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Garpenberg mine, Bergslagen.
Photo: Boliden AB.



PowerROC T50 surface drill rig.
Photo: Atlas Copco.

1 Executive summary

THE STRATEGIC RESEARCH AND INNOVATION AGENDA FOR THE SWEDISH MINING AND METAL PRODUCING INDUSTRY (STRIM) 2017–2020 is subdivided into nine main agenda areas:

- Exploration
- Resource Characterisation
- Mining
- Mineral Processing
- Recycling & Metallurgy
- Reclamation & Environmental Performance
- Attractive Workplaces
- Gender and Diversity in Mining
- Social License to Operate

The sustainable supply of raw materials is a major challenge to Europe, and the dependence on the import of metallic and mineral raw materials is the highest for any region in the world apart from Japan. Sweden has an excellent geological potential, high-tech industry, a good infrastructure and stable political conditions – all of which are factors that may contribute to a competitive Swedish mining, metal and supply sector. Sweden is in the forefront of efficient mining, both underground and in open cast mining operations, and has leading global suppliers of underground equipment for the mining industry and one of the most competitive academic environments related to raw materials.

This agenda is a continuation and update of the STRIM Agenda 2013–2016, which is further explained in Chapter 2. In Chapter 3, a common vision is set for the STRIM Agenda organisations. The nine agenda areas related to primary and secondary resources are described in Chapter 4. Each agenda area has defined the research and innovation needs in the short (2017–2020), medium (2020–2024) and

long (beyond 2024) terms. In addition, each agenda area has defined a vision for 2030 and beyond, based on key performance indicators.

All agenda areas have defined short- and medium-term measures that can be implemented within national and international RDI initiatives. The measures have been targeted against expected technical, economic, environmental and social impacts in a clearly defined way (summarised in Chapter 6). In Chapter 7, the proposed measures are summarised in a table. The ambition is also to implement the measures in various international initiatives as described in Chapter 5.

Each STRIM Agenda area is described according to 1) Vision (with key performance indicators), 2) State of the art, 3) Research and innovation needs and strategies and measures, and 4) Expected impact.

*“Three of the world’s four
processing plants that generate
the least carbon dioxide
emissions per produced tonne
of pellets are in Sweden and
belong to LKAB.”*

JAN MOSTRÖM, CEO LKAB,
ANNUAL REPORT 2015

*“Atlas Copco is all about the
innovative spirit.”*

RONNIE LETEN, CEO ATLAS COPCO,
ANNUAL REPORT 2015

*“ABB stands for
groundbreaking innovations
that are paving the way to the
ongoing digital revolution.”*

ULRICH SPIESSHOFER, CEO ABB,
ANNUAL REPORT 2015



DR-pellets.
Photo: Fredric Alm, LKAB.

2 Introduction

This second Strategic Research and Innovation Agenda for the Mining and Metal Producing Industry (STRIM) has been developed in response to societal needs of raw materials. Sweden is one of the major mining countries in Europe and it is the ambition of the Swedish mining industry – together with suppliers, research organisations, academia, authorities and other stakeholders – to develop an industry that is in the forefront of global innovation and thus competitiveness.

The basic starting point for the first STRIM agenda (2013–2016) was the international cooperative work on developing a programme for the project Sustainable Mining and Innovation for the Future (SMIFU) that was completed in 2012 by international collaboration between ABB, ÅF, AGH (Poland), Atlas Copco, Boliden, KGHM (Poland), LKAB, LTU, Metso, Outotec and Sandvik, and led by Rock Tech Centre (RTC). The ambition in the STRIM Agenda goes beyond the SMIFU work in that it defines the challenges of the SMIFU work and suggests an implementation plan for the findings in the SMIFU report. The first STRIM Agenda also extended the ambitions of SMIFU and broadened the scope to cover the entire primary resources value chain by also incorporating the early stages of the value chain, i.e. exploration, and the downstream parts of the primary value chain, i.e. metallurgy. This second STRIM Agenda (2017–2020) is based on the first STRIM Agenda published in 2013 and is further extended with a section on Social License to Operate.

A strategic research and innovation agenda should specify why it is needed, how it will be realised and by what means. This is further explained in the different chapters of this agenda and summarised in Figure 2-1.

Society has always had, and will continue to have, a fundamental need of metals and minerals. An average citizen of the Western world consumes about 17.94 tonnes (Table 2-1) of minerals and metals per year which are used for roads, building materials, cars, refrigerators, computers etc. A society without minerals and metals is unthinkable.

Table 2-1. Amount of minerals that an average citizen in the Western world consumes every year.

Source: <http://www.mii.org>.

Commodity	Use	
Aggregates	7208	kg
Cement	279	kg
Iron ore	150	kg
Salt	191	kg
Phosphate	96	kg
Clay	66	kg
Bauxite (Al)	30	kg
Copper	6	kg
Lead	5	kg
Zinc	3	kg
Soda ash	15	kg
Manganese	3	kg
Other nonmetals	243	kg
Other metals	10	kg
Petroleum	3464	L
Coal	2609	kg
Natural gas	2500	m ³
Uranium	0,08	kg

THE STRIM AGENDA

Why

The sustainable supply of raw materials is a major challenge to European industry. Import dependence is the highest for any region in the world, apart from Japan, and Sweden has an excellent geological potential, a high-tech industry, a good infrastructure, and stable political conditions – all of which are factors that contribute to a competitive Swedish mining and supply sector. Sweden is in the forefront of efficient mining both underground and in open pit mining operations. Sweden has leading global suppliers of underground equipment for the mining industry and one of the world's leading companies in recycling of electronic scrap. In addition, Sweden has one of the most competitive academic environments related to raw materials.

What

By developing a common vision (Chapter 3) and clearly setting the aims and goals on a national and international level, the

STRIM Agenda – based on nine agenda areas (Chapter 4) related to primary and secondary resources – clearly paves the way. Each agenda area has defined the research and innovation needs in the short (2017–2020), medium (2020–2024) and long (beyond 2024) terms. Each agenda area also has a defined vision for 2030 and beyond, based on key performance indicators.

How

All agenda areas have defined short- and medium-term measures that can be implemented within national and international RDI initiatives. The measures have been targeted on expected impact in a clearly defined way (Chapter 6). In Chapter 7, the proposed actions for future implementation are listed. The form of collaboration for execution is further defined in a national strategic innovation programme – SIP STRIM – to be annexed to this STRIM Agenda. The ambition is also to implement the measures in various international initiatives described in Chapter 5.

Figure 2-1. Strategic ambitions for the STRIM agenda.

It is estimated that there will be an additional 3 billion members of the middle-class by 2030, and this will create a strong long-term need for the supply of raw materials. Sweden has a unique opportunity to contribute towards the needs of the many. Sweden possesses untapped geological potential for a growing mining industry that can expand in harmony with society and the environment. The global technology providers with a strong home base in the Nordic countries will, as in the past, continue to develop the technology of the future in close co-operation with the Swedish mining and metal producing industry.

The Swedish Association of Mines, Mineral and Metal Producers (SveMin) recently released the sector's vision for growth (see Section 2.2.3). One of the conditions for this growth is a research and innovation programme to maintain Sweden's leadership in R&D and industrial expertise throughout the entire value chain (Fig. 2-2).

The mining and metal producing industry, including technology providers, works on a truly global, international market. The world as well as the market conditions are constantly changing, and the only way to survive and prosper is through competitiveness. This is ensured by constant development of products, processes and competence, in which research and innovation are at the core of the corporate strategies.

Frontline research is fundamental for high quality education and nurturing of business skills. A good industrial research infrastructure, with deep roots in basic and applied sciences, brings forth a number of benefits: an education system that is well versed in current research and development issues, access to an industrial network, and an international academic network in which efficient research activities can be pursued.

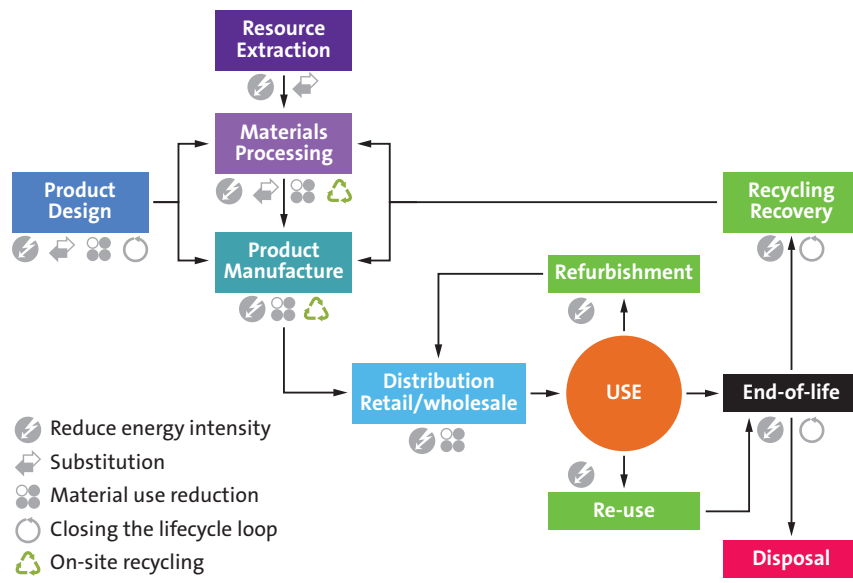


Figure 2-2. Raw materials in the value chain. Modified from: European Round Table, 2013. Raw Materials in the Industrial Value Chain. An Overview. <http://www.ert.eu>.

For additional global competitiveness, the mining and metal producing industry must have a positive image and reinforce diversified capacity building. A challenge for the future is to encourage skilled employees and new talents, particularly women and young people, to apply for jobs and pursue education and research within the industry. In order to create more attractive workplaces, the industry must give consideration to the interface between human, technology and organisation with respect to safety, occupational health, ergonomics, management, workplace-culture, learning, career opportunities, diversity, gender equality etc. By taking these considerations into account, the industry will create attractive organisations that are more efficient and more innovative, as well as flexible to societal change and technological development.

