the massive investment that enabled the rivers of Norrland to be tamed to produce clean, environmentally friendly and reliable electricity. Now we are seeing how access to fossil-free electricity in combination with the innovative power that characterises the Swedish mining cluster is giving Sweden an edge in the climate transition. From a global perspective, the

1. Material Economics (2021).
2. Copenhagen Economics (2021).

climate footprint of metals produced in Sweden is low, a full 60–90 percent lower than comparable countries supplying the same markets.[3]

A COMMON RESEARCH AND INNOVATION ROADMAP

To advance research and innovation, the industry seized the initiative early on to launch a collective discussion about the mining cluster's priorities. The first common research and innovation roadmap was published in 2013 and contributed directly to concentrating effort and advancing research and innovation where the needs were perceived to be greatest. However, this was not the first initiative. Several years earlier other joint research roadmaps were developed by the cluster.

The current roadmap describes the challenges facing the Swedish mineral and mining industry, the metal-producing industry and equipment suppliers, along with the research and innovation needs that are crucial to maintain a competitive, sustainable and responsible industry. This is the fourth edition of the roadmap since the start of 2013.

KEY TOOLS FOR IMPLEMENTATION

Sweden is one of the most research- and development-oriented countries in the world. Companies are responsible for around 70 percent of research investment.[4] It is a similar picture in the mining industry: most of the input on research and innovation carried out in the mining cluster to realise the priorities on the roadmap is financed by the big companies.

The significant injection of public funding in Sweden to support innovation over the last twenty years has strengthened the competitiveness of the mining industry in the international arena. A distinctive feature of the Swedish approach to innovation is the ability to swiftly apply the outcome of research in industrial settings. Over time, this type of research has acquired increasing importance. At the same time, it is crucial for public resources to be provided for basic research in the long term. An effective research and innovation system should contribute both to fundamental and needs-driven research.

PUBLICLY FINANCED RESEARCH AND INNOVATION

One of the long-term financing tools for implementing the roadmap is the investment in strategic innovation programs funded by Vinnova, Formas and the Swedish Energy Agency. The venture, which was initiated in 2012, covers a total of 17 programs. Many of these are relevant for the mining industry and metal-producing industry, but the single most important program is the strategic innovation program for the mining industry and metal-producing industry, Swedish Mining Innovation (SIP SMI).

As with other innovation programs, Swedish Mining Innovation funds investment tailored to the requirements of companies with a view to strengthening their competitiveness and innovative power. The aim is to develop cooperation between companies, academia, institutes and public sector, as well as to widen the cooperation already existing in respect of innovation to include more actors. Swedish Mining Innovation has also contributed to greater internationalisation by creating meeting places and forms of collaboration and to increased funding for Swedish players from various EU instruments.

There are several examples of financing tools that have been and continue to be of major importance for development in the sector and for establishing knowledge clusters, see fact box.

3. Material Economics (2021).
4. Confederation of Swedish Enterprise (2019).

Important financing tools

STRATEGIC INNOVATION PROGRAMMES

The strategic innovation programme (SIP) funded by Vinnova, Formas and the Swedish Energy Agency is an actor-driven initiative. SIP Swedish Mining Innovation is by far the most important instrument for the mining cluster, not only providing funding for research and innovation projects, but also enabling strategic dialogue, internationalization activities and events strengthening the innovation system.

INDUSTRIKLIVET

To support the transition, the Swedish Parliament decided in 2018 to establish Industriklivet. Through the program, which is financed by the Swedish Energy Agency, support is provided for preliminary studies, research projects, pilot and demonstration projects, and investment in developing solutions to reduce the process-related and often inaccessible emissions in industry. Since 2019, support has also been provided for developing what are known as negative emissions techniques. In 2020, Industriklivet was enlarged to include other industrial projects that can make a substantial contribution to achieving the climate objectives.

STRATEGIC RESEARCH AREAS

The Center for Advanced Mining and Metallurgy (CAMM) at Luleå University of Technology was established as part of the venture to create strategic research areas. Since 2010 it has become an important arena for targeted basic research in Sweden. The centre funds multidisciplinary research projects covering topics such as sustainable mining, reuse and recycling.

CHALLENGE-DRIVEN INNOVATION

Innovation and collaboration are a prerequisite for a sustainable society. The Challenge-driven innovation project, which is financed by Vinnova, funds collaborative projects that contribute to the sustainability goals of Agenda 2030.

BATTERY VEHICLE PROGRAM

Battery technology development is moving fast, but there is still a dearth of functional recycling methods for utilising components in the form of metals and minerals. The battery vehicle project financed by the Swedish Energy Agency provides support for research into battery performance and new recycling methods.

ADVANCED DIGITALISATION

Sweden is at the forefront of digitalisation, but this position cannot be taken for granted. To enable new products and services to be developed in Sweden, Vinnova is offering support to consortiums that by working together can contribute to components and system solutions for use in next-generation industrial digital solutions.

SUSTAINABLE INDUSTRY

Many of the initiatives taken to increase sustainability in Swedish industry are at a relatively early stage of development. Vinnova's prioritised Sustainable industry area supports ventures judged to have the prerequisites for growing into pilot and demonstration projects that can be developed into industrial solutions in the long term.

Formulation and development of the roadmap

The national research and innovation roadmap 2022 was compiled during the autumn and winter of 2021/2022. The work entailed the collection of a large quantity of information from public sources and discussions with representatives of the mining industry, academia, local authorities and the educational system. In addition, around ten structured, open workshops were arranged with representatives of the mining cluster.

The roadmap comprises two main parts.

PART 1 offers an introduction to the mining cluster and the important research and innovation needed to meet society's need for sustainably produced metals and minerals. This part of the roadmap has been elaborated in close collaboration with representatives of the mining cluster. The primary target group is decision-makers who want to understand the challenges facing the industry and the potential of research and innovation to secure a sustainable raw materials supply, support the industry's transition to a lower climate impact, increased energy-efficiency and to strengthen the Swedish mining clusters competitiveness.

PART 2 sets out the industry's research and innovation focus and needs in the short and longer term. This part has been developed jointly by representatives from the industry, institutes, academia, SMEs, NGOs and relevant authorities. It gives the reader an in-depth description of the urgent challenges confronting the research and innovation effort and pinpoints the urgent research and innovation needs.

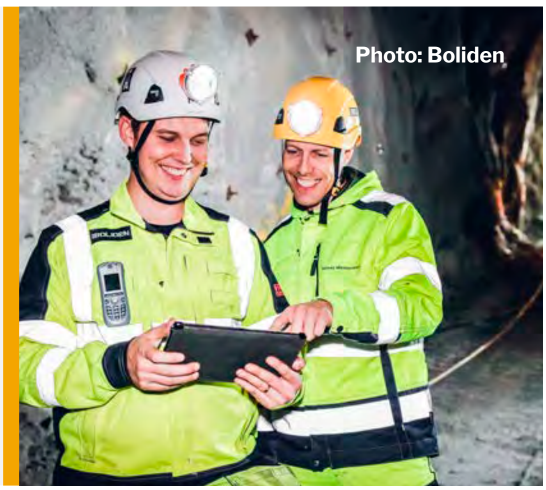
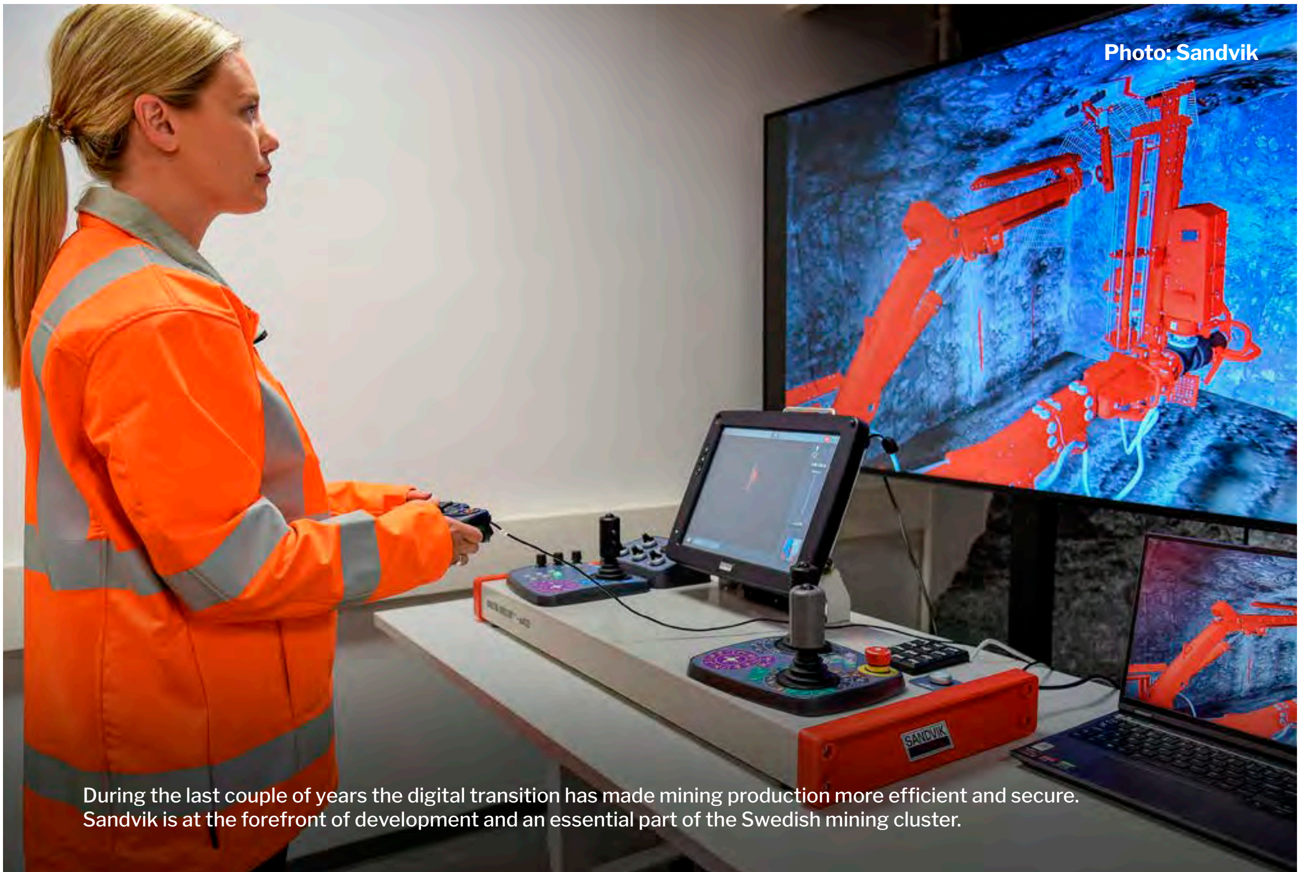


Photo: Boliden

The research and innovation roadmap is published in two versions, one in Swedish and one in English. The complete summary of the industry's research and innovation needs is reproduced in the English version, which can be accessed at swedishmininginnovation.se

Current examples of successful cooperation

The cooperation within the mining cluster is a unique but by no means new phenomenon. Up to the present there are many examples of collaboration extending back over a hundred years, and new collaborative initiatives are launched at regular intervals. A selection of some of the projects initiated or undertaken in recent years follows below.



During the last couple of years the digital transition has made mining production more efficient and secure. Sandvik is at the forefront of development and an essential part of the Swedish mining cluster.

JOINT DEVELOPMENT BY THE MINING CLUSTER OF A TEST MINE FOR DEEPER MINING

LKAB is aware that it may need to move its iron ore mining deeper below Kiruna and Malmberget by the mid-2030s. Such an investment, which would be one of the biggest industrial undertakings in Sweden's history, is complex and will call for close cooperation.

Since 2018, LKAB, Epiroc, Sandvik, ABB, Volvo and Combitech have together been operating a test mine in Kiruna as part of the Sustainable Underground Mining (SUM) project to test autonomous methods of working and fossil-free solutions. Each actor contributes its expertise: while Epiroc and Sandvik supply battery-powered, efficient and autonomous machinery, for example, ABB contributes know-how and solutions relating to electrification, automation, service and maintenance. Also taking part in the project are Luleå University of Technology, Örebro University and Mälardalens University.

Photo: Epiroc

BATTERY-DRIVEN AUTONOMOUS MACHINERY TO INCREASE PRODUCTIVITY AND REDUCE THE CLIMATE IMPACT

Autonomous or remotely operated machinery is important for making mining more efficient, reducing the climate impact and improving the working environment in underground mines. In the Sustainable Intelligent Mining Systems (SIMS) projects and the follow-up project NEXGEN SIMS, funded by the EU's Horizon 2020 research program, battery-powered, self-driving machines for use in underground mines were developed, tested and demonstrated. The projects focus on sustainable smart systems and technologies for autonomous, fossil-free underground mines and are the biggest mine-related projects to be financed by the EU to date.