In the Government's research and innovation bill for 2013–2016, special provisions are made for "strategic areas for innovation" to meet societal challenges and strengthen the competitiveness of companies in Sweden. Mining, mineral and steel research is one of the strategic areas selected, and the government states that the "research is eminent, and Sweden is one of the leading mining countries. The government would, however, ensure that Sweden in the future is at the cutting edge in the field." In general terms, the following actions are needed along the whole value chain:

- Technology and methodology for the exploration and evaluation of new mineral deposits as the basis for new mines.
- Safer, leaner and greener primary extraction.
- Resource efficient mineral processing.



Figure 2-3. The first Strategic Research and Innovation Agenda for the Mining and Metal Producing Industry (STRIM).

- The development of new value-added products.
- Reuse and recycling as part of a sustainable society.
- Excellent and diverse capacity building.
- Attractive workplaces and attractive municipalities.
- Social license to operate for mines and metal producers.

During 2006–2010, a national Strategic Mining Research Programme was conducted. One of the projects initiated was the conceptual study entitled “*Smart Mine of the Future*”. In this project, Swedish and Polish mining companies together with academia joined forces with the competitive global Nordic technology providers to develop a common vision for 2030, a shared commitment and the embryo for a Strategic Research and Innovation Agenda to meet this vision. The defined areas of focus were resource characterisation; safer, leaner and greener mining; and attractive workplaces. The feasibility stage of the project was later continued and the results of this stage also formed the core of the first Strategic Research and Innovation Agenda (STRIM, Fig. 2-3) and also of the present Agenda. Safer, leaner and greener mining, developments in mineral processing, and laying a foundation for attractive workplaces were areas covered in the research, development and innovation programme for 2013–2016. Three additional core areas of the programme were 1) Exploration, 2) Metallurgy and Recycling, and 3) Gender Equality in Mining.

It is anticipated that the Swedish research programme will be a strong platform for the realisation of further exchange and cooperation with leading global research institutes in different countries. Of special importance in this respect is participation in the new EU framework programme Horizon 2020 (see section 2.1).

2.1 DEVELOPMENT OF PROGRAMMES FOR RESEARCH AND INNOVATION IN THE MINING SECTOR FROM YEAR 2005 AND ONWARDS

The mining and metal producing sector is directly responsible for one of the core pillars for the functioning of the society in the past, present and the future – the supply of minerals and metals. Development and growth of the society are directly correlated to a sustainable supply of raw materials, and any interruption of the supply can lead to serious societal challenges. There is therefore consensus within the EU that raw materials supply is a major societal challenge for the society at large. Since 2008, activities within the Commission related to raw materials supply has been based on the Raw Materials Initiative (RMI).

The year 2005 was a Swedish mining research milestone as the Swedish mining industry and Luleå University of Technology (LTU) jointly defined a national and a European ambition for research, education and innovation within the sector. As a consequence, the Swedish mining industry was instrumental in establishing the national mining think-tank Bergforsk (www.bergforsk.se) as well

as the European Technology Platform on Sustainable Mineral Resources (ETP SMR, www.etpsmr.org). The efforts were a direct consequence of a Vision 2010 previously established within the industry.

In 2006, the Swedish government decided to establish a national mining research programme for 2006–2010 to be led by the Swedish agency Vinnova (www.vinnova.se). The programme was jointly funded by the government (via Vinnova) and the mining industry in the range of SEK 100 million. The Strategic Mining Research Programme for 2006–2010 received a favourable evaluation from independent reviewers¹. They concluded, for example, that the research work “*in the areas of mining engineering, geology and enrichment technology, is of high scientific quality and is at the forefront of international research in each area. The projects are likely to contribute to the strengthening of the Swedish mining industry’s technology leadership and global competitiveness, creating strong educational, research and innovation environments, and a successful Swedish participation in the international community initiatives in the EU, but also increased collaboration with researchers in other major countries.*”

Another milestone in the research, development and innovation related to the mining industry was the publishing of the “*The Raw Materials Initiative — meeting our critical needs for growth and jobs in Europe*” by the EU Commission in 2008². The RMI is based on the following three pillars:

- Ensure access to raw materials from international markets under the same conditions as other industrial competitors.
- Set the right framework conditions within the EU in order to foster a sustainable supply of raw materials from European sources.
- Boost overall resource efficiency and promote recycling to reduce the EU’s consumption of primary raw materials and decrease the relative import dependence.

Subsequent to the publication of the RMI, the Commission’s European Framework Programme for Research and Development (FP7) launched several calls directly related to raw materials along the primary raw materials value chain. The Swedish mining industry has been very successful in these calls and has been active partner as coordinators or WP-leaders in two FP7 flagship projects related to raw materials: Promine³ and I2Mine⁴. The Geological Survey of Sweden (SGU) has been involved in several FP7 projects, some of them directly related to raw materials, such as EURARE.

¹ Stern, P., Terrell, M., Åström, T. & Blomqvist, L., 2012: Evaluation of the Strategic Mining Research Programme (In Swedish with English Executive Summary). Vinnova Rapport VR 2012:01.

² COM (2008)699.

³ <http://promine.gtk.fi>

⁴ <http://www.i2mine.eu>

In the research and innovation proposal advanced by the Swedish government in 2008⁵, twenty-three Strategic Research Areas were identified as being of importance. One of these areas was “sustainable natural resources”, which was in turn divided into forest and mining and minerals. The government invited Swedish universities and research institutes to submit applications in open competition, either alone or as joint applications within these twenty-three areas. LTU decided together with the Swedish mining industry and Swerea MEFOS to submit an application entitled “Sustainable use of Mineral Resources – Securing the Future”. This proved to be the winning proposal within mining and minerals, and LTU formed the centre of excellence known as the Centre of Advanced Mining and Metallurgy (CAMM)⁶ to operate within six key areas:

- Geometallurgy and 4D geological modelling (with time as the 4th dimension).
- Deep mining.
- Lean mining – development of production systems modelling.
- Particle technology.
- Green mining – reducing the environmental footprint.
- Raw materials for future iron- and steelmaking, a cooperation between LTU and Swerea MEFOS.

After evaluation of CAMM in 2014, the recommendation from the funding agencies was that the government should make the funding for CAMM at the same level permanent. Therefore, LTU defined a CAMM2 programme for the period 2016–2020 which focuses on five key areas: Exploration, Mining, Mineral Processing, Metallurgy, and Environment. The collaboration with Swerea MEFOS was also prolonged for the new programme period.

This is the second updated agenda for the STRIM stakeholders. Based on the successful application for a Strategic Innovation Programme (SIP) from Vinnova it was envisaged that for each three-year programme period the STRIM agenda should be updated. The SIP STRIM programme⁷, which has now been operational for three years, will not be described in detail here. In short, the programme includes several activities besides innovation projects and is funded to 50% by Vinnova and to 50% by partner organisations, mainly the Swedish industry. The programme has been instrumental for providing new results at a TRL (Technology Readiness Level) of 3–6. The new three-year programme period 2017–2019 is currently being defined.

In November 2012, the Nordic Council of Ministers announced a new Nordic initiative related to raw materials called NordMin. NordMin is managed from LTU and serves as a network of excellence within the full value chain of raw ma-

⁵ Proposal. 2008/09:50.

⁶ <http://www.ltu.se/centres/camm>

⁷ <http://www.sipstrim.se>

terials. NordMin involves academia, industry and research institutes in Sweden, Norway, Finland, Denmark, Iceland and Greenland. NordMin will operate from 2013 until 2017 with a total of DKR 30 million in funding. Swedish organisations are engaged in research projects and preparatory projects for leverage within EU in workshops and PhD-courses. Currently an extension of NordMin through funding from different Nordic sources is evaluated.

The European Union has, since the publication of the Raw Materials Initiative in 2008, defined several schemes to tackle the challenges defined in the RMI. Currently there are four major initiatives within the framework of FP7 and Horizon 2020 in which the Swedish mining industry, Luleå University of Technology, the Geological Survey of Sweden and other organisations are or have been involved in (outside regular calls) and where EU support for any RDI action related to raw materials is realised:

- The European Innovation Partnership (EIP) on Raw Materials will contribute to the mid- and long-term security of a sustainable supply of raw materials (including critical raw materials, industrial minerals and wood-based materials) that are required to meet the fundamental needs of a modern resource-efficient society. It is an essential contribution to the competitiveness of European industries, to increased resource efficiency in the EU, and to the development of new European-based recycling activities. The Strategic Impelementation Plan (SIP) of the EIP on Raw materials is an important document where suggested actions are implemented in the H2020 calls, especially under SC5. Several Swedish partners have been active within the EIP on Raw Materials, in the High Level Group (previously the Swedish minister for environment and currently the Swedish minister of enterprise, the CEOs of Atlas Copco and LKAB), and many other organisations in the operational groups to define the SIP.
- The ERA-NET called ERA-MIN⁸ was a joint action between 19 European research agencies from 15 countries (Vinnova and the Geological Survey of Sweden were the Swedish partners) for joint calls along the value chain of raw materials including primary resources, recycling, substitution, education, legal framework and international collaboration. ERA-MIN was operational between 2012 and 2015. Swedish partners were well represented in the network-funded projects (see ERA-MIN project catalogue⁹). Currently an ERA-NET cofund is evaluated by the commission.
- SPIRE is a consortium¹⁰ where the European process industry, including for example mining, minerals and steel, joins forces to increase energy and resource

⁸ <http://www.era-min-eu.org>

⁹ <http://www.era-min-eu.org/news/130-era-min-project-catalogue>

¹⁰ See <http://www.spire2030.eu>

efficiency. The expectation is that SPIRE will be a Private Public Partnership in the order of €2–3 billion.

- In December 2014, a Knowledge Innovation Community (KIC) on raw materials under the auspices of the European Institute of Technology (EIT) was established after an intense work with a proposal by a pan-European consortium where Swedish partners played a central role. The KIC EIT Raw Materials consists of more than 120 partners from 22 European countries¹¹ and is organised with six co-location centres in Europe, one of which is based in Luleå, Sweden (Northern CLC). The headquarter is based in Berlin. The EIT Raw Materials will probably have a large influence on raw materials action in Europe for the coming 5+7 years of its operational life and also beyond.

It is the ambition to make sure that any national Swedish initiative will be in harmony with the European initiatives in order to maximise the leverage of both national and EU actions within research and innovation.

2.2 CURRENT STATUS

In a global comparison, the Swedish mining companies are mid-sized to small. However, as a result of forward-looking research and development they are competitive and, in many cases, at the forefront of global technology and environmental issues. In a European perspective, the Swedish mining companies account for a large part of the EU27 production of metals and are, for many of them, market leaders (Fig. 2-4). With research and development in well-selected areas, competitiveness will be strengthened and at the same time the ability to work in harmony with society and the environment will be fostered.

There are, at present (2015), fifteen metal mines in operation in Sweden, producing around 80.8 million tonnes of ores¹². In 2010, the Swedish mining and mineral industry employed 8,400 people. Export volumes in the sector increase steadily, and amounted in 2011 to 12% of all goods export, i.e. SEK 145 billion. The share of the Gross National Product (GDP) in 2010 was 0.85%. During 2011, the sector made investments of approximately SEK 9.3 billion. With the expected growth, the mining industry would by 2025 account for 3–5% of GDP and more than 20% of industrial investment in Sweden.

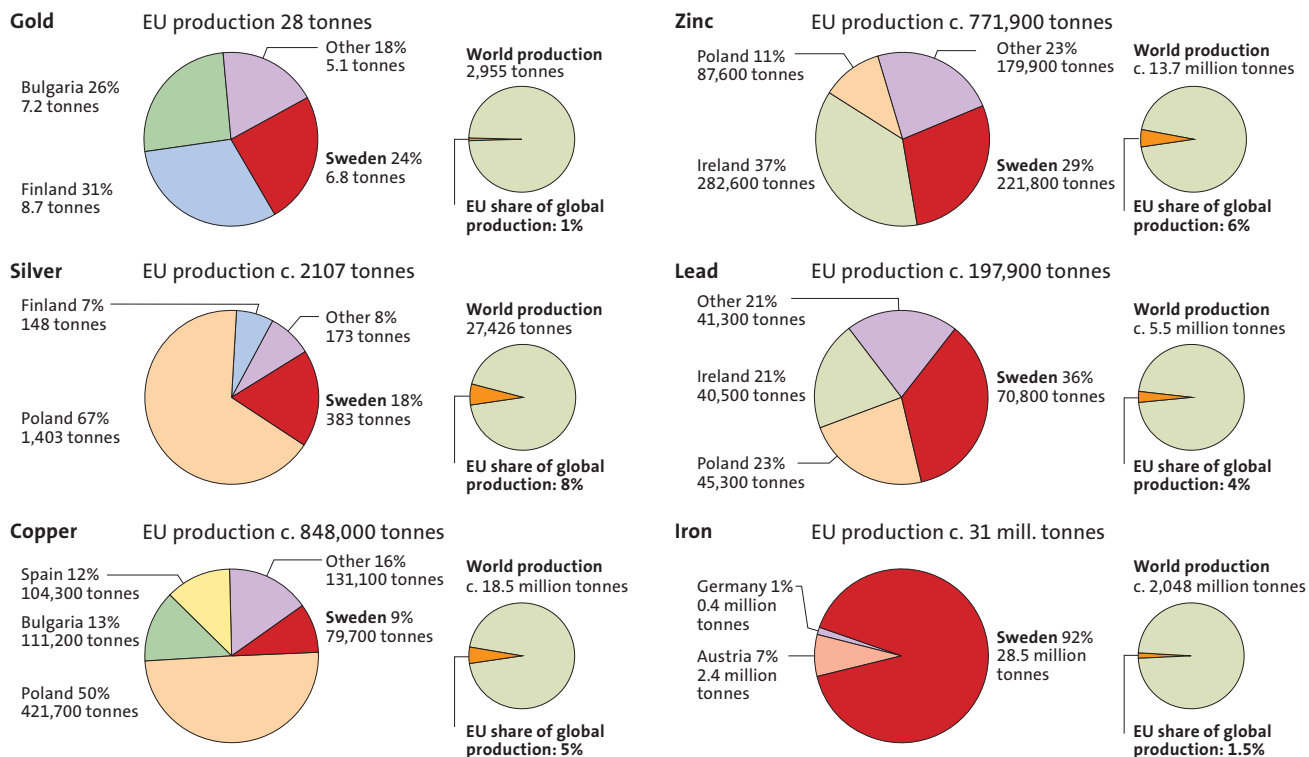
In addition, there is a strong cluster of Swedish technology providers. The global market share for underground mining equipment is around 50–70%¹³. The Swedish service and technology providers Atlas Copco and Sandvik in 2012 had a turnover of SEK 91 and 98 billion, respectively. They employed around 88,000 people of which almost 16,000 were employed in Sweden. In 2012, they invested

¹¹ <http://eitrawmaterials.eu>

¹² Statistics of the Swedish Mining Industry 2014. SGU Periodic Publication 2015:1.

¹³ 2012: The mining sector – an engine for growth in Sweden (in Swedish). SveMin, Stockholm. Download from www.sveemin.se.

Sweden's mine production for 2014 in relation to EU27 and the world



more than SEK 5 billion in research and development which amounts to around 3% of the turnover.

It must be remembered, however, that success in the past is no guarantee for a long-term success in the future. International competition is fierce, not only in terms of products but also with respect to competence. As an example, the OECD reports¹⁴ that Australian companies provide more than 60% of all software used in mining globally. Exports from the mining technology and services sector are in excess of USD 3 billion. In 2001, before the commodity boom, the industry was made up of more than 500 companies with sales of over USD 2 billion and double-digit growth rates, employing more than 17,000 people, most of them highly specialised. In Canada, more than 3,100 companies provided mining services in 2009, of which 238 companies provided consulting services on environmental issues, 152 on finance and management issues, and 140 on exploration.

With respect to research infrastructure, the northern part of Sweden has a strong steel and metal cluster. LKAB owns and operates the only experimental blast furnace in the world with operations focused on developing the performance in steel making. Swerea MEFOS and LTU (in addition to the well established

Figure 2-4. Sweden's share of EU27 mine production of selected metals (Source: SGU Periodiska Publikationer 2015:1).

¹⁴ 2013: Mineral resources trade in Chile: contribution to development policy implications. OECD TAD/TC/ WP(2012)16/FINAL.

strong research environment regarding Mining) are renowned for their research in recycling and steel. On top of this, there are excellent operators of blast furnaces (SSAB), and smelters for primary resources and e-scrap recycling (Boliden).

The Geological Survey of Sweden and the Mining Inspectorate of Sweden are competent authorities that are instrumental in providing services and expertise to the sector in the form of geological maps and reports, and the efficient handling of permits for exploration and extraction.

2.2.1 A Swedish mineral strategy

A Swedish mineral strategy was published in February 2013. The mining industry, LTU and other stakeholders were invited to contribute. Some of the key issues identified in the suggestions from industry and academia were:

- The mineral strategy should highlight Sweden's role as a leading mining nation in Europe. This role means that Sweden should take greater political responsibility with regard to mineral policy issues not only nationally, but also within the EU. In this way, the mining industry, which accounts for 40% of the Swedish net export value, could take better advantage of the political momentum that now exists in the EU.
- A Swedish mineral strategy should include long-term financing of the national mining and minerals research. As the leading mining nation with top mining companies and suppliers, it is important not to transfer knowledge from Sweden.
- The mineral strategy should define how the government intends to support long-term research, education and innovation in the field.
- A national mineral strategy should show how the government strategically helps to strengthen Swedish research in Europe. Here we proposed that Sweden should work for a European research institute located in Sweden, and closely related to the research environment in Luleå (LTU, LKAB, Swerea MEFOS, SSAB, Emea, Bergsstaten etc.). The institute should work with research and innovation in the context of what is defined in the three pillars of the RMI.
- A Swedish mineral strategy should contain concrete proposals on how closer Nordic cooperation can be financed within the mining and minerals sector with a focus on research, education and innovation. Here, special consideration should be given to how the EU focus in the area can be utilised as an important part of the domestic mineral supply.
- A Swedish mineral strategy should give careful consideration to the question of skills and education. It was recommended that the mineral strategy should suggest how nationally unique educational programmes that meet the needs of industry, although with relatively few students, can be conducted in economic balance.
- A Swedish mineral strategy should also describe how Sweden should implement geoscience education in primary and secondary education. This is the single

most important issue for ensuring recruitment to universities and colleges in the longer term for the mining area.

Below a summary is given of what we believe are the key findings, actions and initiatives with relevance for the Strategic Research and Innovation Agenda for the Swedish Mining and Metal Producing Industry, STRIM (the translation from Swedish into English has been done by the authors).

The organisations behind this STRIM Agenda support the vision of the Swedish mineral strategy: *“Through a sustainable utilisation of the national mineral resources in harmony with the environment and natural and culture values, growth is created throughout the entire country. The position of Sweden as Europe’s leading mining and mineral country is thereby strengthened.”* This vision can be reached with the following strategies:

- A mining and minerals sector in harmony with the environment, culture and other business sectors.
- Dialogue and cooperation encourage innovation and growth.
- Framework conditions and infrastructure for competitiveness and growth.
- An innovative mining and minerals sector with an excellent knowledge base.
- An internationally well-known, active and attractive mining and minerals sector.

The STRIM partnership will especially contribute under the action: *Research and innovation that develops growth and competitiveness* in which the aim is defined as: “Swedish research within mining and minerals related areas should be world leading and should be characterised by well-developed cooperation between industry and academia. The research results should be implemented by industry and should strengthen the competitiveness of the mining and minerals industry.”

We also welcome the actions defined under *Capacity building to meet the needs of the industry and regions*. Here the aim is expressed as: *“The work of the industry and the region on attracting skilled labour should be made secure by closer collaboration between the industry and organisations on a local, regional and national level.”* This Strategic Research and Innovation Agenda for the Mining and Metal Producing Industry is authored in close collaboration between the industry and academia, and we anticipate close collaboration with organisations on a local, regional and national level to put the Agenda into action.