The two three-year SIMS projects, which finished in 2020, and NEXGEN SIMS, which commenced in 2021, are headed by Epiroc and also involve Boliden, Ericsson, ABB, Mobilaris, LKAB and Luleå University of Technology as well as a number of foreign mining companies.

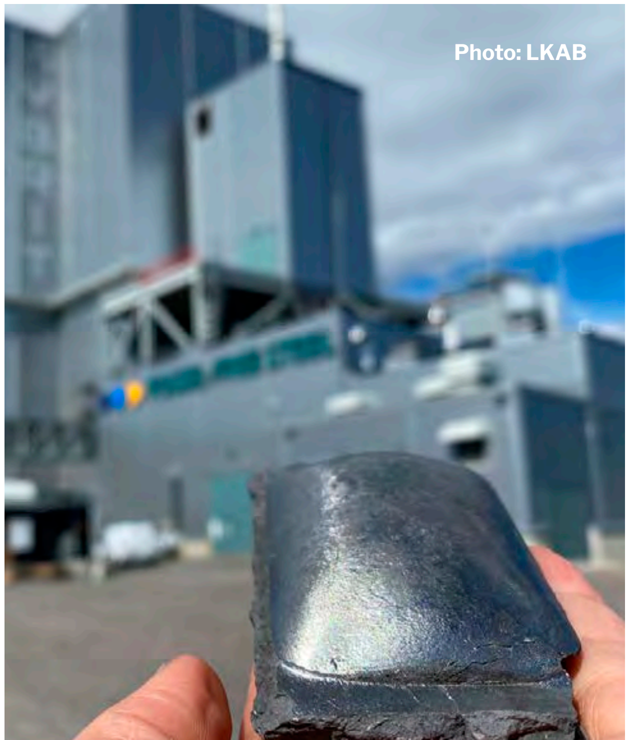


Photo: LKAB

INNOVATIVE PRODUCTION METHOD TO RENDER STEEL PRODUCTION FOSSIL-FREE

An important step in reducing the climate footprint of mining is to modernise the production methods deployed. Under the joint Hybrit initiative, LKAB, SSAB and Vattenfall introduced a test operation for producing hydrogen-reduced iron sponge. In August 2021, the companies presented the world's first fossil-free steel. Hydrogen is used instead of coal and coke to remove the oxygen from iron without giving rise to carbon dioxide emissions. The goal is to achieve completely fossil-free iron and steel production in Luleå by 2030.

Phosphorus is an essential nutrient and thus also an important component in agricultural fertilizers.

NEW METHODS OF RECYCLING MINE WASTE

Phosphorus is a key element used in agriculture and is on the EU's list of critical raw materials. When phosphorus is encountered in iron ore mining, however, it is normally treated as mine waste and disposed of as landfill. For a long time, no closer consideration was given to the landfill, but as Lantmännen agricultural cooperative states in a report, the phosphorus reserves found primarily in mining waste streams could make Sweden self-sufficient.[5] In light of the supply problems arising in the early stages of the war in Ukraine in 2022, this is a strategically important priority.

Boliden and LKAB are now working together to find solutions for recovering phosphorus and also rare earth metals in mine waste. Instead of depositing the pyrite contained in mine waste from the Aitik mine in the sand magazine, it will be extracted using flotation as a concentrate that LKAB needs to produce sulphuric acid. The sulphuric acid is used in turn to extract phosphorus from LKAB's mine waste. Collaboration taking place in the context of the ReeMAP project will give rise to a number of new plants and facilities linked to the mines in Kiruna and Malmberget. A chemical technology industrial park for refining the products is also to be constructed.

5. Lantmännen (2021).


Photo: Boliden

WORLD-FIRST INVESTMENT IN ELECTRICALLY POWERED, AUTOMATED DRILLING

There are many mines around the world using automated drilling machines, a common feature of which is that they are diesel-powered. This results in emissions that have impact the climate and adversely affect the working environment for the operators.

Boliden, Epiroc and Technology/ Mine Automation launched a joint project in 2017 with the aim of replacing the existing manual blast hole drilling technique at Aitik mine in Gällivare with a fully automated, electrically powered drilling process. In addition to improving the working environment in the mine, the ambition was to increase production and resource utilisation at the same time.

Photo: Boliden

ROBOTS TO IMPROVE MINE SAFETY

Prior to blasting in an underground mine, the preparations for blasting are undertaken by special charge operators. The work is complex and takes time: the boreholes must be identified, blast caps and detonators fitted, and then the lines to pump the explosive and the mix of explosives are applied.

ABB, Boliden, LKAB and explosive suppliers Forcit and LKAB Kimit have therefore begun to collaborate with the aim of equipping ordinary industrial robots with the technology required to perform these tasks. Instead of a charge operator having to program the robot prior to each detonation, the robot shall be able to locate the holes to be charged itself with the aid of an online AI solution that supplies the precise coordinates. If the process can be automated, it would improve safety and the working environment as well as making production more efficient.

Photo: LKAB

"We drive the technological transformation of the industry and utilise our expertise in mining, processing and logistics."

Jan Moström, President and CEO LKAB

The Iron Ore Line is an approximately 500 kilometer long railway line that runs between Luleå in Sweden and Narvik in Norway. The railway is one of the world's oldest ore railways and crucial for Swedish iron ore exports.

Metals and minerals are key for achieving climate goals and a sustainable future

JOINING FORCES GLOBALLY TO REDUCE EMISSIONS

Growing concentrations of carbon dioxide and other greenhouse gases in the atmosphere are raising the Earth's temperature and having an impact on the conditions of existence for humans, animals and the entire ecosystem. An awareness of the challenge this poses and the risks it entails has meant that the climate transition has moved up the list of political priorities. Over the last few years the global community has enacted a series of agreements aimed at reducing emissions.

Shortly after the UN's global targets for sustainable development were adopted in September 2015, world leaders signed the international treaty on climate change in Paris. Two years later, the Swedish Parliament adopted a climate policy framework for achieving the objectives set out in the Paris Agreement. In June 2021, the EU adopted a resolution on climate targets. Negotiations are presently in progress in the EU regarding the distribution of responsibility between the member states.

AN INDUSTRY INSTRUMENTAL FOR THE CLIMATE TRANSITION

The climate transition involves a comprehensive and fundamental change in society. This includes ending the dependence on fossil energy types, significant expansion of renewable power production, electricity networks and the production of electric vehicles, and facilitating and strengthening strategic mineral technology value chains and circular material flows.

Sustainably produced, high-quality minerals and metals are a prerequisite for this. Major investments will be required in infrastructure, buildings and industrial facilities. We face a growing demand for commodities like iron ore, zinc, lead and copper. Without these, future good living standards, necessary infrastructure and the urgent transition is not possible. A sustainable society rests, in the literal sense, on the value chain that starts in the bedrock. To achieve increased electrification, significantly increased extraction of copper and rare earth metals is also needed. The requirement is huge: the International Energy Agency (IEA) believes that the world will need six times more minerals and metals in 2040 compared with today to achieve the ambition of net-zero emissions. The demand for important battery minerals such as lithium is even greater and is expected to be 40 times greater by 2040.[6] According to Material Economics, global demand will grow sharply by 2050. Demand for lithium, rare earth metals, graphite and indium is expected to at least fivefold.[7] Many other analysts give similar assessments.

The world is thus moving at speed along the road from a fossil-dependent society to one

6. International Energy Agency (2021).
7. Svemin (2021).

that relies on metals. Since the Swedish bedrock holds significant quantities of the crucial metals needed for the climate transition, the mining industry plays a hugely decisive role in the ability of Sweden and the EU to achieve their climate goals.[8] By striving for greater resource efficiency and circularity, Sweden can reduce its dependence on imports of innovation-critical minerals and metals, such as battery minerals. Resource-efficient mining entails utilising as much as possible of the minerals and metals extracted from the ground. It also means maximising the recycling of minerals and metals from material previously regarded as waste and consigned to landfill.

SWEDISH MINING LEADS THE WAY WITH A LIMITED CLIMATE FOOTPRINT

The transition to a sustainable society also means that industry players will need to change their production processes. Mining industry emissions, ranging from those deriving from mining and processes for refining iron ore and metals to transport, currently account for around eight percent of Sweden's overall emissions of carbon dioxide.

The climate framework adopted by the Swedish Parliament in 2017 means achieving net-zero emissions of greenhouse gases in Sweden by 2045. To increase the pace of the transition by industry and to promote fossil-free competitiveness, the government appointed a national coordinator. The role of the coordinator was to engage in dialogue with industry to develop roadmaps showing how each sector could become fossil-free or climate-neutral by 2045. In the climate roadmap for the mining and mineral industry, a number of measures have been identified for reducing the industry's impact on the climate.[9]

In March 2022, the Swedish Climate Policy Council identified four key areas to take Sweden to net-zero emissions of greenhouse gases by 2045, including more efficient use of energy and resources and fossil-free electrification.[10] The Swedish mining industry has set ambitious targets for fossil-free operation. By 2035, the mining process shall be fossil-free and this shall also be the case for downstream process stages ten years later. The industry's initiative is already yielding promising results, above all in the mining process. For example, the industry has come a long way in working to replace diesel-powered machinery with electrically-driven machines. In the same way, companies have optimised the mining process and made it more efficient as well as reducing energy and fuel consumption by exploiting the possibilities offered by digitalisation and automation. A lot remains to be done, however, not least to realise fossil-free refining processes.

At the same time, it is important to note that the emissions of the Swedish mining industry are very low compared with the industry in other countries. Today mining production in Sweden is already 70 percent less emission-intensive than international production.[11] This is not an argument for lowering the industry's climate ambitions, but on the contrary a powerful reason for increasing the share of minerals and metals produced in Sweden. It's important to note that even if Sweden reaches 100 percent recycling, the need for new minerals and metals is significant and growing.

8. Nordic Innovation (2021).
9. Fossil-free Sweden (2020).
10. Swedish Climate Policy Council (2022).
11. Material Economics (2021).

> *"Innovation at all levels is important for our investment in safe, sustainable and competitive extraction of base metals. Both the industry and the state need to prioritize research and innovation in order to safeguard Sweden's world-leading position."*
>
> **Staffan Sandström, CEO Zinkgruvan Mining**

CONCENTRATED EFFORT TO AUGMENT BIODIVERSITY

Production processes in the mining industry need to change to reduce the climate impact, but also to slow down the ecological impact and above all to contribute to greater biodiversity. In contrast to most other industries, where localisation is of secondary importance, mines have to operate where the ore deposits are located. This means taking up new land. To minimise the impact on flora and fauna, the industry has worked on nature conservation issues for a long time – for example, considering how sand magazines should be designed and how remedial work on sites previously used for mining is to be carried out.

The aim of the mining industry's roadmap for biodiversity, which was launched in 2020, is to increase biodiversity in all the regions in which prospecting and mining/mineral operations take place by 2030. To achieve this goal, further research and innovation is required.[13]

SUSTAINABLE WATER USAGE

The Swedish mining industry set high environmental targets for its operations a long time ago. During the 1990s and at the start of the 21st century, a number of important initiatives were taken, which substantially mitigated the industry's impact on water. In recent years, water has once again risen up the agenda and contributed to increased application of the precautionary principle.

One important aspect among others for ensuring sustainable mining in the long term is to implement EU directives relating to water, biodiversity and waste and to review these on an ongoing basis with reference to research-based assessments.

12. Material Economics (2021).
13. Svemin (2020).

Photo: LKAB

Robotic dog Spot, equipped with modern AI technology, is the latest employee at LKAB. Spot can recognize environments and develop movement patterns. The ambition is that it will eventually be able to take over certain tasks from the operators and thus contribute to making the work environment safer.

Digitalisation and automation boost mining industry’s competitiveness

NEW TECHNOLOGIES DRIVE DEVELOPMENT AND REGENERATION

If the mining industry is to play a part in societys climate transition and in securing a sustainable supply of metals and minerals, while also reducing its own production-related emissions, initiatives are required that safeguard and increase the competitiveness of the companies involved. There are important reasons for the major investment in electrification, digitalisation and automation that has been taking place in the industry for a number of years. With a view to achieving more efficient processes, more energy and cost-effective production and a better working environment, robots, self-driving, electrically powered machines and digital wireless positioning technology are now being introduced into the mines.