Many of the actions defined in the current mineral strategy have been reported. More information on individual actions can be found at the website of the Geological Survey of Sweden (SGU)¹⁵. Here the actions 1) Development of methods for regional plans for raw material supply and 2) Increased knowledge regarding the importance of geology for society planning and growth are reported.

¹⁵ <http://www.sgu.se/om-sgu/verksamhet/regeringsuppdrag/regeringsuppdrag-inom-sveriges-mineral-strategi/>

A regional mineral strategy for the counties of Norrbotten and Västerbotten was also published in 2014.¹⁶

2.2.2 A Swedish innovation strategy

The Swedish government published the Swedish innovation strategy¹⁷ in 2012. As with the Europe 2020 strategy,¹⁸ the national strategy specifies the visions with the horizon 2020. The purpose of the national strategy is *“to contribute to a climate with the best possible conditions for innovation in Sweden with the year 2020 in focus. People and organisations in industry, the public sector and society will be able to develop and more effectively contribute to new or improved solutions meeting needs and demand. Societal challenges faced by Sweden, together with the rest of the world, are both extensive and complex in nature. Therefore, no single player or area of society has sufficient knowledge or resources to meet these challenges on their own. It is important to further develop coordination between different players in order to create the best conditions possible for innovation. The development of this innovation strategy has taken place in broad consultation with stakeholders in different parts of society. The work has been conducted with a high degree of involvement from all ministries within the Government Offices. This strategy constitutes a basis for a long-term approach in order to enhance the Swedish innovation climate and innovation capacity.”* The Swedish innovation strategy is based on three main principles:

The best possible conditions for innovation:

- Innovative people.
- High quality research and higher education for innovation.
- Framework conditions and infrastructures for innovation.

People, businesses and organisations that work systematically with innovation:

- Innovative businesses and organisations.
- Innovation in the public sector.
- Innovative regions and environments. Implementation of the strategy based on a holistic view:
 - In developed coordination between policy areas and policy levels.
 - In dialogue with players in industry, the public sector and society.
 - In a process of continuous learning.

Based on these principles and sub-targets, Figure 2-5 illustrates how the Swedish mining and metal producing industry contributes to the overall aims of the na-

¹⁶ <http://www.lansstyrelsen.se/norrboten/Sv/naringsliv-och-foreningar/naringslivsutveckling/program-och-strategier/Pages/regional-m.aspx>

¹⁷ Publication N2012.33.

¹⁸ COM(2011) 808 final.

How we contribute to world-class mining and metallurgy innovation climate in 2020

Figure 2-5. How the Swedish mining and metal producing industry contributes to the overall aims of the national innovation strategy.

INNOVATIVE PEOPLE	RESEARCH AND HIGHER EDUCATION FOR INNOVATION	FRAMEWORK CONDITIONS AND INFRASTRUCTURE FOR INNOVATION
<p>Goal: Capacity building is a key action area of the STRIM and is implemented for 2013–2016 in Strategic Innovation Programme (SIP) STRIM.</p> <p>Subtarget: People have the knowledge, skills and expertise to contribute to innovation.</p> <p>Subtarget: People have the courage and willingness to contribute to innovation as an entrepreneur, manager, and employee.</p> <p>Subtarget: Swedish metal extractive and producing industry is attractive on an international level and welcomes diversity and mobility.</p>	<p>Goal: Research and higher education in mining and metallurgy is of a high quality by international standards and contributes to innovation in many ways.</p> <p>Subtarget: Education and research in mining and metallurgy at universities with world-class quality and relevance contribute to innovation.</p> <p>Subtarget: World-class research institutes in mining and metallurgy established in Luleå meet knowledge and development needs in businesses and society.</p> <p>Subtarget: Strong Swedish research nodes in mining and metallurgy have strong positions in global knowledge networks such as EIT KIC RM.</p>	<p>Goal: The mineral strategy provides framework conditions and infrastructure that lays the foundation for a strong innovation climate in the metal extractive and producing sector.</p> <p>Subtarget: Regulations, market conditions and norms that promote innovation within exploration, mining, processing and recycling.</p> <p>Subtarget: Functioning access to capital that invests in the mining sectors capacity for innovation and growth.</p> <p>Subtarget: Sustainable and predictable legislation for the metal extractive and producing industry.</p>
INNOVATIVE BUSINESSES AND ORGANISATIONS	INNOVATIVE PUBLIC SERVICES	INNOVATIVE REGIONS AND ENVIRONMENTS
<p>Goal: Metal extractive and producing businesses and organisations in Sweden have world-class innovation capacity.</p> <p>Subtarget: Businesses in Sweden grow by offering innovative solutions on global markets.</p> <p>Subtarget: Mining and metallurgical sector in Sweden grow by offering innovative solutions on global markets.</p> <p>Subtarget: Using the potential in social innovation and social entrepreneurship to contribute to attractive workplace and mining regions.</p>	<p>Goal: Innovative and collaborative geological survey organisation that has a high degree of quality, service and availability.</p> <p>Subtarget: Environmental protection agency and the Geological Survey of Sweden contribute in developing innovative ways of meeting societal challenges.</p> <p>Subtarget: Regional authorities works systematically with innovation in order to create growth in the mining sector.</p> <p>Subtarget: Efficient public sector support for innovation with a focus on SMEs in the metal extractive and producing sector.</p>	<p>Goal: Luleå's regional innovation environments in the mining and metallurgical sector have international appeal.</p> <p>Subtarget: Mining regions are increasing their innovation capacity based on their unique conditions.</p> <p>Subtarget: Regional mineral strategies for innovation are grounded in combined regional leadership.</p>

Five initiatives enables the growth vision for the Swedish mining industry

Competence A common action plan for regions, industries and universities with national and regional initiatives in order to make the industry and key regions, including residences and infrastructure more attractive and increase the supply of competence.	Transport A national plan of the rail-road infrastructure which supports the mining industry's need for good transportation.	Permit Handling A common action plan with concerned authorities for increased discipline and higher pace of handling of permits within the boarders of current environmental legislation.	Research and Development A program to maintain Sweden's strong position in R&D and industry know-how along the value chain, in order to ensure efficient resource use and sustainable development in Sweden and globally.	Energy Continuous collaboration across industries to ensure supply of competitive electricity and other forms of energy, e.g. by enabling for supply of natural gas in Sweden.
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Fig 2-6. The five areas where actions are needed for growth in the Swedish mining industry as defined in the vision for growth for the mining industry (SveMin, Stockholm 2012: The mining sector – an engine for growth in Sweden, in Swedish).

tional innovation strategy. The goals and sub-targets set by the mining and metal producing industry should also be related to the vision for 2030 and are further subdivided into research needs in the short-, medium- and long-terms in Chapter 4. The research needs that are proposed to be transformed into actions within the short- and medium-terms (Chapter 7) are also measures of how the sector contributes to the sub-targets shown in Figure 2-5.

2.2.3 A vision of growth for the Swedish mining industry

The Swedish Association of Mines, Mineral and Metal Producers (SveMin) recently released a vision for the mining sectors growth¹⁹ and this is shown in Figure 2-6. The vision comprises an increase in production by a factor of three and the creation of an additional 50,000 new jobs by 2025. One of the conditions for this growth is a research and innovation programme to maintain Sweden's leadership in research, education, innovation and business development throughout the entire value chain. Sweden is not only a strong player in primary extraction, but also in secondary extraction. Boliden, for example, is a leading European company in e-scrap recycling.

The global technology providers with a strong home base in the Nordic countries would, as in the past, continue to develop the technology of the future in close co-operation with the Swedish mining industry. Sweden has much competitive strength in a global comparison, not least in underground mining, the processing of low-grade complex sulphide ores, and delivering performance in iron-making by customised iron ore pellets.

With respect to the value chain, particular focus is on the mining part and the advance of underground mining from a current state of complete mechanisation to a full potential for remote-controlled operation. Projections from the Swedish Employment Service indicate that mining companies alone may need to recruit about 5,000 people in the coming years. The vision forecasts that the mining industry may have to recruit 10,000 to 15,000 people before 2025 in order to cope

¹⁹ 2012: The mining sector – an engine for growth in Sweden (in Swedish). SveMin, Stockholm. Download from www.svemin.se.

with the expansion. The need for academically-trained labour, such as geologists and engineers with expertise in rock and process engineering, is most urgent. The need for miners and process-operators is also considerable. A survey conducted by SveMin of education at colleges and universities shows that the number of educational places is relatively good. The shortage of people with the right skills will instead come from a low interest in education within the mining sector.

Efforts should therefore be made primarily by the industry to present the mining sector as being an attractive industry with interesting and stimulating work. An investment in gender equality in the industry is a key issue for increasing both the recruitment to and the attraction of the industry.

2.2.4 Resource and energy efficiency

The Swedish Mineral Strategy²⁰ underlines the societal relevance of research and innovation in raw materials. Regional support is also essential, especially with respect to innovation. The importance of the mineral sectors is strongly endorsed by the counties of Norrbotten and Västerbotten as expressed in their regional mineral strategy²¹. An expansion of the mining industry will offer more jobs in regions that for many years have suffered from stagnation and unemployment. An ongoing dialogue between the mining industry and local players aims at creating attractive, socially sustainable mining communities for both women and men, preventing fly-in-fly-out societies and supporting entrepreneurial cultures that will contribute to sustainable economic growth in rural regions of Sweden.

Of particular importance for the prosperity of the future society is improved resource efficiency. *“Resource efficiency of raw materials involves the optimal use of resources across the product lifecycle and value chain, from raw material extraction and conversion, product design and manufacture, transportation, consumption and re-use, to recovery, disposal or recycling.”*²²

Metals may, in theory, be recycled countless times, with significant savings in energy and reduction of waste compared to primary processing. In addition, recycling contributes to the saving of scarce resources²³. Although high recycling rates are achieved already today for many metals, there is a loss of metals in the collection and processing chain. There is thus a potential to improve recycling rates and strive towards 100% recycling.

Introduction of new process steps in the upgrading and pretreatment of ores has also a considerable potential to decrease both energy consumption and the loss of metals to waste. As examples the introduction of heap leaching of ores and crude concentrates can be mentioned. Furthermore, a systematic analysis of

20 Sweden's mineral strategy for sustainable use of Sweden's mineral resources for growth in the whole nation. (In Swedish). Regeringskansliet.

21 Regional mineral strategies for Norrbotten and Västerbotten (In Swedish).

22 2013. Raw Materials in the Industrial Value Chain. An Overview. European Round Table. Download from www.ert.eu.

23 M.A. Reuter et.al. The metrics of material and metal ecology. ISBN 0-444-51137-7.

the whole process chain from upgrading to metal extraction through hydro- or pyrometallurgical methods have the potential to significantly increase resource and energy efficiency.

Green technology would not be possible without access to metals and minerals. The recent publication of the European Round Table shows the importance of “technology metals” in order, for example, to develop energy-efficient smartphones, LED lighting, electric cars and wind turbines. The future challenges of raw materials supply can only be met by enhanced resource productivity²⁴. To meet the need for increased resource and energy efficiency, the following challenges will be addressed:

- Maximising recovery of the value-bearing minerals through innovations in mining and mineral and refining processing technology. New technology would enable the viable primary extraction of complex low-grade mineralisations.
- Innovations in recycling technology to maximise the recovery of value-bearing minerals.
- Methods to increase energy efficiency. Of special importance are new or radically improved methods for minimising the energy needed for grinding.

Measures taken in connection with energy efficiency should be strongly coupled with efforts to reduce greenhouse emissions. The mining sector is a huge energy consumer. It has been estimated that comminution processes worldwide use about 3% of all electricity generated. The consumption of grinding media and wear-resistant liners consumes about the same order of energy in terms of greenhouse gas production, which means that the total energy equivalent for these processes is more like 6%. This can be exemplified by the company LKAB, which currently uses 4 TWh of energy annually. 50% of this energy is supplied by electricity and the remaining part by fossil fuels²⁵. The growth of the company would require the consumption of 7 TWh of energy in the year 2020, unless measures are taken to make the processes more energy efficient. Of special importance for improved energy efficiency for the Swedish mining companies are actions in connection with underground ventilation and grinding. The mining companies Boliden and LKAB have participated in the successful *Programme for Energy Efficiency* under the auspices of the Swedish Energy Agency. Unfortunately, the programme will have to be discontinued due to non-compliance with the EU State Aid Rules.

The STRIM Agenda emphasises energy efficiency as an overarching goal. Key performance indicators are presented in Chapter 4 for Agenda actions related to energy efficiency.

²⁴ McKinsey Global Institute 2011: Resource revolution. Meeting the world’s need of energy, material food and water needs.

²⁵ 2012: LKAB Energy and Climate Strategy 2012–2030. LKAB.

2.3 RELATIONSHIP TO OTHER RESEARCH AND INNOVATION AGENDAS

There are a number of existing initiatives, programmes and agendas where we see a potential for future collaboration:

The Strategic Innovation Agenda and Programme Process Industrial IT and Automation (PiiA)

(Strategiska innovationsprogrammet och agenda för processindustriell IT och automation)

The Process Industrial IT and Automation Programme and Agenda deals with research and innovation related to ICT in the process industry, which includes the mining industry. Process IT and automation are horizontal RDI actions in the STRIM Agenda and actions related to this area are therefore coordinated with Process-IT Innovations.

The Strategic Innovation Programme and Agenda for the Swedish steel industry (Nationell samling för metalliska material)

The Swedish steel agenda has been developed by Jernkontoret – the Swedish Steel Producers Association. The STRIM Agenda area *Recycling and Metallurgy* has been evaluated against the agenda for the Swedish steel industry (see Section 4.5).

The Strategic Innovation Programme and Agenda Internet of Things (SIP IoT) (Strategiska innovationsprogrammet och agenda för Sakernas internet)

Internet of Things (IoT) is a collective phrase for the development of sensor- and computer-based machinery, vehicles, consumer goods, household equipment, clothes and other items. Sensor- and computer-based mining equipment is a key development area for the mining and supplier industry and thus any coordinated actions within this field should be a joint effort between the STRIM Agenda and IoT.

The Strategic Innovation Programme RE:Source (Strategiska innovationsprogrammet RE:Source)

The programme RE:Source has a vision of a society where minimal amounts of waste are being generated and waste is managed in a resource-efficient and environmentally friendly way. Waste is considered as a resource which is re-used and recycled to high quality raw materials and energy products. The two programmes SIP STRIM and SIP RE:Source has potential for collaboration within the areas of re-use and recycling of metal components in WEEE (waste electric electronic equipment) and residues from waste-to-energy.

The Agenda for the Swedish minerals industry (MinBaS Innovation)

The Swedish minerals industry has developed excellence in research and innovation through their MinBaS programme. Many areas of research and innovation

are of mutual interest for the two sectors, and the STRIM organisations see the following areas as being of particular relevance for future collaboration on a project basis:

- Automation and process control (together with ProcessIT-Innovation and IoT).
- Safe and resource-efficient production.
- Efficient fragmentation: drilling and blasting.
- Energy-efficient hauling, skipping and transportation.
- Energy-efficient comminution: crushing and grinding.
- Efficient sieving and classification.
- Attractive workplaces – safety and health issues.
- Environment-friendly technology.

The Agenda for gender and diversity aspects in the mining industry (Bryta malm och könsmönster)

The agenda is based on a gender perspective in the male-dominated mining sector to meet future challenges of talent recruitment, productivity and innovation for a competitive and socially sustainable mining industry. The agenda suggests a direction towards a gender-equal mining sector and identifies needs, challenges and opportunities based on gender and organisational research as a field of excellence in the Swedish mining sector. The gender agenda is integrated into the STRIM agenda (see section 4.8)



Gold casting at Harjavalta.
Photo: Boliden AB.



Bildtext behövs och tillstånd och ny
fil helst.
Photo: ABB.

3 Vision

The 2030 vision for the Swedish mining industry is developed under each research area in Chapter 4. This Strategic Research and Innovation Agenda for the Mining and Metal Producing Industry (STRIM) contributes to the overarching Vision in the following ways:

- Strengthening the international competitiveness of the Swedish mining and metal producing sector, including mining and recycling companies, academia and technology providers.
- Fostering leading centres and clusters for research, innovation and education that become European centres of excellence and where domestic and international participants are developing sustainable solutions for the future.

To achieve our vision and meet the research needs for the short, medium and long terms, the sector decided to adopt the following general strategies:

- World-leading and efficient research, development and education.
- A sustainable and secure supply of primary raw materials with due consideration to Sweden's geological potential, and of secondary raw materials with due consideration to the anthropogenic stocks in Sweden.
- A well-developed ability to act on the international market in profitable niches with high added value products.
- Promote a legal and regulatory framework that is compatible with a growing industry and that should entail no disadvantages in international competition.
- More efficient use of energy and resources including the recovery of materials and energy. Promote actions to ensure low prices for energy.
- Strengthening of the Swedish mining regions to make them an innovative and attractive environment for investments and living.

- Improve the image of the mining sector by taking social and environmental responsibility and offering attractive workplaces and sustainable production processes.

While the Swedish mining and metal producing cluster will only survive if globally competitive, research and innovation are at the very heart of the companies' business strategies. Our tactics for methods of fostering world-leading and efficient research, development and education are manifold:

- Strengthening the excellence of the Swedish mining cluster by fostering strong cross-sector knowledge, technologies, expertise and services.
- Active participation for instance in the industry-led European Technology Platform for Sustainable Mineral Resources (www.etpsmr.org) and also active participation in the European Innovation Partnership on Raw Materials for a Modern Society, created and managed by the European Commission.
- Continue to develop Luleå University of Technology and associated partners, e.g. Swedish research institutes, into an excellent European Centre for Minerals and Metal Extraction. The recent establishment of a Co-location Centre within the Knowledge and Innovation Community on Raw Materials in Sweden (Luleå), where several Swedish partners are involved as core and associated partners, is an important milestone along this path.
- The Bergforsk foundation remains as the think-tank for the mining sector in discussing, prioritising and actively supporting the common efforts made in research, development and innovation for the mining sector and in co-ordination and co-operation with the public sector.
- The Bergforsk subsidiary Nordic Rock Tech Centre AB (RTC www.rocktech-centre.se) will continue to be a link between research and implementation with the ambition to “move theory into practice” within the mining sector.

“By launching energy-efficient solutions, we enable our customers to raise their productivity, lessen their environmental impact and improve the health and safety of their employees.”

BJÖRN ROSENGREN, CEO SANDVIK,
ANNUAL REPORT 2015

“The fact that our operations are highly competitive is largely due to the fact that we have managed to attract and retain employees with different skillsets and different backgrounds.”

LENNART EVRELL, CEO BOLIDEN,
ANNUAL REPORT 2015



Aitik open pit.
Photo: Boliden AB.

4 Agenda

The Strategic Research and Innovation Agenda for the Swedish Mining and Metal Producing Industry (STRIM) is subdivided into nine main research and innovation areas:

- Exploration
- Resource Characterisation
- Mining
- Mineral Processing
- Recycling and Metallurgy
- Reclamation and Environmental Performance
- Attractive Workplaces
- Gender and Diversity in Mining
- Social License to Operate

This agenda deals with actions needed in the primary and secondary resources value chains and covers the related technological areas complemented by relevant non-technological areas. In Figure 4-1, the different raw material value chains are expressed as routes for primary, secondary and tertiary resources. It should be stressed that these research and innovation areas which can be subdivided into technological and non-technological areas are both vertical (disciplinary-defined) and horizontal (multidisciplinary).

The STRIM 2017 Agenda is based on the STRIM 2013 Agenda and the content has been revised and complemented with a research and innovation area on Resource Characterisation (which was included in the area Mining in the STRIM 2013 Agenda), and a research and innovation area focusing on Social License to Operate.