Boliden, for example, is pursuing an ambitious mine automation program. A few years ago, the company introduced wireless mobile communication into the mine at Kankberg, which is nearly half a kilometre underground. The technology is used to monitor movements in the rock, temperature and air quality remotely and in real time as well as for using robots and for remote control of wheel loaders and other machinery in mining production. Apart from increasing mine productivity, the project has improved the working environment for the employees, who have been able to perform more tasks above ground.

LKAB is on a corresponding digitalisation and automation journey to Boliden. In the iron ore mines in Kiruna and Malmberget, the company is driving the development of electrified, autonomous mine operation. A number of mining machines are already controlled remotely. Mobile working methods constitute a central component of mine digitalisation. One of LKAB’s goals is that its employees shall always have access to the correct information, regardless of time and place, thereby supporting better decision-making in their work. Continued investment in the wireless infrastructure together with new, smart positioning services is a prerequisite for this.

OPPORTUNITIES AND CHALLENGES WHEN DIGITALISATION AND AUTOMATION ENTER A NEW PHASE

As computing power has grown and Internet speeds have risen, it has become evident that digitalisation and automation are still at an early stage and that the potential applications in the industry are huge. Above all, the possibility of processing extremely large quantities of data in real time and of utilising advanced machine learning and artificial intelligence is prompting hopes of optimising processes from the introductory prospecting phase to metal recycling. Sandvik, for example, has developed a maintenance system that can predict and prevent machine damage using artificial intelligence and machine learning.

The introduction of new, digital tools and applications into existing industrial processes, organisations and working methods poses a major challenge at the same time. Advanced digital solutions will call for staff to possess a completely new type of knowledge and skills, for example.

Photo: LKAB

The Swedish mining industry in 2045

Our vision of the sustainable mine

As society's needs for sustainably produced metals and minerals is increasing, the mining and metal-producing industry in Sweden is currently planning and implementing record investment. Across the country, billions are being invested in existing mines and steelmaking plants, while many more initiatives are at the planning stage.

For the mining cluster, 2045 represents a goal and an opportunity to enhance the competitiveness of the industry, expand operations and demonstrate global leadership on the road to a fossil-free world. "The sustainable mine" is an attempt to illustrate the objectives using the research and innovation that is now being undertaken.[14]

STRONG LONG-TERM INVESTMENT GAVE SWEDEN AN EDGE

The historically large investment in mines and the industry that attracted considerable attention at the start of the 2020s has become a reality in 2045. Swedish mining production is regarded as the most resource- and energy-efficient in the world and has a minimal impact on the climate. This is not surprising: the production processes require minimal water use and take place with a limited ecological impact, while emissions have been drastically reduced compared with the 2020s.

Technological development since the 2020s has been driven by increasingly stringent climate targets, a growing requirement for safe working environments and increased mining of deposits located deeper in the rock. Demand is high for the products now certified as sustainable that have their origin in the Swedish bedrock. There is also demand for Swedish-manufactured equipment required for sustainable, safe mine operation.

SWEDISH MINES CONTRIBUTE TO THE EU'S SELF-SUFFICIENCY IN CRITICAL METALS

In the same way as iron ore once laid the foundations for Swedish prosperity, the bedrock has led the way in the climate transition. In 2045, Sweden continues to be one of the leading producers of iron, copper and zinc in the EU while also being a leader in sustainable production of rare earth metals, phosphorus and battery minerals such as graphite.

Swedish mining of the increasingly valuable critical metals has raised the EU's level of self-sufficiency and reduced its dependence on imports from countries such as China and Russia. It has thus reduced the vulnerability of the EU to a sudden stops or disturbances in the international flow of goods.

WIDE SOCIAL ACCEPTANCE OF MINES

The public has a new-found understanding of the mining industry's crucial role in the climate transition in 2045. A clear shift is taking place.

The reforms that took place in environmental assessment at the end of the 2020s have not only made the permit process more effective and more predictable, but have also made it more transparent for all interested parties concerned. The rights of the indigenous people are respected and the mining industry has established stable, long-term relationships with the local communities affected. The mining industry coexists with other land-based industries.

14. Section compiled on the basis of the research and innovation roadmap 2019, high-level meeting dated 21 December 2021, Roadmap for a competitive and fossil-free mining and mineral industry and what was said at the panel discussion of the Royal Swedish Academy of Engineering Sciences, "The circular mine – an opportunity or Utopia?", *www.iva.se/event/den-cirkulara-gruvan--en-mojlighet-eller-utopi*

SKILLS SUPPLY MAINTAINED WITH THE FOCUS ON SAFETY

Sweden continues to be recognised internationally as a world leader in the work environment, health and safety. People will still be working underground in twenty years' time, but the automation of mining means that most tasks are performed above ground or remotely.

Automation and digitalisation have contributed to enhancing the appeal of the industry. Young people are more interested than previously in the industry; the courses offered at high schools, vocational and other colleges are popular and the vacancies offered are in high demand. The mining and metal-producing industry in 2045 attracts a variety of groups and competent staff and equality of opportunity exists at all levels of the companies.

LARGE-SCALE ELECTRIFICATION OF SOCIETY AND INDUSTRY

Thanks to extensive investment in new, fossil-free electricity production and dynamic expansion of electricity networks, it has proved possible to electrify significant portions of mining operations. At the same time, the electricity requirement per ton of ore produced has been substantially reduced.

Since the mid-2030s, machinery and internal transportation has been operated using electricity, hydrogen gas or biofuel. Above all, the introduction of self-driving machinery with artificial intelligence and the advanced use of real-time data from the mine has optimised both mine processes and energy consumption.

HUB OF THE CIRCULAR ECONOMY

In theory, metal can be reused any number of times. Improved product design and a clear value chain for reuse and recycling mean that an extremely high proportion of Swedish metal and minerals is recycled in 2045. Sweden is well on the way to achieving the target of "zero waste".

The mining cluster has seized important initiatives for cooperation with other sections of society and is perceived as the hub of the circular economy. The phosphorus and rare earth metals now found in grey rock tips and in the sand magazine are being recovered and refined. The development of new technical solutions has meant that material is being recovered even from existing landfill sites. In cooperation with battery and vehicle manufacturers, the mining industry has also developed processes for recovering and reusing the metals in spent batteries, and a large proportion of the minerals and metals needed for battery manufacture are extracted in Sweden.

CUTTING-EDGE RESEARCH AND EDUCATION

Swedish universities, colleges and institutes have conducive research environments and a well-funded research infrastructure. Mine-related research in Sweden takes place in close collaboration with Swedish industry and is regarded as being at the cutting edge from an international perspective. The unique cooperation between industry and academia strengthens both parties and helps to safeguard Sweden's position as a leader in mine-related innovation. Swedish educational courses, which are characterised by a strong industrial component, satisfy the needs of both industry and academia for competence at all levels in 2045. Students from all over the world move to Sweden and the mining universities lead the world.

Photo: Epiroc

Policies required for success

The efforts now being made by the mining cluster to contribute to the climate transition and to meet society's need for sustainably produced metals and minerals, to reduce the environmental impact and to strengthen the industry's global competitiveness demand the input of both time and capital. Long-term political commitment to Swedish research and an understanding of the industry's fundamental need for a functioning public infrastructure is necessary for success.

Initiatives and reforms to advance research and development

Significant investment in research and innovation will be needed for the mineral and mining industry to succeed both in reducing its own climate footprint and in helping increase the EU's level of self-sufficiency and secure a sustainable supply of metals and minerals. The government should take the initiative to undertake large-scale, nationally focused investment in both basic research and applied research for a sustainable mining and mineral industry.

SUPPORT BASIC RESEARCH AND LOOK INTO A NATIONAL SKILLS CENTRE

Despite research being the key to a competitive mining industry, state funding for basic research is much too low. Public support for research also suffers from a lack of long-term thinking. It is not clear in the Swedish Government's 2020 research proposition, for example, whether the strategic research areas are to continue, and if so for how long.[15] The absence of long-term clarity creates uncertainty and means that academic institutions are hesitant about appointing new staff, which makes it difficult to build strong research environments. This is extremely unfortunate at a stage when national knowledge needs to be consolidated.

The government should therefore make a targeted effort and provide resources for the necessary basic research for sustainable extraction and recycling of minerals and metals, not least of raw materials that are crucial for innovation. The government should also look into setting up a national skills centre for basic research in the field.

MAKE NATIONAL INVESTMENT IN APPLIED RESEARCH AND INNOVATION

Swedish mining technology is contributing to significant climate benefit and is globally at the forefront in its field. An important part of the work to protect the export of environmental and technology innovations is to utilise the long tradition of collaboration that exists in the Swedish mining cluster.

A positive example of this is Vinnova's funding of the player-driven strategic innovation program that has enabled those involved to join forces and has inspired a major commitment from them. Collaborative research and innovation has achieved the desired effects and brought important results. One weakness of the strategic innovation programs is that major investments do not normally fall within the budget framework. Another positive example is the Advanced Digitalisation program, which gives support to consortiums cooperating to contribute components and system solutions that will be advantageous for next-generation industrial digital solutions.

To guarantee access to sustainably produced minerals and metals and functional mineral value chains, large-scale, long-term national support for applied research and innovation in the mining and mineral cluster is required. The focus should be on all aspects of sustainability – economic, environmental and social aspects – and the aim should be to stimulate collaborative projects between those carrying out research, industry, institutes and other players. Some areas should be pri-

15. Government (2o20).

oritised. For example, initiatives that promote cooperation between companies developing digitalisation solutions and digitalisation infrastructure and the industries that use digitalisation fall into this category. Environmental research that aims to secure sustainable mining, extraction and recycling, and cooperation in research and innovation to create resource-, energy- and production-efficient solutions should also be a priority.

INCREASE SUPPORT FOR GEOSCIENTIFIC RESEARCH

Research is needed into regional geology, the groundwater and surface water conditions and ore formation processes to increase understanding of the preconditions of the mineral and mining industry and its environmental impact. SGU, the mission of which is to support applied geoscientific research and targeted basic research at Swedish universities, colleges and research institutes, has limited research funds, however. The budget of around six million SEK per year that is at the agency's disposal must cover everything from groundwater to soil and bedrock, but its resources are insufficient to meet the requirements. To facilitate research that can help to increase the knowledge of Sweden's geology and reduce the ecological effects of the mineral and mining industry, the appropriation to the SGU needs to be increased.

STRENGTHEN THE MINING CLUSTER THROUGH NEXT-GENERATION STRATEGIC RESEARCH PROGRAMS

The mining cluster is a unique group representing the industry, the system and subcontractor segment, academia and the IT and telecom companies sector. Cooperation between the actors has made Sweden one of the world's leading mining nations. Continued positive development of the mining cluster will, as the government recently stated, result in innovation, development and sustainability along the entire processing chain.[16] During the present program period, Swedish Mining Innovation has become the mining cluster's most important collaborative platform for research and innovation. The strategic research programs of the next generation should be formulated with the aim of safeguarding and advancing the cooperation, joint effort and strategic consensus that have their origins in Swedish Mining Innovation.

PROMOTE RESEARCH COOPERATION IN THE EU AND INTERNATIONALLY

A number of international cooperative ventures in the mineral and mining industry are already up and running. The goal of a sustainable supply of minerals means, however, that there is a major requirement to strengthen cooperation, not least within the EU. For this to succeed, existing instruments such as the pan-European support network ERA-MIN must be maintained and developed. In parallel with this, the conditions and opportunities for bilateral international cooperation and initiatives for Nordic research cooperation must be improved.

16. Swedish Government Offices (2022).

Initiatives and reforms for developing the mineral and mining industry

SECURE THE STRATEGIC SIGNIFICANCE OF THE MINES

Even though both the EU's Green Deal[17] and its new industrial strategy[18] make it clear that access to raw materials is a question of strategic security and a prerequisite for achieving the climate transition, the mining industry lacks consistent support within the European Union. During the compilation of the EU taxonomy, it has sometimes sounded as if mines have no long-term place in the EU at all. The government should stand up for the mining industry's strategic importance for the climate transition; in this way Sweden can contribute to securing the EU's mineral and metal supply and at the same time demonstrate global leadership.

17. EU Commission (2019).
18. EU Commission (2019).

PROMOTE FREE COMPETITION

Renewal and development are a crucial element of a functioning market economy and over time it is only profitable companies that can realise the investment required. The trend in the EU in recent years has been in the direction of greater state intervention and control. This can bring advantages in the short term, but over time the trend risks undermining entrepreneurship, regeneration and the desire for innovation that is crucial for a competitive economy. Sweden must stand up in the EU for basic market-economy principles and free competition. The focus should instead be on identifying and remedying the factors that diminish the global competitiveness of the mineral and mining industry and lessen the attraction for investment, for example risks in taking up land and water.