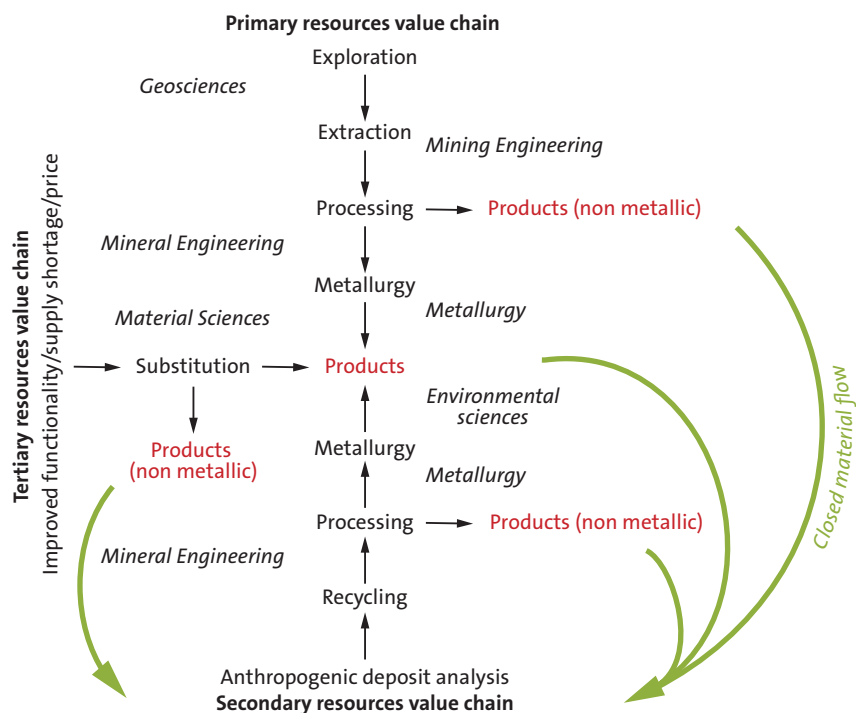


Figure 4-1. Raw materials value chain. This agenda addresses the primary and secondary value chains. The secondary value chain also includes mine waste and tailings from processing. All value chains lead to products (red) utilising research and innovation within the different steps defined (black). The research subject areas involved are expressed in black italic and the green arrows explain the closed loop approach.

4.1 EXPLORATION

A proposal is made for an *Exploration* agenda owing to the need to improve the supply of metals and minerals from domestic resources.

4.1.1 Vision

Deep exploration calls for improved drilling technology, improved depth penetration of geophysical techniques and improved targeting based on a three-dimensional knowledge base and a genetic concept of ore forming processes. The vision for these areas is expressed below as established targets and Key Performance Indicators (KPIs) for 2030 and beyond 2030 (Fig. 4-2).

4.1.2 State of the art

European resource demands rest strongly on the import of many minerals and metals. While Europe contributes to more than 20% of the global consumption of metals and minerals, we only produce around 3%. It is generally considered that this relationship between consumption and production to a large extent is due to the lack of many commodities in European crust, i.e. that the geological potential is lacking. However, this is mainly based on models that rely on the current

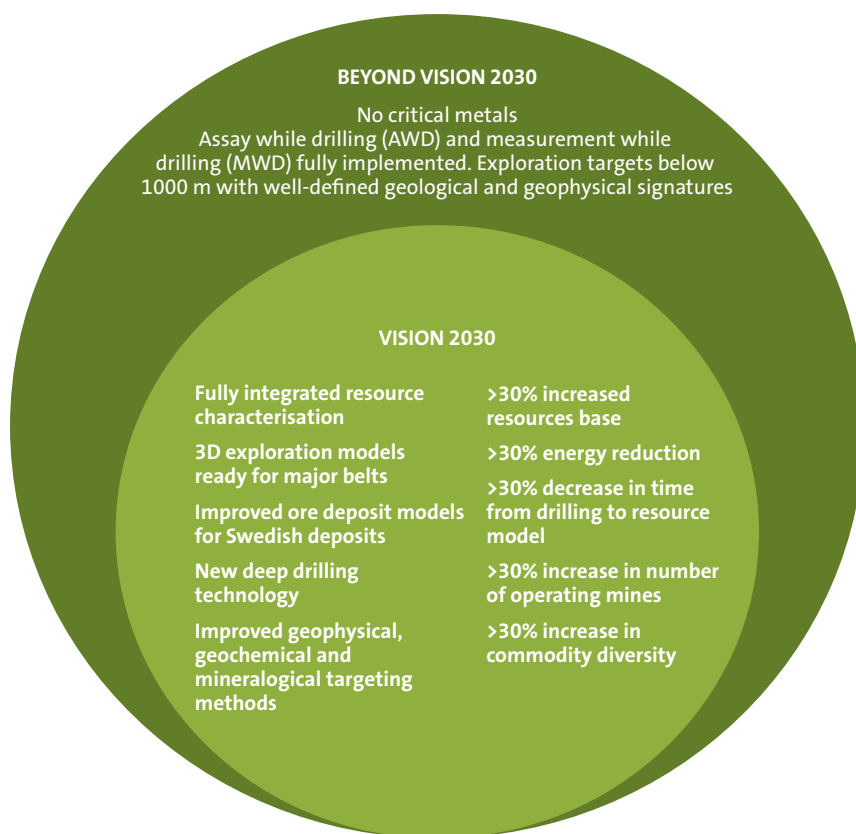


Figure 4-2. Vision 2030 and Key Performance Indicators for the agenda *Exploration*.

knowledge base of previously and currently mined commodities in Europe and not on a sound geological estimation of undiscovered resources and predictive modelling of geology in three dimensions down to mineable depth in the European continental or oceanic crust.

In any region, sustainable extraction is in the long run dependent on exploration. Since any one deposit of metals and minerals is by nature non-renewable, extraction without exploration will inevitably exhaust known mineral resources. Even if this is mitigated by increased recycling and substitution, urbanisation and population growth in the modern high-tech society will inevitably lead to the fact that if there is no exploration investment in a region, self-sufficiency will decrease instead of increase. The global expenditure on exploration for metals and minerals was approximately USD 12.8 billion in 2014 (SGU, Bergverksstatistik 2014). In Europe, the exploration expenditure was about 4% of the global expenditure. The amount of money invested in exploration per square kilometre is thus much lower in Europe compared to elsewhere in the world and this indicates that Europe's import dependence will increase. Furthermore, if the investment in exploration remains at these low figures, it is anticipated

that the import dependence will increase despite increased recycling rates and potential substitution.

Based on recent results from mining-related projects, among others the FP7 Promine project, it can be demonstrated that Europe possesses several world class mineral deposits and mineral districts. Europe has a very high potential for the extraction of critical metals, and is a leading technology provider for underground mining and drilling.

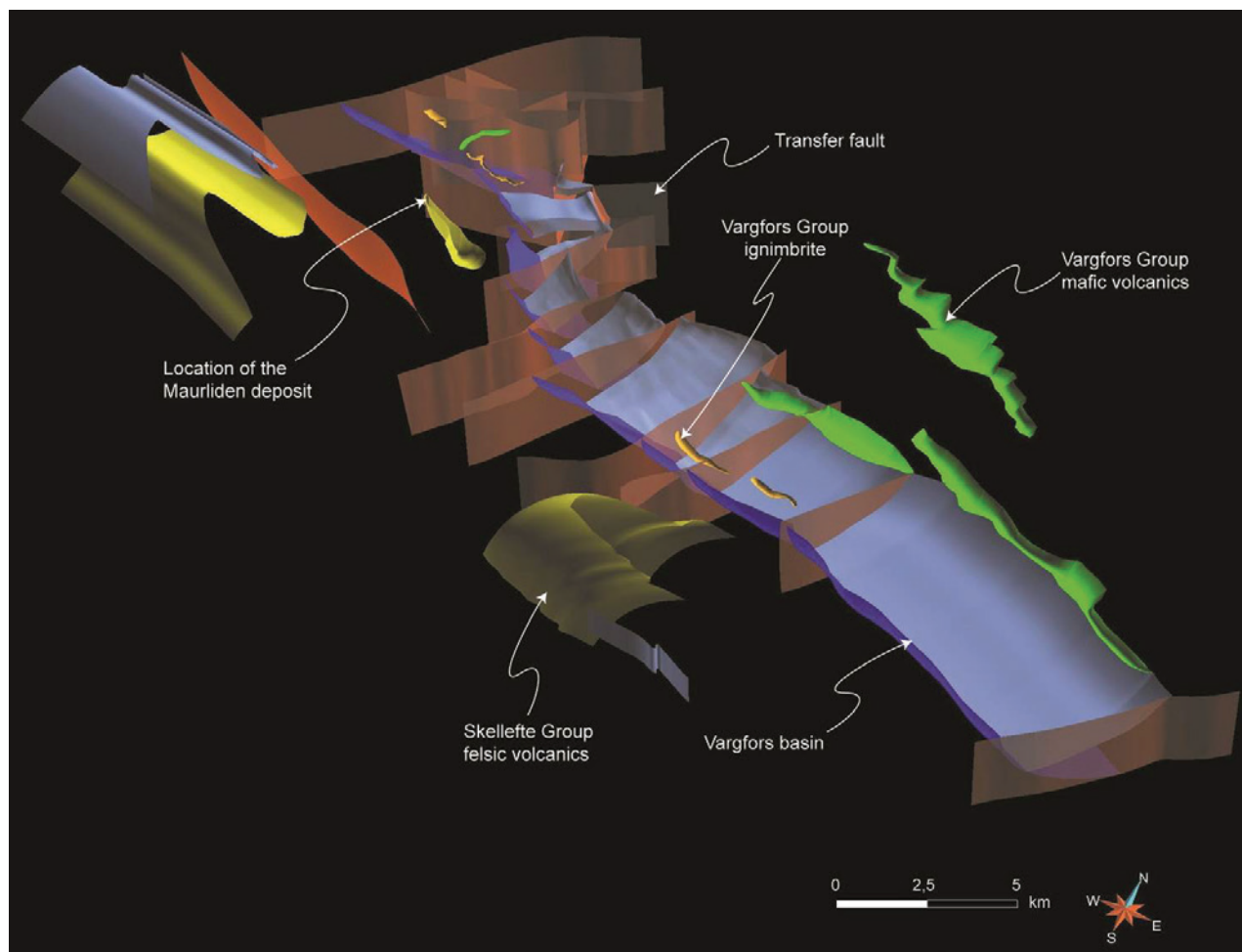
In Europe, especially in the central and southern parts, competition for land is a major concern for the extractive industry. At the same time, fewer and fewer new “world class” discoveries are made on the surface, and exploration will in the future be focused to a larger extent on deep, hidden resources. This is now a global trend, and since the potential for finding new economic metal and mineral deposits is very high in Europe, the fact that most of these will be mined in underground mines will also decrease the burden for land utilisation by extractive industry. The deepest mine in the world is now 4,000 m, and the deepest mine in Europe is 1,500 m below the surface.