Photo: LKAB

IMPROVE THE CLIMATE FOR INVESTMENT IN THE MINERAL AND MINING INDUSTRY

In the course of time it has become increasingly difficult to obtain permits for changes to mines or permits for entirely new mining operations in Sweden. The development delays investment and obstructs the introduction of new, fossil-free technology. To secure the future of the mineral and mining industry – and Sweden's conditions for achieving the climate goals set – sweeping reform of the environmental permit examination process is needed.

SECURE THE SUPPLY OF ELECTRICITY AND BIOENERGY

The climate transition means that large sections of society must be electrified in a short time. The demand for electricity may double from 140 TWh today to 310 TWh up to 2045, according to Swedenergy's high-level scenario.[19] The Swedish power grid notes that the electricity networks need to be expanded at a significantly faster pace to meet the expected increase in demand.[20] Without substantial investment in the electricity networks and electricity production, both the existing mineral and mining industry and the future projects planned are jeopardised. To secure the future existence of the mining industry and its competitiveness, therefore, a suitably dimensioned and secure supply of electricity is needed, electricity at competitive prices and supplementing of electrified systems. Access to renewable diesel (HVO) is severely limited, however, and the international competition is fierce. To minimise big price variations, Sweden must ensure access to bioenergy.

19. Swedenergy (2021).
20. Svenska kraftnät (2021).

SECURE MINE OPERATION IN THE EVENT OF A CRISIS

The mining industry relies on technical systems and machinery for its daily operations. The pandemic and the war in Ukraine have shown how vulnerable production is in the event of disruption of global supplies. International trade is crucial for a small country such as Sweden and it is neither desirable nor even possible to make it independent of imports. Sweden should, however, work to get the EU to review and if necessary bolster its options for handling supply disruptions in respect of crucial technical components and input goods, at least over short periods of time.

INVEST IN EDUCATIONAL COURSES THAT LEAD TO JOBS IN THE INDUSTRY

Despite the key role of the mining industry in the climate transition, many companies are experiencing growing difficulties in finding the right staff. Educational courses that offer exciting and stimulating career opportunities in the industry have also found it hard to reach out to young people, and many study places are vacant. To meet a huge increase in demand for staff, not least as a consequence of the industrial ventures now being planned and undertaken in the northern parts of Sweden, the educational offering must be reviewed and reformed.

Photo: Boliden

Focus for research and innovation

Eight prioritised thematic areas

The mining companies have a unique opportunity to contribute to the climate transition and a secure a sustainable supply of minerals and metals, both by mining minerals and metals and by reducing their own climate footprint. The industry can evolve into the hub of the circular economy. To do this, however, the methods for how new deposits are identified, investigated and extracted must be developed. A much bigger share of the minerals and metals produced also needs to be reused.

In the national roadmap, research and innovation requirements in a total of eight areas have been identified. These are summarised below. More detailed descriptions of objectives, priorities and expected results can be found in part 2 of the roadmap.

EXPLORATION AND RESOURCE CHARACTERISATION

Despite the significant potential of Sweden's bedrock for locating new mineral deposits, large areas are still under-explored. To reach deeper mineral deposits containing both base metals and critical metals, 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 the ore body, the quality of the rock and how the rock is affected by mining. A more resource-efficient mining operation will be achieved thereby with a smaller environmental impact.

MINING

Open pit and underground mines are complex operations with a number of interconnected processes and systems. Low grades and increasingly deep mineral deposits makes high demands on production and energy efficiency to ensure competitiveness. In addition to this, the mining operations environmental and climate effects need to be minimised and resource efficiency and minimised waste must be ensured.

Research and innovation in this area aims to develop methods, processes, tools and equipment for net zero, fully autonomous, production-, energy- and resource efficient safe mining operations.

MINERAL PROCESSING

How great the quantity of valuable minerals is that can be recovered in mineral separation is determined by how successfully the ore is liberated. This stage, which entails crushing and grinding the ore in multiple stages, is also the most energy-intensive part of the enrichment process.

The goal of research in this area is to develop advanced and innovative production systems that allow for more minerals to be extracted, even from complex ores, to enhance resource efficiency considerably, reduce the consumption of energy and water and to cut the amount of waste.

METALLURGY AND RECYCLING

There is great potential to improve the collection and recycling of minerals, including innovation-critical metals from electronic waste, and to utilise metals that are currently lost in the material streams.

Research in this area is aimed at developing resource-efficient, carbon-neutral processes that make it possible to increase the yield of recycled metals and to extract further elements that end up in slag, dust and mud.

ENVIRONMENTAL PERFORMANCE

Swedish mineral production is considerably less emission-intensive than international production and the industry is considered among the global leaders in productivity and sustainability. To safeguard Sweden's position, continuous development of technology, processes and working methods is called for.

The aim of this research and innovation area is to support companies in their endeavours to minimise the environmental effects of their operations, including the impact on water and of extracted waste.

ATTRACTIVE WORKPLACES

The historically large investments in existing and potential new mines now taking place makes the recruitment and retention of staff a key issue. To realize this expansion and transformation, the industry needs to invest in creating attractive workplaces with good work environments located in attractive and thriving communities. The ambition is to create global centres of excellence close to mining sites where mining takes place in a safe and healthy environments supported by digitalization and automation.

The purpose of research in this area is to enhance industry performance by focusing on the working environment and connected opportunities.

MINING AND SOCIETY

The mining of iron ore and copper, among other things, laid the early foundations of Swedish prosperity and the industry still has major importance for progress, not least in the regions where it operates. Its opportunities for contributing to jobs, development – not least in terms of industry climate change – and growth in the future are conditional on a clear focus on the social and environmental dimensions of the business.

Research in this area is focused on developing methods for local relations work and contributing to foreseeable, transparent, and effective permit processes.

GENDER EQUALITY AND DIVERSITY

The mining industry has traditionally been male-dominated, but international competition and an increased need for social and environmental sustainability have played a part in broadening the skills requirement. An important prerequisite for maintaining competitiveness is that the industry is perceived as being open to all.

Research in this area aims to promote a deeper understanding of the consequences of a lack of equal opportunities and diversity and how greater inclusivity can help to move companies forward.

Foto: Boliden

Research and innovation areas

Exploration and resource characterisation

Even though Sweden's bedrock is believed to contain many important minerals that are in high demand, finding ore deposits that are economically viable is a challenge.

The exploration phase begins with mapping of land areas and the analysis of possible mineral deposits using various methods. These include geochemical analyses of rock and soil samples and measurements of the rock's magnetic or other geophysical properties. If the exploratory mapping shows promising results, exploration drilling is carried out to study the composition and distribution of the mineral deposit below ground in more detail.

Future exploration must focus on finding mineralisation containing base metals and critical metals in new, unexplored areas as well as in currently underexplored areas. This will require both improved and entirely new geological, geochemical, geophysical, drilling and mineral-chemistry methods.

With the benefit of knowledge about the formation of the bedrock and improved mineral systems models, exploration targets will be easier to locate. A sound knowledge of a mineral resource serves as the basis for effective extraction and increases the value of the ore body. Knowledge of the structure of the ore body, the commodity grade and how it is affected by mining is also important. Existing analysis methods need to be developed further to achieve more resource-efficient mining with a lower environmental impact and to identify the potential even where complex and low-grade mineralisation exists. There is also potential for identifying and extracting innovation-critical metals as by-products.

OBJECTIVES

The main objectives of this research and innovation area are to provide Sweden with the technology and knowledge required to find and characterise new mineralisation. This should lead to a higher degree of self-sufficiency in minerals and metals, while at the same time reducing conflicts related to land use.

Before 2030:

- Improve exploration and research on minerals and mineral deposits in the Swedish bedrock, including critical raw materials and innovation-critical minerals and metals.
- Increase exploration targets, resources base and commodity diversity, including critical minerals in ore and waste.
- Improve geoscientific data in digital format across Sweden (geological mapping, geophysics, and geochemistry).
- Improve ore genetic models, geometallurgical models and mineral systems models for Swedish mineral deposits.
- Improve geophysical, geochemical, and mineralogical targeting methods, sensor technology and integrated modelling.

Towards 2040:

- Improve integrated geodata analysis through machine learning and statistical methods, automated and online systems.
- Reduce ore losses through improved mineral deposit models.
- Reduce energy and related CO2 emissions throughout the mineral and metal value chain.
- Reduce the amount of mining waste through resource efficiency.
- Increase use of waste both as a secondary raw material and in climate change mitigation through improved resource characterisation.

RESEARCH AND INNOVATION AIMS, STRATEGIES, AND ACTIONS

Research and innovation are needed to:

- Develop mineral systems analysis and related ore genetic models by defining deposit types with a focus on both main mined commodities and related critical minerals (multi-scale) and by defining the geological, geochemical, mineral chemical, and geophysical vectors.
- Test and validate ore genetic and exploration models with predictive models in pilot areas.
- Improve integration of petrophysical data with geophysical, geochemical, and geological modelling.

- Establish procedures for ensuring a fully integrated data- and knowledge-driven approach. Better data/communication/idea flow and better implementation of innovations.
- Develop interdisciplinary tools for rock mass characterisation.
- Develop new geophysical and geochemical methods and instruments.
- Facilitate the use of new online tools, micro-analytical tools, sensing methods and management tools, all integrated in a geometallurgical model and resource management system.
- Improve interdisciplinary communication along the entire mineral value chain by education of company staff and university students.
- Intensify fieldwork, pilot actions on new exploration techniques, feeding ore genetic and mineral systems models with data.
- Develop new geophysical methods for deep exploration from surface, airborne and borehole observations.
- Develop new geochemical and mineral chemical vectors to ore through advanced microanalysis, new geochemical techniques, and data interpretation. Practical integration of new vectors into exploration workflows.
- Expand research and exploration activities to areas outside the traditional ore locations.
- Train decision makers in resource geography and potential and predictive models will lead to better resource governance and actively promote results among the exploration industry at large. Improve awareness of the need for minerals and metals, and continued exploration, to create a sustainable and green society, both publicly and throughout the entire government.
- Develop and implement novel resource characterisation techniques and methodologies for identification and quantification of critical raw materials.
- Improve methodologies and technologies to enable mining waste beneficiation.

EXPECTED IMPACT

Progress in this area is expected to lead to the following results:

Technical

- Provide Sweden with innovative, world-class technology for mineral exploration leading to the discovery of new ore deposits.
- Provide Sweden with innovative, world-class technology for ore characterisation leading to increased resource efficiency.

Economic

- New mineral deposits and exploration targets can be defined and economically evaluated with better and more secure parameters yielding safer investments
- Improved self-sufficiency and a stable supply of base, critical and other minerals and metals, for the Swedish and European economy.
- Sustainable mineral value and supply chains based on responsible domestic sourcing.
- Foster the development of Sweden-based downstream industries based on domestic mineral resources, e.g., battery manufacturing.
- Growth in less densely populated areas of Sweden.
- More cost-effective and energy-efficient production.
- New value-added products.

Environmental

- Detailed definition of resources for improved targeting of ore bodies to optimise exploratory drilling and mining, thereby reducing CO2 emissions and the negative impact on land use.
- Define geographical areas for potential mineral resources and mining in the coming century which can then be used as a tool for decision-making on land use and dealing with conflicting land uses.
- Reduced energy consumption, waste, and emissions.
- Efficient use of mining waste as a secondary raw material and for climate change mitigation.

Social

- Fewer land use conflicts through better planning processes and communication.
- An awareness of the need for minerals and metals to create a sustainable and green society, both publicly and throughout the entire government.
- Increased employment opportunities in less densely populated and rural regions of Sweden.
- Improved governance of Swedish resources.
- Improved working environment and safe workplaces.
- Effective and systematic community engagement.

Mining

Mining is becoming an increasingly complex process. Iron ore deposits, for example, are found at greater depth, while environmental demands in respect of open pit mining are increasing. These factors pose several challenges both for mining operations and the industry's ambitions for achieving sustainability.

To meet the challenges, the working environment needs to improve and energy efficiency and productivity need to be increased, decreasing the environmental impact.

Safety will be achieved by automation, improved ground control methods and reduced human exposure at mining faces. This will also require the development of new mining methods and remotely controlled and/or autonomous mining equipment.

To make the mining process fully sustainable, an extensive reduction of emissions is needed throughout the entire process without reducing economic sustainability. Additionally, the extraction process must be extremely energy-efficient and interact with the downstream processes. Potential new products from waste materials and the surrounding rock could also affect the mining operation, which requires new solutions across the whole mining chain.

To achieve safe and sustainable mining, new innovations and technical solutions must be developed and implemented. These are dependent on reliable monitoring and communications within a mine. Therefore, data-driven decision-making is a requirement for future mining.

OBJECTIVES

The main objective for this research and innovation area is to improve the sustainability and competitiveness of the industry. This requires more efficient and sustainable mining processes and methods and underground as well as open pit extraction must be safe and energy-efficient.

Before 2030:

- Improved mining methods/layouts that ensure safe mining conditions and results in no fatalities and minimised Lost Time Injuries (LTI).
- No CO2 emissions from the mining process,
- Energy-effective mining processes.
- Improved ore recovery and minimum dilution.
- Minimised waste.
- Ground control measures that can ensure safe conditions with no unforeseen fallouts.
- Fragmentation processes that give optimum fragmentation and a minimum of undetonated explosives and no spillage.
- Continuous excavation methods that can be used in most mines.
- Improved process control.
- Reliable communication networks with real-time capabilities – 100 percent coverage 24/7.

Towards 2040:

- Almost all waste transformed to useful material.
- 100 percent continuous/online process control and dispatch in 100 percent of the mine.
- Mine process systems in partnership with mining machines (of varying brands) that can handle mixed traffic scenarios, i.e. interaction between automatic/autonomous machines and/or interaction between automatic/autonomous machines and manually driven machines and/or people.
- Reliable monitoring systems for production and rock mechanics purposes (e.g. positioning, surface detection, rock fall detection, deformation and seismicity).

RESEARCH AND INNOVATION AIMS, STRATEGIES, AND ACTIONS

Research and innovation are needed for:

Short term (2030)

- Develop fossil-free mining equipment and design mines for optimal use

with ambition to reduce the environmental and climate impact (fossil-free operation).
- Evaluating the impact of new blast initiation systems on mine design.
- Autonomous or remote-controlled operations.
- Digital twins, from geo models to production systems, to proactively predict, analyse and optimise production from a rock mechanical perspective.
- Develop Methods for handling big data collected by different instruments.
- Exploring alternative materials for backfill, rock support and explosives to reduce emissions.
- Implementing autonomous mining machines that can handle mixed traffic environments.
- Implementing reliable communication networks with real-time capabilities that include localisation and navigation systems.
- Applying KPI-supported procedures that drive continuous improvement in a selected area of optimisation, from management to quality control.
- Introducing deep mining solutions that handle higher rock stress and apply adaptive actions for reliable production.
- Implementing mine planning adapted to rock conditions, including pre-conditioning to prevent stress peaks.
- Implementing condition-based and predictive maintenance of mining equipment and systems, ore passes, ventilation shafts and rock support.
- Reducing total energy consumption per ton of ore, including explosives.
- Improving and developing ventilation, air quality control and on-demand temperature control.
- Developing reliable autonomous systems and mechanical excavation methods for hard rock conditions to enable continuous mining
- Using selective mining to reduce waste and exploring potential products based on waste rock.
- Applying full digital twins as a mine-planning tool to enable proactive mining and provide the best possible conditions for deep mining.
- Exploring replacement of large individual machines with a number of small autonomous units.

Long term (2040 and beyond)

- Implementing monitoring instruments to replace human sensing with reliable just-in-time data collection.
- Developing alternative rock support with high stiffness and ductile behaviour for deep mining conditions.
- Minimising nitrogen emissions.

EXPECTED IMPACT

Progress in this area is expected to lead to the following results:

Technical

- Reduced energy consumption.
- Increased production efficiency
- Minimised dilution and maximised ore recovery.
- Reduced waste rock.
- Improved mining process and design through a sustainable approach.
- Integrated process control and proactive decision-making.
- Minimised human exposure to hazardous situations.
- Improved air quality.

Economic

- Reduced cost per ton.
- More cost-effective rock support.
- More cost-effective mining process overall.

Environmental

- Minimised environmental footprint.
- Reduced CO2, nitrogen and other emissions.
- Reduced mining-induced vibrations.
- Reduced water consumption.
- Reduced environmental impact from water used in mines.

Social

- Safer mining with fewer incidents.
- Increased social acceptance.
- Increased job satisfaction.
- Increased holistic work understanding (from planning to performance) for all employees.
- Acting as a responsible and active partner in society.

Mineral processing

Mineral processing is usually the first step after mining and produces an ore concentrate for subsequent metallurgical extraction, an industrial mineral or an aggregate product. The main steps are typically comminution and classification, concentration and, where wet processing is used, dewatering.

Comminution is needed to adjust the particle size and to liberate the valuable minerals from gangue. This stage is usually the most energy-intensive step within mineral processing plants and is crucial for all subsequent beneficiations. However, the selection and operation of comminution circuits are often not optimal due to insufficient knowledge of ore properties and non-optimal parameter settings. In recent years, steps have been taken to develop new and more energy-efficient technologies for ore comminution.

Within ore concentration, the efficiency of separation processes needs to be further improved to make them more sustainable. For instance, flotation separation requires suitable particle size ranges as losses occur in the very fine and coarse fractions. Adjusted hydrodynamics and suitable reagent schemes are required for selective and environmentally friendly flotation of minerals.

Besides improving individual unit operations, also flowsheets need to become more efficient and flexible, as well as being better integrated with upstream and downstream processes. One option to reduce the amount of ore that needs to be processed downstream is to separate liberated gangue earlier at coarser particle sizes. Other approaches, such as more efficient classification steps within comminution circuits or successive concentration and size reduction, increase resource efficiency but often at the expense of more complex flowsheets.

OBJECTIVES

The main objective for this research and innovation area is to significantly improve resource efficiency. This will result in added value from: high-quality products and new by-products; lower energy consumption; decreased losses of valuable minerals; improved environmental performance through reduced water consumption and emissions.

For these goals, the following key performance indicators are defined:

- Reduce energy consumption.
- Reduce losses of valuable minerals.
- Increase recovery of by-products.
- Minimise the environmental footprint (related climate impact, water consumption, emissions, tailings).

RESEARCH AND INNOVATION AIMS, STRATEGIES, AND ACTIONS

Research and innovation are needed to:

- Develop energy-efficient comminution processes.
- Develop more efficient wet and dry separation processes for treating fine-grained, polymetallic ores and removing impurities.
- Develop suitable pre-concentration processes for separation of coarse material close to the mining production face.
- Optimise beneficiation processes for turning rejects into products.
- Enhance water management for process water (reduction, recirculation) and improved water quality.
- Introduce environmentally friendly and safe reagents with better performance.
- Develop new processing routes for dry processing (comminution, separation).

Research and development strategies are proposed in the fields of comminution and separation, as well as their combined use in a systems approach to optimise entire mineral-processing chains. The research aims and suggested actions presented involve both fundamental and applied research.

Comminution

For more efficient crushing and grinding, currently existing processes need to be optimised or novel technologies provided, such as:

- Improved comminution technologies and machinery for ore comminution with regard to energy efficiency for grinding and wear characteristics.
- Optimised fragmentation chain from mine to mill.

- Development of measurement technology and advanced models for optimising design and control of comminution circuits.
- Enhanced mineral liberation by adjustment of the breakage mechanism (comminution and assisting pre-weakening technologies,) to ore properties.
- Investigation of alternative fragmentation methods and mill types for the efficient grinding of coarse and fine particles (considering dry and wet grinding).

Separation

Improvements in separation technology are required particularly for coarse and very fine particle sizes, involving the investigation of:

- Processing routes for bulk sorting prior to the concentrator, considering separation at coarser particle sizes.
- Optimised wet concentration processes, including magnetic and gravity separation.
- Novel reagents, reagent schemes and hydrodynamic concepts for improved flotation (direct, reverse), particularly for very fine and coarse size fractions and for flotation in cold climates.
- Stability and degradation of flotation reagents and their effect on downstream processing and water recirculation.
- Processing routes for separation of complex ores, removing impurities and facilitating the recovery of low-grade critical minerals.
- Dry processing technologies particularly for finer size ranges (classification, sorting, magnetic, electrostatic and gravity separation).

Process design and analysis

Improvements along the entire processing chain need to be investigated, involving the introduction of new and smart process designs and methods. Innovative process design and control optimisation of comminution and separation processes will lead to intelligent production systems.

- Hybrid flowsheets based on successive separation and size reduction for efficient comminution circuits.
- Process mineralogy and geometallurgical modelling together with innovative analytics for resource characterisation and ore traceability.
- Increased flexibility in process design and plant operation for different ore characteristics and for maximised economic potential.
- Strategies and integrated models for the efficient management and treatment of process water.
- Digitised processing plants using advanced online characterisation, sensor technology and data analytics.
- Development and implementation of model-predictive control concepts using first principles and data-driven (“digital twin”) models.

EXPECTED IMPACT

Progress in this area is expected to lead to the following results:

Technical

- Availability of energy-efficient comminution equipment and process designs.
- Reduced wear and enhanced mill control based on innovative measurement solutions and mill modelling.
- Provision of efficient coarse and fine particle separation processes, for wet and dry processing modes.

Economic

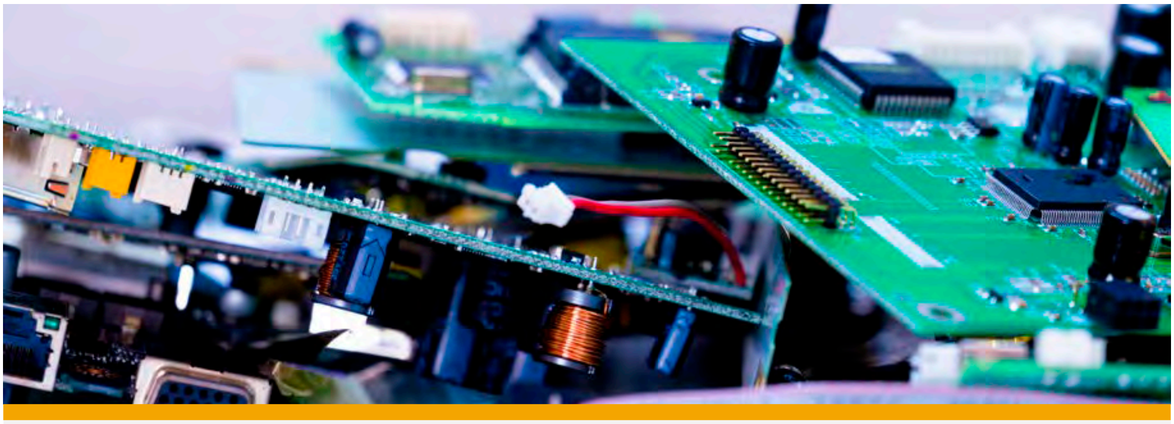
- Reduced costs due to less energy consumption and wear in comminution.
- Higher revenue from increased recovery of valuable minerals and metals.
- Increased production due to reduced material amounts after pre-concentration.
- Increased revenue through production of by-products.

Environmental

- Reduced CO2 emissions due to decreased energy consumption and utilisation of renewables.
- Less water usage due to more dry processing and reducing tonnages in downstream processes.
- Less material to be deposited and coarser tailings.
- Stabilised processing rejects with reduced hazards or harm.

Social

- Improved social acceptance of mineral processing plant operation due to higher resource efficiency and lower emissions and waste.
- Increased awareness in civil society of how the mining industry can improve the quality of life.
- Generation of new knowledge through research to be included in educational programmes and training.



Metallurgy and recycling

Metal production has historically focused on ore but is now increasingly also about collecting and recycling metals, including innovation-critical metals from electronic scrap, and utilising the metals currently lost in the material streams.

High demands are placed on metal extraction processes from primary and secondary raw materials to achieve low emission levels and low energy consumption. Furthermore, these processes need to be competitive as well as cost- and resource-efficient. The process steps for extracting metals from primary and secondary resources are highly interconnected for many metals. A thorough understanding of the processes involved as well as a holistic view of ore-based metallurgy and recycling are needed to increase metal extraction yields.

Fossil coal and reagents with a carbon footprint are commonly used for metal extraction. Increased levels of CO2 equivalents in the atmosphere and the challenge of climate change mean that metallurgical operations need to become CO2-neutral. The transition to CO2-neutral operations will have an impact on processes and products. Further research is needed to understand the effects of this transition, to ensure efficient processes and required product quality. One of the challenges to develop competitive carbon neutral processes is the availability of fossil free electricity.