In the Promine project, pilot actions have been taken for the first robust three-dimensional models (Fig. 4-3) of the continental crust down to mineable depth in some of Europe’s major mineral belts, in Sweden focusing on the Skellefte district. The results are proof of concept and now call for a coordinated action to put Sweden in the forefront of deep exploration. By building on the concept defined in Promine it is time to add full-scale development of new deep penetrating geophysical technologies and new geochemical and mineralogical analysis and interpretation techniques in order to implement a better understanding for where the mineral deposits have been formed in Sweden. A goal is also to build knowledge and develop skills in Swedish industry, geological survey bodies and academia to foster an environment which will attract exploration investment based on a sound knowledge of Swedish mineral resources down to mineable depth.

4.1.2.1 Content

Deep exploration should target commodities that in general are known to exist in Sweden. Specific focus should be on ferrous, base, precious and critical commodities, bearing in mind that within the time frame of the project the criticality aspect for some currently critical materials may change. The *Exploration* agenda encompasses six main areas:

- “*Technology*”. Development of new drilling technology for deep (>1,000 m) drill holes.
 - Deep, >1,000 m diamond and percussion drill holes with master and daughter drill holes.
 - Fan or cone type drilling patterns at depth, developed MWD.



- “*Location*”. Development of 4D modelling of resources.
 - Three-dimensional models of the Swedish crust in all areas of high potential for deep mineralisation with a target depth of 1–5 km.
 - Models of the evolution and formation of geology and mineralisation over time: Four-dimensional modelling.
- “*Penetration*”. Development of new, deep penetrating geophysical techniques.
 - Develop new seismic techniques with data acquisition in 3D utilising three-dimensional infrastructure such as mines and drill holes. Target: good resolution in xyz in the top 5 km.
 - Develop new electromagnetic and other geophysical methods with improved resolution at a range of depths, from shallow to below 1,000 m.
 - Development of improved 3D inversion techniques for magnetic, electric and gravimetric geophysical data.

Figure 4-3. Geological 3D-model of the Vargfors basin, Skellefte district. From Bauer et al., 2009: 3-D modelling of the Central Skellefte District, Sweden. Smart science for exploration and mining: Proceedings of the 10th biennial SGA meeting, Townsville, Australia, 394–396.

- “*Formation*”. Conceptual modelling of deposit types.
 - Establish genetic and exploration models for major ore types in Sweden, including models for deposits containing critical raw materials with economic potential.
 - Define exploration targets and the geological, geochemical and geophysical vectors to ore for the most pertinent ore types in Sweden at depth. A target is increased investment in deep exploration in Sweden.
 - Compare and contrast major Swedish ore deposits and mineral belts with equivalent deposits and belts internationally in order to better define ore deposit models, ore genesis and vectors to ore.
- “*Education*”. Building knowledge and developing skills in Europe.
 - Define a knowledge base of metals and minerals in Sweden. A target is to implement the teaching of economic geology based on Swedish resources in Swedish universities.
 - Improving skills in the staffs of industry and survey organisations for future forefront predictive targeting of resources in Sweden.
- “*Integration*”. Integration of data into real-time exploration and geometallurgical tools.
 - Developing tools for data collection while drilling: 3D camera, geochemical assay while drilling (AWD), down hole geophysical measurements while drilling (GWD).
 - Integration of data sets in one software system in real time.

4.1.2.2 Innovative technologies and solutions

The indicated actions can be subdivided into technology-based and non-technology-based actions.

Technology-based actions

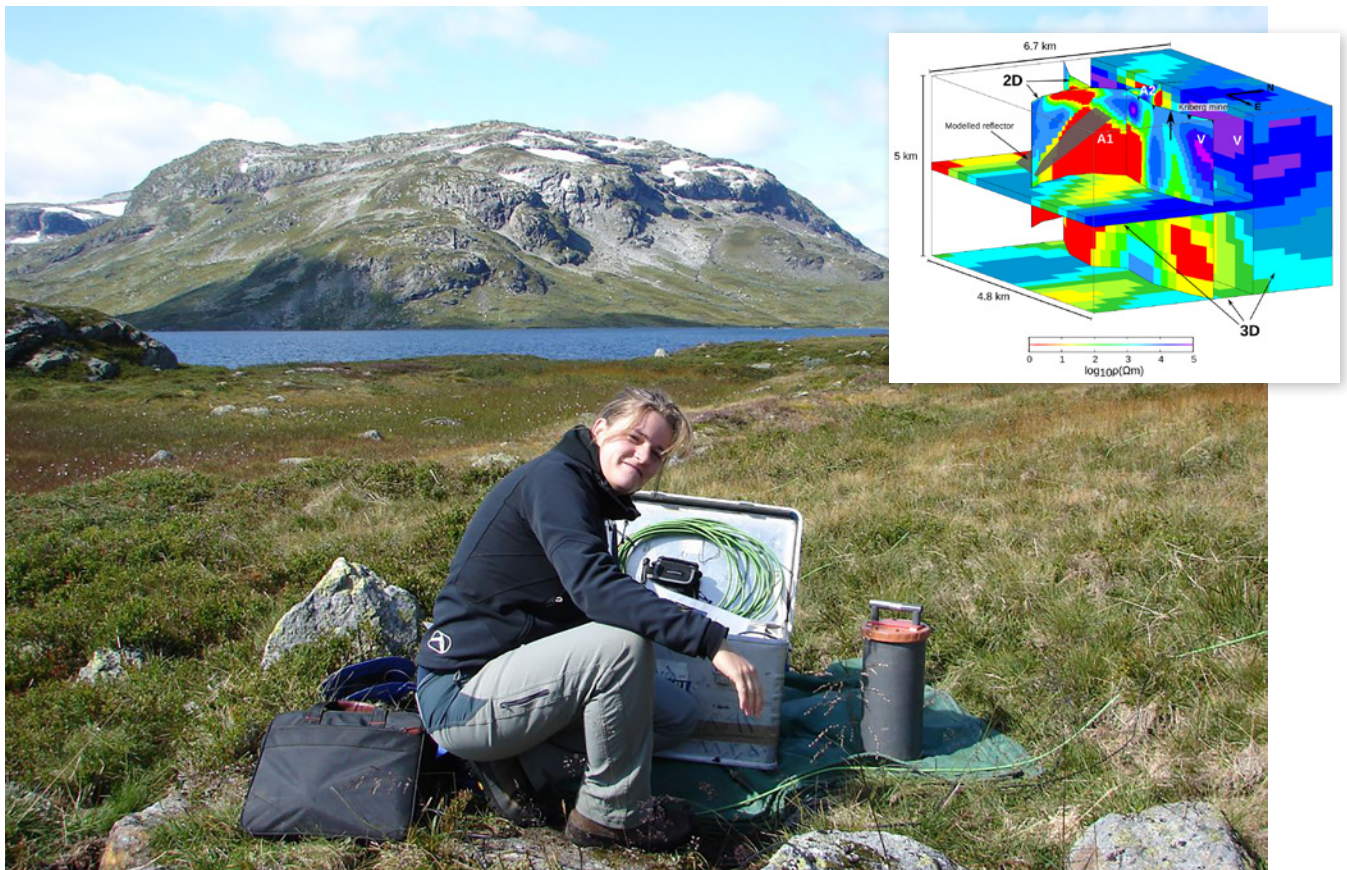
- Develop new drilling technology for cheaper and faster deep drill holes.
- Develop three-dimensional software.
- Develop three-dimensional database structure.
- New software for forward and backward modelling of geological evolution, structures etc.
- New visualisation tools of continental crust (cf. oil industry).
- New acquisition tools for seismic tomography, develop new equipment.
- Improved technology in electromagnetic surveying, develop new equipment.
- Improved analytical techniques for defining ore genetic parameters.
- New integrated software tools for real-time analysis while drilling.
- New 3D geophysical inversion modelling techniques for magnetic, electrical and gravimetric data.

Non-technology-based actions

- Redefine ore deposit genesis models.
- Access to geological information, drillhole data, old mine geological data, geophysical surveys etc.
- Access to land for further geophysical measurements for constructing 3D models.
- Improved knowledge and skills that would guarantee a leading position for Sweden in mineral deposit knowledge and exploration technology.
- Develop ore deposit exploration models including geological, geochemical and geophysical vectors to ore.

One important factor for success is access to existing information. This means that the exploration agenda needs a broad partnership with good connections to local and regional authorities as well as industry and survey organisations. Furthermore, the exploration agenda will collect new information regarding the subsurface of Sweden and the agenda must be accepted by all local and regional authorities.

Julianne Hübner from Uppsala University performing magnetotelluric measurements in the north of Sweden. By measuring natural variations in the Earth's magnetic and electric fields at different stations distributed over an area it is possible to map the large scale resistivity structure of the crust (inset). Photo: Christopher Juhlin, Uppsala University.