OBJECTIVES

The main objective for this research and innovation area is to satisfy future metal demand while still meeting sustainability targets and ensuring resource-efficient and carbon-neutral processes. The challenge is to increase recovery yields and extract additional elements contained in the material streams that are not extracted today. Increased utilisation of by-products such as slag, dust and sludge is needed. Depending on their properties, this can be done through recycling and recovery of elements, in external applications or as raw material in other industrial sectors.

Based on the above demands and challenges, the objectives are to:

- Provide society with metals through sustainable processing.
- Develop metal extraction operations that contribute to achieving climate change goals.
- Fully utilise the material and energy content in raw materials through enhanced extraction of metals from primary and secondary raw materials, including the extraction of elements contained in existing material streams but so far not extracted.
- Secure a viable use of by-products without compromising the quality of products and by-products.
- Maximise recyclability of discarded consumer goods.
- Limit atmospheric and water emissions to levels that have no negative environmental impact.

RESEARCH AND INNOVATION AIMS, STRATEGIES, AND ACTIONS

As part of the transition to CO2-neutral processing, there are a number of factors to be considered. These include alternative reduction agents, substitution of reagents that have a carbon footprint, non-fossil energy sources and increased recycling and utilisation of by-products.

To increase metal recovery from ores and increase recycling of metals, it is necessary to view the entire processing and recycling chain from a holistic perspective. Processing of primary raw materials and recycling of secondary raw materials need to be closely interlinked with benefits obtained from the combination of different material streams. To meet the challenge of variations in raw material streams, flexibility in processing due to innovative combinations of metallurgical and/or mineral processing methods should be considered.

Research should be encouraged regarding the utilisation of metal-containing side streams, understanding their generation and how metal content can be enriched. Examples include dust and sludge from gas cleaning and side streams from mining and recycling operations. To secure the quality of by-products such as slag, research is required to ensure the environmental and technical properties of the material, which may need modification in the extraction processes. This needs to be done without jeopardising the overall outcome of the processes.

Models based on the fundamental properties and chemistry of the materials and implemented as part of overall process models will aid in optimising material, gas and energy utilisation and predicting the consequences of, for example, changed material streams.

Thermodynamic data for some systems is not well covered. To improve the utility of thermodynamic models, fundamental studies to complement available data should be encouraged.

The potential for extracting metals from secondary sources not utilised today should be evaluated with respect to technical, economic and environmental aspects. Trade-offs using secondary materials versus primary materials and suitable models for evaluation should be developed and implemented.

Future competence, collaboration between sectors and social acceptance needs to be secured through education and dissemination of knowledge.

Research and innovation are needed in the following areas:

Technology

Adaptation of the processing of raw material to carbon-neutral operations, increased product quality and simultaneously optimised gas, water and energy utilisation. This should be based on fundamental knowledge related to processing and be implemented in process models.

- Develop and adopt automation systems.
- Develop knowledge and technology for use of by-products such as slag in new applications.
- Develop knowledge and technology for extracting metals from secondary materials, for example side streams in mining operations.
- Develop knowledge and technology for increasing existing process yields, taking account of the whole raw material value chain.
- Develop technologies needed to extract more elements from material streams already processed.
- Develop technology for carbon-neutral operations.

Resource efficiency and process control

Optimise the existing process chains for simultaneous extraction of metals from ore concentrates and secondary materials, including the whole system covering exploration, beneficiation of ores and scrap, and processes for extraction of the metals, for example, through improved process modelling.

- Develop methods to enhance the metal content in and secure the quality of all by-product streams to increase the ability to extract more metals from the material streams.
- Share knowledge about recycling opportunities and limitations with designers of consumer products (design for recycling).
- Introduce new methods to control processes more efficiently through new measurement techniques.
- Develop further knowledge to control slag properties and an ability to control/adjust the effect of varying slag composition to ensure the quality of by-product.
- Develop methods to utilise secondary materials or side streams from own processes or across business sectors to enhance efficiency and the recovery of metals. For example, the use of organic or lime-containing waste materials as reagents in the extraction of metals.
- Enhance understanding of element distribution and develop models for tracing elements in material streams throughout the whole value chain.
- Develop methods for optimised use of energy and fresh water.

EXPECTED IMPACT

Progress in this area is expected to lead to the following results:

Technical

- Contribute to enabling a carbon-neutral metal and mineral supply.
- Optimised use of upgrading, pre-treatment and smelting operations.
- Advice on the improved design of products to enhance recycling opportunities.
- Increased efficiency in process routes through new measurement techniques, process modelling and automation.
- Optimised processing routes for primary and secondary materials, increasing overall metal yields.
- Side streams not currently used are potentially valuable raw materials for metal extraction.
- Adaption of slag properties for new and existing slag product uses.

Economic

- Improved industry competitiveness through more efficient use of existing process streams.
- Known and new mineralisation could be turned into ores due to increased ability to process lower grade ores economically.
- New and unused process streams become economically viable.
- Further developed market for by-products.

Environmental

- Increased resource efficiency.
- Lower amounts of materials to landfill/tailings.
- Decreased energy and freshwater consumption.
- Holistic perspective of the total mineral and metal extraction chain resulting in lower total carbon footprint.

Social

- Increased employment opportunities and creation of an attractive sector for career opportunities.
- Higher awareness of sustainability issues connected to metallurgy and recycling among mining and metal industry, product designers, recycling industry and society.
- Legislation and environmental regulations are harmonised to promote recycling.

Environmental performance

Mineral production in Sweden in 2022 is considerably less emission-intensive than production in many other countries. This is the result of previous efforts. In the 1990s and early 2000s, a focus on water and waste management led to a dramatic decrease in water emissions and the development of closure strategies for mine waste deposits. Today the Swedish mining industry is considered among the global leaders in productivity and sustainability.

To safeguard Sweden's position, continuous development of technology, processes and working methods is called for. For successful environmental performance, a holistic and long-term perspective over the entire mine life from exploration to mine closure is necessary.

New legislation and operating permits require control of water and biodiversity status and the use of water and waste management technologies adapted to climate change impacts.

Waste valorisation to supply the green transition as well as reduced waste and carbon capture calls for innovations and new business models.

Acid and neutral mine drainage is the most prominent root cause of environmental issues in the mining industry and the development of additional preventive measures is required along with a reduction in emissions.

There will always be waste that needs to be safely stored from a long-term perspective, and specific treatment and prevention measures must be developed to address these issues. At the same time, risk reduction, consequence modelling of dam or waste storage failure, long-term geochemical and geotechnical stability of storage facilities, and technologies adapted to cold climates are still important.

OBJECTIVES

The main objectives for this research and innovation area are to minimise the potential negative environmental impact of mining, adapt to climate change impacts, and reduce financial and legal risk related to water, biodiversity and extracted waste management.

Before 2030:

- Optimise water management throughout mine life, from exploration phase to after mine closure.
- Improve characterisation, prediction, modelling and environmental impact tools.
- Design cost-efficient treatment and prevention technologies early in the mine life.
- Technologies and business models for the valorisation of waste to optimise resource efficiency and improve the circular economy.
- Minimise risk of dam failure from both a short- and long-term perspective.

Towards 2040:

- Long-term safe, stable and cost-efficient technologies for storage of waste.
- Broadly accepted post-mining land-use and design of added value early in the mine life.
- Long-term perspectives on preserving and developing good status of biodiversity.
- Improved scientific methology and data enables science-based adaption and implementation of directives, standards and legislation.

RESEARCH AND INNOVATION AIMS, STRATEGIES, AND ACTIONS

Research and innovation are needed to:

Optimise water management over the entire mining process

Water needs to be managed based on geochemical data and interpreted and modelled in all steps of the mining process. To prevent emissions of pollutants to the receiving ecosystem and water, efficient water management utilisation should cover ground water, pit lakes, water used in the beneficiation process, recycled water, water in the tailings storage facilities, and mine drainage. To prevent dissolution and mobilisation of metals, treatment is required as early as possible in the mining operation steps or good characterisation of solid and water phases, knowledge of solid and water interactions, and understanding of climate change impact and geohydrology are needed.

A growing field is the use of fungus and bacteria for mobilisation of elements, and capture of elements or minerals should be further investigated. Implementation of better integrated water quality data, developed prediction tests and predictive modelling will require better systems together with online monitoring and data management.

Improve characterisation, prediction and environmental impact tools

Knowledge of ore and waste characteristics, storage techniques, and historical and current downstream mine effluent impact is crucial for understanding and verifying the short- and long-term impact on biodiversity and ecosystems, including sediments and lakes. Baseline knowledge of water and ecosystem quality prior to mining is important to evaluate the impact of mining and utilisation of chemical signatures such as isotopes to distinguish pollution sources and determine geochemical processes. Today's tests are static tests and short term, and the long-term tests are costly and time-consuming.

The development of realistic prediction tests and geochemical and hydrodynamic prediction modelling of the environmental impacts are needed for implementation of reliable prevention and treatment measures. New knowledge, adaption and modelling of the impact of climate change are crucial in the development of technologies and evaluation tools.

Design of cost-efficient treatment, reclamation and prevention technologies

To be able to meet new and even more stringent legal requirements in respect of specific elements, new treatment and prevention technologies need to be developed as early as possible in the mine life and mining operation. This is to enable the preservation of good water and ecological status with low impacts from mining over the long term. Emerging elements in need of treatment and prevention measures are sulphur and nitrogen. The treatment systems and prevention technologies to reduce the release and mobilisation of unwanted elements can be either passive or active and must be considered over the entire mining process and mine life.

Methodologies should be developed for holistic assessments of the net environmental impact of new technologies. Historical and existing national technologies and standards need to be scientifically evaluated and both positive and negative aspects should be examined so as to avoid future failures. The outputs should be further developed and disseminated, including long-term climate change adaptation measures.

Develop technologies and business models for the valorisation of waste

Optimising resource efficiency from an environmental perspective also means reducing waste. A large part of the residue can be used as a resource and the remaining waste will require safe geochemical and geotechnical storage. Detailed geochemical and geotechnical characterisation of solid resources early in the mine life and throughout the mining process, together with innovative beneficiation processes, will contribute to better utilisation of the resource and facilitate product durability and reduced environmental impact.

A multidisciplinary approach is needed for waste to become a resource. Current waste at Swedish mines contains minerals, hosting metals and other elements that are not currently extracted but could be a resource in the future. Valorisation of existing or historical waste requires good geochemical and geotechnical characterisation, new extraction and excavation technologies, specific environmental prediction and durability tests. Other disposal and treatment methodologies are also required to ensure long-term environmental and economic stability. When it comes to valorisation development and environmental risk assessment, the limiting factors in most cases are the potential market and economic benefits. These are therefore important aspects in research. Traditionally, valorisation of extractive waste has been done solely for economic reasons. In the business development and decision process, the key question has therefore been whether the total cost of extracting valuable components from waste is smaller or larger than the sales price for these commodities.

It is important to strive for a paradigm shift in which environmental values are recognised in the calculations. If the valorisation of extractive waste leads to smaller waste volumes and smaller waste storage facility footprints as well as the removal of environmentally hazardous waste components, the environmental value of valorisation for the mining company could be far greater than the economic value of the extracted commodities alone.

A few examples of valorisation with the potential to contribute economically as well as reduce waste volumes and environmental impact are:

1. **SCM:** The use of tailings in the production of SCM (Supplementary Cementous Materials) for the construction industry.
2. **CCS/CCSU:** Mine waste with the potential to undergo carbonatisation for carbon capture and storage as well as in the utilisation of carbon dioxide in, for instance, technosoils.
3. **Energy:** Extractive waste may contain high volumes of chemically bound energy that could be extracted. Certain mine waste could also potentially be utilised for large-scale energy storage applications.

The new Soil Strategy 2030 and its implementation in Sweden needs a scientifically based proactive approach to adapt implementation to the mining environment and to allow evaluation of the impacts. The strategy will probably lead to a requirement for improved soil characterisation, prediction and risk assessment to be able to store and use soil at mining areas. Dusting is the environmental aspect that receives most complaints from the neighbouring stakeholders at almost all mine sites in Sweden.

While dust from crushers and other point sources is controlled with well-established technologies, dust generated from diffuse sources in mining operations and during loading, transport and handling of ore and waste can constitute a significant source of particles. This can lead to particle sedimentation close to the mine, exposure of workers and to the ambient air quality exceeding required levels in neighbouring communities. Improved methods for characterisation, prevention, monitoring and modelling of emissions and dispersion of particles should be developed as well as cost-effective measures to prevent dust generation.

Develop long-term safe, stable and cost-efficient technologies for storage of waste

In the foreseeable future, there will always be a need for long-term storage of waste. This applies both to waste for which there is no market or which cannot be excavated, and to waste requiring safely storage to avoid contamination of the environment. The development of innovative, cost-effective stabilisation techniques as well as cover and encapsulation materials and systems needs to continue. One important aspect is to evaluate the long-term performance and durability of any solution. Increased knowledge of the mechanical properties of waste streams, morphology of storage facilities, and the dewatering and design of storage facilities is needed. A lot of work has been done on thickened and paste tailings and dry stacking disposal.

However, there are still problems to be solved relating to geochemical and geotechnical aspects of the deposition technique and upscaling, as most of the work so far has been on pilot scale. Disposal and covering technologies must be adapted to the Nordic climate and climate change requirements. Disposal technologies are closely linked to dam construction, and therefore aspects of water management and dams must be designed early in the mine life to minimise dam failure risk from both a short- and long-term perspective.

The role of bacteria and fungus for stabilisation of waste is a growing field and should be further developed. New mines, valorisation and changes in the beneficiation process will have a direct impact on geotechnical and geochemical properties and thereby an impact on stability and safety. The implementation of better systems for real-time online monitoring (e.g. satellite, drones, sensors), automation and data management is needed. Predictive and consequence modelling is an important factor with regard to waste storage facilities to minimise the risk of failures and liquefaction.

Develop broadly accepted post-mining land-use and design of added value early in the mine life

The main footprint of a mine site is related to the mine itself in the case of open pit mining, and to waste deposits, such as waste rock dumps and storage facilities. Research is needed into maximising the added value of a mining area after closure, including the development of opportunities to create economic value through secondary business implementation or other measures. This relates also to the design of a sustainable landscape as well as improved biodiversity and beneficial land use. Pit lakes are often left and managed after closure and methods are needed to improve the water quality sufficient for utilisation of the water as a resource.

Develop a long-term perspective for preserving and developing the good status of biodiversity

The Swedish mining industry is developing innovative and responsible solutions to include biodiversity and ecosystem services in its daily operations. Performing rehabilitation with social and ecological added value and ecological compensation is becoming an established way of working. However, the scientific background and experience are limited.

To strengthen this work, methodologies should be developed regarding, for example, practical advice on how to work with ecological rehabilitation and compensation and how the quality of this work can be monitored and evaluated. Work also needs to be undertaken on how to identify, quantify, estimate and evaluate the benefits and improvement of biodiversity and ecological compensation. The environmental impact of mining on the downstream ground water, surface water and soil in relation to biodiversity needs to be investigated. The ability to determine the adaption of biota to changes in water quality due to mining is required as a baseline for good biodiversity status.

Adaption and implementation of directives, standards and EU directives are not always based on realistic geomaterial properties and reactivity, the potential for pollutant release, environmental and geochemical chemical conditions, and environmental impact. Proactive research is needed before national implementation of EU directives, standards and legislation to increase resource efficiency, minimise the risks of resource disposal and impacts on the environment due to poor interpretation of the legislation. Existing legislation and standards need adaption and interpretation based on new research findings. This is multidisciplinary and important for all steps in a mine life and mining operation.

EXPECTED IMPACT

Progress in this area is expected to lead to the following results:

Technical

This research agenda has the potential to contribute to the development and implementation of new water and waste management technologies, successful valorisation, and adaptation of environmental performance to climate change:

- Mineralogical and geochemical characterisation and waste management including waste reduction, utilisation of waste, stabilisation of waste, new disposal and storage techniques and mine closure that preserve the environment.

- Water management, improved modelling, impact assessments and treatment.
- Risk management including aspects such as deposition methods, consequence modelling, online monitoring, and data management systems.
- Tools for assessment and improvement to secure good status of biodiversity, water and ecological compensation.

Economic

- Development of business models and decision processes that include waste volume minimisation and other positive environmental impacts in the business development of mining generally and management/valorisation of extractive waste specifically.
- With business models based on ESG values and not just NPV calculations, it will provide a strong incentive to further process and minimize extractive waste. This will enable the extraction of value from waste that is not currently valorised due to strict NPV profitability reasons and a lack of circular economy in waste management. This can include commodity industrial minerals as well as rare earth elements and other innovation critical metals.

Environmental

- The overall aim of this thematic area is to minimise the negative environmental impact (footprint) of mining and increase the use of waste as a resource.

Social

- Given the expected impact above on environmental performance and economy, the outcome would also contribute to an improved social license to operate, if successfully communicated.

Attractive workplaces

To cope with the future labour supply, the mining industry must change its image from the notion of being an industry with dangerous workplaces that destroy the environment to becoming an attractive employer that is a prime player in the green transformation.

Digitalization opens up new opportunities to create attractive workplaces in a safe environment as well as jobs that provide space for the employee's full expertise and creativity. But there are also risks that need to be addressed, such as privacy issues, increased stress, and work-life balance.

With increased digitization, new qualifications are needed. These must be identified and programmes for reskilling and lifelong learning must be formed. A new way of looking at learning as part of the work is required.

Research on health and safety has been successful, but digitization creates a new way of working that require the concept to be expanded and focused more on health promotion.

New technologies and the green transformation will require a new way of organizing production and business, methods that are shaped to fit a more circular economy. From this perspective, the view of work must expand to incorporate a prosperous human-centred society where all people can feel included.

Our ambition is to make the mining industry more prepared to meet technological development on human terms, an industry recognized as an ethical, ecological, and diverse industry that can offer challenging jobs and attractive workplaces.

OBJECTIVES

The main objective for this research and innovation area is to make the mining industry a safe and attractive workplace. Before 2030, the division between blue- and white-collar workers has disappeared, and safety is not an issue any more. Most dangerous work tasks are performed by robots. All machines are self-regulated or remotely controlled from workplaces that are designed to promote co-operation and creative problem-solving in multiskilled teams of men and women. These new types of jobs can be located in different geographical areas but are all connected in global excellence centres close to mining sites with long-standing competence in mining processes.

Based on the above demands and challenges, the objectives are to:

- Use modern technology and digital aids to achieve increased productivity.
- Use personal sensors for safety and well-being.
- Adapt technology to human conditions.
- Give workers autonomy and influence in relation both to other people and the technical systems.
- Develop jobs that provide physical, intellectual, and cultural stimulation and include learning and professional development.
- Provide a work environment where physical risks are eliminated.
- Provide an equal environment that is designed for both women and men.
- Offer workers a good work-life balance between work and private life.
- Offer workers the health resources and opportunity to create a rich and sustainable life in a prosperous local community.

As we approach 2040, all mining workplaces in Sweden must meet all the requirements above.

RESEARCH AND INNOVATION AIMS, STRATEGIES, AND ACTIONS

Research and innovation are needed to answer the following questions:

- What is required of new technology on human terms?
- How can the work be organised and jobs designed to meet the values and expectations that young women and men have when they enter working life?
- How does the green industrial transformation interact with demands for new organisational forms and work roles?
- How should digitised production systems address privacy issues?
- How to gain acceptance and avoid resistance to new technologies?

Furthermore, competence development, learning at work and other learning strategies should be prioritised. These topics are vital to meet the demands of new technologies and can ensure both flexibility for the company and development of a person's professional role. New forms of continuous competency development that are integrated into mining companies' day-to-day operations are required. Important focus areas for research are:

- Identification of future skills requirements.
- Development of new forms of lifelong learning for reskilling and competence development.
- Development of methods so that the elderly can participate longer in working life.

Health and safety at work must have top priority. Mechanisation, remote control, and automation are efficient preventive safety measures, but they are not enough. The organisational and social work environment must be emphasised more in order to create a deeply rooted safety culture as well as attractive workplaces. We also need to change our focus from rehabilitation to health promotion. Leadership and employeeship are important factors that directly affect health and well-being. In short, there is a need for:

- Broader analysis of the impact of digitalisation on health and safety.
- Development of health promotion in all jobs and at all workplaces.
- Development of a safety culture that also includes contractors.

Finally, although the traditional image of mining is not particularly attractive, we think it is possible to create a new, challenging vision of future mining. To succeed, mining companies must actively demonstrate their role as a key player in the green transformation. Employees want to feel proud to work in the company, which means that issues such as vision, mission and core values are important.

The new vision must be based on progress-oriented action points together with a well thought-out internal and external communication process about the working environment. Another important aspect to consider is that work is embedded in a social context. Active work is not enough; there must also be an attractive community that can offer good housing conditions, schools and childcare along with a diverse cultural environment. All these factors affect the company's image, and thus the possibility of recruiting young, talented people to the industry. Overall, broader strategic research areas should include matters related to:

- Utilisation of the industry's unique position as a prime contributor to the green industrial transformation.

- Development of a holistic concept which not only includes the mine site, but also a rich and sustainable life in a prosperous local community.
- Giving the industry a new image that can attract young people.

EXPECTED IMPACT

Progress in this area is expected to lead to the following results:

Technical

- Digitalisation on human terms.
- New forms of continuous competence development.
- New methods for managing and controlling the work environment.
- A shift in perspective from rehabilitation to health promotion.

Economic

- Reduced cost by keeping qualified miners and staff.
- Increased efficiency at work.

Social

- Increasing young people's interest in the mining industry.
- Contribute to the creation of an attractive society.

Environmental

- Recognition of mining as a prime contributor to the green industrial transformation.


Photo: LKAB

Mining and society

Everywhere mining occurs, there is an impact on the local community. While mines often provide jobs and economic benefits, operations also have potential environmental and social dimensions.

To contribute to sustainable development, the mining and metal-producing industry and other parts of society need to recognise the wider positive and negative impacts of mining on society at local, regional, national and global levels. This entails developing methods for local relations work and contributing to foreseeable, transparent, and effective permit processes.

Achieving this requires an increased understanding of the range of societal impacts, including legislation and its application, employment and income generation, distributional effects, land use conflicts, indigenous rights, demographics, and cultural heritage. The research and innovation area addresses all three dimensions of sustainable development, and it also recognises important trade-offs and synergies between the dimensions. A related issue concerns how the different responsibilities for sustainable development can be shared between the industry and different public authorities.

This research and innovation area focuses on four main sub-areas:

- Corporate social responsibility (CSR) and sustainable business regional development.
- Innovation management and systems.
- Managing land-use conflicts.
- Permitting processes including environmental regulations and how they are applied.

OBJECTIVES

The main objectives for this research and innovation area are to:

Before 2030:

- Develop an understanding of how current permitting processes impact the mining industry.
- Develop innovative suggestions on how to improve permitting processes with a view to making them predictable, transparent, efficient and appropriate.
- Initiate strong social science research addressing the industry's relationship with other stakeholders and its contribution to sustainable development.
- Develop and operationalise sustainability criteria and measurable indicators addressing various environmental and community values.
- Develop impact assessment tools, institutions and deliberative approaches that can support the various decision-making processes (e.g. the permitting of new mines).

Towards 2040:

- Adopt sustainability criteria and indicators that are recognised by key stakeholders.
- Integrate stakeholder management tools.
- Implement sustainability management systems (SMS) and a sustainability label for minerals and metals.
- Practice social innovation and make sure the industry is recognised as a value-adding corporate citizen.

RESEARCH AND INNOVATION AIMS, STRATEGIES, AND ACTIONS

Research and innovation are needed to:

Develop corporate social responsibility and sustainable business

Corporate social responsibility (CSR) and sustainable business requires a company to incorporate social and environmental considerations into its decision-ma king processes and to be accountable for the impacts of its decisions and activities on society. CSR can generate shared value through sustainable business models, by the integration of sustainability considerations into the entire value chain, and by identifying, assessing and involving stakeholders in decision-making. The integration of CSR is essential and implies improving existing operations and integrating sustainability considerations into daily operations. It also promotes social responsibility along the value chain.

To demonstrate responsibility in a transparent and accountable way, companies use sustainability reporting or certification of the company or its products in accordance with a social or environmental standard or label.

Through social innovation, companies create new ideas that meet social needs, establish social relationships, and form new collaborations in order to become a value-adding corporate citizen.

Before 2030:

- Develop new business models to address various social or environmental problems or conflicts of interest.
- Identify and implement industry-wide sustainability criteria and measurable indicators and their applicability.
- Develop strategic tools and guidelines for improved stakeholder management, sustainable supply chain management, sustainability auditing, community development practices and social innovation.

Towards 2040:

- Develop SMS by integrating and implemen ting sustainability criteria and indicators into existing operational management systems.
- Develop a method for traceability and a framework for sustainability labelling of metals and minerals.
- Achieve social innovation through new collaborations, partnerships and practices to create environmental, social and economic benefits and build trust, including with local communities.

Develop innovation management and systems

Innovation management focuses on management processes to allow industrial companies to respond to external and internal opportunities and create new ideas, products, services or business models. The objective is to increase knowledge about innovation in the mineral and metals industries and identify how this work can be improved over time. Innovation management is of particular importance in extracting commercial value from new technologies.

It can be company-centric (i.e. within a company) but frequently occurs across an industry, such as when mining companies and suppliers of process technologies create joint research and development projects and engage in open innovation. At the macro level, innovation can also be studied as an ecosystem, which stresses the flow of technology and information among the key participants, firms and institutions that set the boundary conditions for new products or services (e.g. circular business models).

Innovation system analysis often focuses on identifying system strengths or weaknesses and may be conducted at national, regional, sector or technological level.

Before 2030:

- Develop new methods, tools and techniques to allow companies to create new products, services and business models.
- Improve knowledge of innovation management "best practices", and adaptation of such best practices to fit the Swedish mining and metal producing sector.
- Identify key system-level strengths and weaknesses to improve the mining ecosystem.

Towards 2040:

- Build world-class innovation capabilities among companies in the mining and metals ecosystem.
- Develop innovative management frameworks to make companies "innovation leaders".
- Remove bottlenecks and weaknesses in the mining eco system so that the whole sector can be strengthened.

Improve regional development: labour markets, migration and benefit-sharing instruments

Improved knowledge about the impact of mining operations on migration and commuting patterns, job creation, and recruitment challenges is needed. This should take account of the fact that the industry's labour market impacts are likely to change over time due to cyclical fluctuations and technological change. The identification and evaluation of different types of instruments that can be adopted to amplify any positive impacts - benefit-sharing – is also an important research field. Finally, empirical research is essential regarding the relationship between social sustainability, social cohesion and company workplaces and practices.

Before 2030:

- Review and investigate current and future labour recruitment needs.
- Review and evaluate existing methods used in Sweden and internationally to assess the regional economic impacts of mining operations and the role of benefit-sharing.
- Analyse labour mobility and population changes in local and regional labour markets impacted by industry developments.
- Review and analyse important developments in social sustainability factors and their relationship to key Swedish mining communities, including company recruitment and personnel practices.

Towards 2040:

- Identify and evaluate management practices with the aim of meeting future demand for the recruitment of qualified labour to the industry.
- Develop and implement new and improved methodologies to assess regional economic impacts of mining operations, including the impacts and trade-offs associated with different types of benefit-sharing mechanisms.
- Identify and evaluate strategies on how to promote economic and social cooperation between the industry and local communities and regions.

Manage land use conflicts: rights, policy, planning and deliberation

Land use conflicts raise questions about the efficient use of scarce resources. Such conflicts also concern legal rights, values and ethical issues such as fairness and procedural justice. Mining development may sometimes be difficult to match with local aspirations and indigenous rights.

Any meaningful decision-making institution and process must therefore be able to articulate and handle such concerns. This calls for the use of a mix of methods to resolve, or handle, land use conflicts. These methods include the recognition of rights, recognised institutional frameworks, efficient and recognised decision-making procedures, as well as properly functioning deliberative practices.

Due to a complex web of legislation at different levels, it is often unclear how mineral interests interact with other land-use interests and how they are considered or valued in relation to each other as well as over time. Underlying many land use conflicts are differing values and aspirations that should be addressed in ways recognised by all parties. This calls for research tools to evaluate impacts and how the existing regulatory frameworks address stakeholders, interests, goals and practices, and how these are implemented in real-life. This includes the role of communication and local participation in planning processes.

Before 2030:

- Identify causes and challenges in land-use conflicts with respect to current institutions and practices.
- Review existing regulatory and planning frameworks in relation to different types of mineral exploration and mining operations as well as experience gained from other industries, including how stakeholder views are evaluated and addressed.
- Review the current use of public consultations and environmental impact assessments, and how these could enhance the quality of stakeholder interaction and relationships.

- Make an international comparison of the strategies employed to permit indigenous rights and mining operations to co-exist.
- Develop and test a social cost-benefit approach in the case of investments in mining and metal-producing industries.

Towards 2040:

- Identify and evaluate different types of strategies, practices and regulations that could improve the legitimacy and the efficiency of land use decision-making with respect to mining concessions, including mechanisms for public participation and involvement in the planning processes.
- Identify and evaluate various strategies, practices and regulations to address the co-existence of different national interests in mining areas.
- Compile a handbook for conducting cost-benefit analyses for mining development to support, for instance, legal processes and decision-making.

Improve permitting processes for mining – regulation, application, compliance and competitiveness

There is increased recognition of the complex, drawn-out and unpredictable nature of permitting processes based on the environmental code. Due to the particular conditions pertaining to mining activities – such as the location necessarily being where a mineral deposit exists, and the necessary changes over time - this development can have a greater impact on the mining sector as compared with other industries. In addition, mine permitting must comply with the Minerals Act, which should act as an enabler for mine permitting, but has instead become a barrier. The permitting process for mines can also be hard to understand for the permitting authorities themselves as well as for courts and other stakeholders.

Research is needed to analyse the root cause of these problems and what actions can be taken to address issues that are recognised by a wide range of stakeholders. Legislation is an important area where comparative studies relating to other countries can be undertaken. However, research concerning the application of EU directives is just as important. Organisational issues, roles and responsibilities concerning environmental courts and authorities constitute another area to be studied.

Research is also needed into how environmental regulations can be designed and implemented to promote continuous pollution reduction while at the same time taking into account long-term industry competitiveness. Future research endeavours could involve new and/or improved methods to evaluate the efficiency and competitiveness impacts of different types of regulations in terms of design and implementation.

Before 2030:

- Develop an understanding of how the current permitting processes affect the mining industry.
- Develop an understanding of how EU directives are applied in different countries.
- Review and evaluate the decision-making processes that underlie the existing permitting conditions with respect to air and water pollution, and solid mine waste.
- Make an international comparison of how other significant mining countries regulate, and have regulated, the environmental impacts of mines and metal smelters.

Towards 2040:

- Develop permitting processes that are recognised by key stakeholders, including the mining industry, government agencies and the general public.
- Develop different regulatory approaches that can be used to improve environmental performance without compromising the industry's long-term competitiveness and requirements for transparency.
- Develop different ways of regulating the rehabilitation of mining areas to ensure that the necessary costs can be covered in an economically efficient manner.
- Analyse best-practice regulations (e.g. experiences from other countries and industries) from the viewpoint of societal efficiency, and the development of cost-benefit tools to assist the permit decision-making process.


Photo: Sandvik

Gender equality and diversity

Traditionally the mining industry has been male-dominated. International competition and an increased need for social and environmental sustainability are now quickly broadening the skills requirement. To maintain competitiveness, the industry needs to be open to all.

Gender equality and diversity are important tools to meet the challenges of an internationally competitive, innovative, green, and socially sustainable mining, mineral, and metal sector as well as for creating prosperous regions and attractive sustainable communities.

Moreover, Horizon Europe states that the higher a country scores on gender equality, the higher its innovation potential. Other research shows that companies with more gender-equal boards deliver more economic growth and that gender equality and diversity contribute to more flexible and agile organisations. The research and innovation area includes developing theories and methods for how to create, sustain and use gender equality and diversity in organisations, workplaces and technology in the Swedish mining, mineral and metal producing industry.

Research, innovation and action have the potential to exert a major impact on the Swedish mining, mineral and metal industry. The research will also contribute to a general and deeper understanding of problematic issues, such as gender inequality and lack of diversity, and how to address these issues.

Some aspects of the gender and diversity research need to be theoretical; some aspects need to be multidisciplinary and integrated in technological, organisational, and social research; some aspects need to be applied and pursued in close collaboration with companies in different parts of the Swedish mining, mineral, and metal sector and local stakeholders.

OBJECTIVES

The main objectives for this research and innovation area are to:

Before 2030:

- Develop healthier, safer and more attractive workplaces for all women and men based on modern leadership, organisation, and technology and included in the digital and green industrial transformations.
- Improve competence development and skills supply, new educational programmes, learning organisations and better processes for both recruiting and retaining all sorts of skilled people in the sector, both women and men.
- Improve flexibility and design, development and implementation of safety systems, organisations, and technologies and services – based on diverse perspectives and diverse groups of leaders, engineers, and designers, both women and men.

Towards 2040:

- Develop a global role model that is competing with attractive, gender-equal, and culturally diverse organisations and teams that are ensuring efficiency, productivity, and innovation in an environmental, economic, and socially sustainable sector.
- Develop the tools to operate in attractive, prosperous, and sustainable mining regions characterised by a diversified labour market and business culture and communities built on inclusion, respect, and a diverse mix of people.

RESEARCH AND INNOVATION AIMS, STRATEGIES, AND ACTIONS

Research and innovation are needed to:

- Map the current diversity and gender patterns (including both men and women) in the whole sector (nationally and globally).
- Examine how gender inequality and lack of diversity are manifested in the sector and at what cost
- Examine how diversity and gender in the sector connect to technological, organisational, and cultural development and innovation processes as well as in the surrounding communities
- Consider how problematic homogeneous and unequal gender positions and patterns in the sector can be challenged and changed – in technological, organisational, and cultural development processes and innovations
- Consider how new diversity and gender equality in the sector can be constructed, implemented, and made productive (i.e. understanding the business effects of gender equality and diversity)

Thematically the research and innovation requirements can be divided into three sub-themes:

Organisation, learning and leadership

- How to both attract and retain people from a broad recruitment base that includes all social groups, regardless of gender, ethnicity, age, etc., to education and jobs in all parts of the sector
- The transformation of skills and competences of existing staff for the future high-tech and sustainable work in the sector.
- Leadership and employeeship for agile and learning organisations and inclusive diverse and gender-equal professions, teams, workplaces, and cultures.
- Good social and organisational work environments for all women and men, for example how to overcome problematic gender stereotypes (for example “the macho culture”), unconscious bias, homosocial cultures, norms, attitudes, and behaviours and excluding jargon.
- Gender equality and diversity measures including not only mining companies, but also subcontractors, infrastructure and technology suppliers, temporary staff and similar.

Innovation and technology

- Create technology and organisations on human terms by placing humans, all types of women and men, at the centre of development and innovation, organisation, technology, and products.
- Development and implementation of sustainable technology and production processes in the sector by using gender and diversity theories as tools in designing new innovations – in services, technology, organisation, and workplaces as well as in clusters and communities.
- Gender and diversity perspectives integrated in the early phases of new technological and organisational development processes to make it possible to build gender equality and diversity from the start.

Society and the wider sector

- The mining sector needs to find ways to cooperate and join forces with academia, municipalities and other industries to ensure skills, technology, innovation, and service supply thanks to a sustainable, gender-equal and diverse society around mining establishments.
- The mining industry shares many gender-equality and diversity problems and solutions, in a complex way, with the rest of the sector – subcontractors, infrastructure and technology suppliers, related business clusters as well as education, research and innovation organisations, authorities and the mining communities and society as a whole.
- Issues of gender equality and diversity must also be addressed at a societal level, perhaps especially in local and regional mining communities and their ongoing social transformations to avoid continuing societal homogeneity, gender stereotypes and the migration of young women from these communities. A gender-segregated economy and labour market with low diversification is vulnerable, both for the industry and society, and it makes the communities unattractive places to live.

Along with the above research and innovation needs, these support actions are suggested:

- Establish a platform for knowledge exchange and collaboration where all actors in the sector can evaluate their diversity and gender-equality measures and related activities – to support implementation of the research results, needs-driven development of methodologies and best practices as well as general cooperation and communication on gender equality and diversity. This can preferably be done jointly with other industries and universities.

- Global sustainability perspectives and comparisons of gender equality and diversity in the global mining sector and the relations with local workplaces and local societies.
- Develop recruitment, promotion, and retention practices based on gender-equality and diversity theories.
- Develop systematic gender-divided statistics (facts and figures) in the sector – industry, clusters, education, and academia etc.
- Develop sector-specific methods for systematic gender and diversity mainstreaming measures including both men and women – mapping, risk assessment, measures, control and learning and communication.
- Develop communication, both externally and internally, of good examples on gender equality and diversity and the importance of ensuring that these issues are prioritised as part of other productivity measures.

Encourage collaboration between industry and (local and regional) society for attractive, diverse and gender-equal mining communities that are also adaptable to change.

EXPECTED IMPACT

Progress in this area is expected to lead to the following results:

Technical

- More innovative climate within the industry.
- New forms of continuous competence development.

Economic

- Reduced cost by keeping qualified miners and staff.
- Higher growth potential.

Social

- Increasing young people's interest in the mining industry, both men and women.
- Contribute to the creation of an attractive workplace.

Environmental

- Increase in social and environmental sustainability.

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