4.1.3 Research and innovation needs, and strategies and actions

Short-term

- Based on the results of recent projects such as Promine, define similar projects in areas of Sweden offering the greatest potential for new deep discoveries, i.e. Bergslagen, Gällivare and Kiruna. Start to develop the ore genetic models by defining ore types in these areas with a focus on both main mined commodities and critical metals. Start to develop exploration models by defining the geological, geochemical and geophysical vectors to ore at both the regional and local mine scale. Start making technical specifications for new exploration technologies. Launch a technology-based project on new drilling, and geophysical and geochemical techniques.
- Build visualisation centres and publish predictive 3D models for Sweden.

Medium-term

- Intensive field work, pilot actions on new exploration techniques, feeding 3–4D models with data and further adjustment of acquisition parameters. Continue to develop genetic ore deposit models and exploration models for Sweden's major ore deposit types. Testing of the genetic and exploration models with predictive models in test areas.
- Development of new geophysical methods for deep penetration from surface or aeromagnetic observations.
- Potential verification of 3D models and new geophysical and geochemical equipment by deep drilling in test areas. Start to utilise results in training across Europe.

Long-term

- Training of decision makers for better resource governance, and actively promoting results among exploration industry at large. Proven new deep drilling, deep geophysical techniques and “real-time” geochemical analysis.

4.1.4 Expected impact

Expected impacts are subdivided per STRIM Agenda area into technical, economic, environmental and social impacts.

Technical

- Providing Sweden with innovative, world-class technology for minerals exploration of deep ore bodies.
- Providing Sweden with a first 3D model of the crust down to several kilometres, to be used for decision making on land planning issues.

Economical

- Deeply located deposits can be defined and economically evaluated.

- Improved self-sufficiency and a stable supply of base, critical and other metals for the Swedish and European economy.
- Foster the development of Swedish-based downstream industries on domestic mineral resources.
- Create wealth in many less densely populated areas of Sweden.

Environmental

- Definition of deeply buried resources to minimise the effect of mining.
- Define where the mining potential is in Sweden for the coming century to be used as a tool for decision making on land use, protection etc.

Social

- Fewer problems with access to land in densely populated areas.
- Increased employment opportunities in less populated and rural regions of Sweden with a good potential for the extraction of metals and minerals.
- Training of decision makers on resource geography, and potential and predictive models will lead to improved governance of Swedish resources.

The defined short-, medium- and long-term needs within each STRIM area defined in Chapter 4.1 are listed in Table 4-1. The short- and medium-term actions can be implemented during the period 2013–2020 and will form the basis for any strategic implementation on a national or international level.

Table 4-1. Vision 2030 and Key Performance Indicators for *Exploration*.

Area	Action	Time frame
Modelling	Geological modelling in the most ore potential areas of Sweden for new deep discoveries, i.e. Bergslagen, Gällivare, Kiruna	Short-term
	Develop the ore genetic models by defining ore types in these areas with a focus on both main mined commodities and critical metals	Short-term
	Pilot actions on new exploration techniques, feeding 3–4D models with data and further adjustment of acquisition parameters	Medium-term
	Testing genetic models with predictive models in the test areas	Medium-term
	Verification of 3D models.	Medium-term
	Predictive 3D models for Europe	Long-term
Technology	Start technical specifications for new exploration technologies	Short-term
	Development of broadband electro-magnetic sounding instruments	Short-term
	Joint interpretation techniques for controlled source frequency domain EM, time-domain EM data and audiomagnetotellurics data	Short term
	Develop and test joint inversion strategies for multi-variable geophysical data types	Short term
	Launch a technology-based project on new drilling and geophysical techniques	Short-term
	New geophysical equipment by deep drilling in test areas.	Medium-term
	Development of new geophysical data acquisition strategies	Medium-term
	Proven new deep drilling and borehole geophysical techniques	Long-term
Infrastructure	Building visualisation centres	Short-term
	Start to utilise results in training across Europe	Medium-term

4.2 RESOURCE CHARACTERISATION

4.2.1 Vision

For the agenda area *Resource Characterisation*, the long-term vision for 2030 and beyond is to improve the competitiveness of the Swedish mining companies with high-quality knowledge of ore bodies and rock mass, high resource efficiency and reliable systems for predicting and managing production from mine to mill. This will help to reach the goals for zero accidents, no human exposure at the production face, greater energy savings, reduced CO₂ emissions and lower ore losses. The long-term vision can be achieved through the following measures:

- Resource characterisation that results in a mathematical and physical (property based) copy of the rock mass, i.e. a detailed description of all parameters (rock material, joints, faults, mineralogy, microstructure, geometallurgy etc.) of the rock mass.
- Resource characterisation that results in the detection of new value-added metals and minerals.
- Geometallurgical approach which captures variability within the ore body significant for mineral processing plants and production management.

The short-term goals (2017–2020) are to develop tools, methods and conceptual models that will facilitate the medium- and long-term objectives, which include implementation and validation.

4.2.2 State of the art

A sound knowledge of the resource serves as a basis for effective extraction and utilisation of the ore body. Besides geological knowledge of geometry and commodity grade, spatial information should be available on how the rock unit (ore type, rock mass) behaves during mining production and minerals processing. In general, four kinds of data are collected and corresponding models are established: 1) geological, 2) geophysical, 3) rock mechanical and 4) geometallurgical (Table 4-2). Novel analysis techniques exist in all these areas.

Geological methods for resource characterisation include both lithological and mineralogical analysis techniques. Lithological data can be obtained in a non-subjective way by e.g. digital photogrammetry, optical borehole imaging (OBI), drill core scanning by optical, X-ray fluorescence and hyperspectral methods, measurement while drilling (MWD) and online analysis (analysis while drilling). These techniques are currently available, but they are only at a very slow rate being adopted by the mines. Mineralogical analysis techniques focus on mineral chemistry and mineral textures. Most mining companies analyse only base and precious metals, since the content and distribution of low-grade by-products has

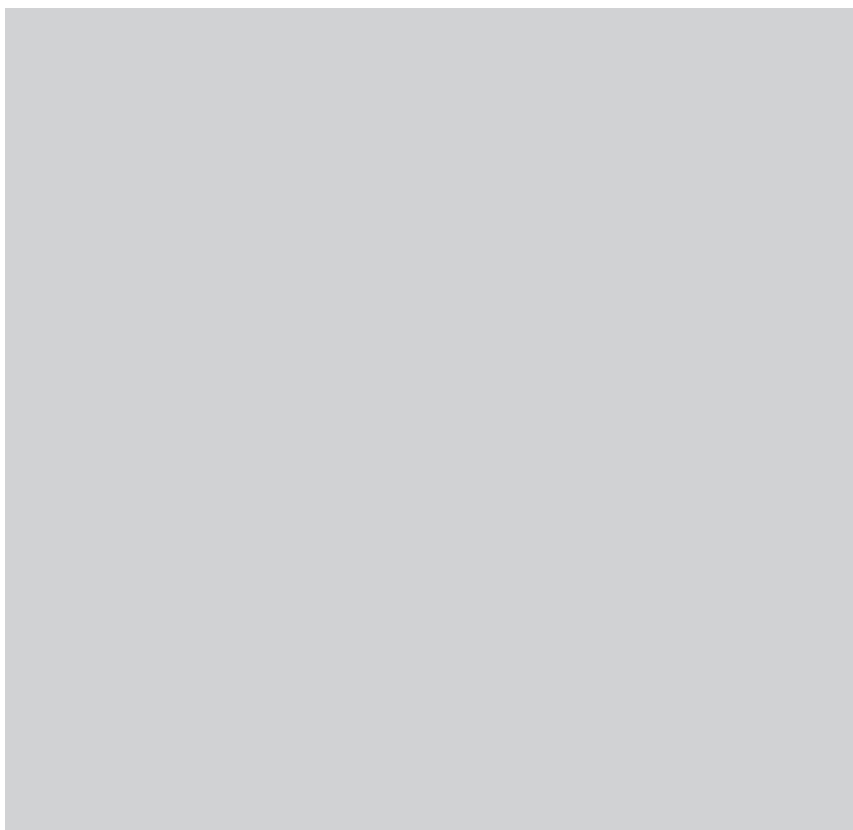


Figure 4-4. Vision 2030 and Key Performance Indicators for *Resource Characterisation*.

not been economical. Several commodities listed by EU as critical raw materials (e.g. Co, Nb, CaF_2 , PGM, Ga, In, Mg, REE, Ge, Sb and W) have a good potential for extraction in present and future Swedish mines. There is, however, a need to better establish the analytical chain of characterisation techniques needed in order to obtain this detailed information of a rock mass in the most efficient way.

The most commonly used approach includes optical microscopy and X-ray diffraction (XRD) for mineralogical characterisation, electron probe micro-analyser (EPMA) for mineral chemistry, and inductively coupled plasma mass spectrometry (ICP-MS) for accurate bulk chemical analysis, combined with scanning electron microscopy (SEM) and optical microscopy for information about microstructures and mineral textures.

Although the referred techniques are the most common ones, other choices can be selected for a more detailed characterisation of ores, waste rock and production waste material in order to clarify where in the mineral phases the valuable metals are concentrated. For the analysis of solid rock samples, instruments such as laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), high-resolution X-ray computed tomography (HRXCT) and mineral liberation

Table 4-2. Front- and end-users of different data utilised in resource characterisation.

Area	Data	Front-user	Model	End-user
Geology	Lithology Mineralogy	Geologist	Geological model	Resource engineer Geologist Mining engineer
	Geology Chemical assays	Geologist	Geological model	Production engineer
Geophysics	Discontinuities Physical properties	Geophysicist	Geophysical model	Geologist Mining engineer
Rock mechanics	Lithology Structures Rock mass behavior	Engineering geologist	Geomechanical model	Production engineer Management
Geometallurgy	Comminution properties	Geologist Geometallurgist Mineral processing engineer	Geometallurgical model	Production engineer Management Mineral processing engineer
	Concentration properties	Geologist Geometallurgist Mineral processing engineer	Geometallurgical model	Production engineer Management Mineral processing engineer
	Tailing properties	Geologist Geometallurgist Mineral processing engineer Environmental engineer	Geometallurgical model	Production engineer Management Mineral processing engineer Environmental engineer

analysis (MLA) can be applied to quantify the spatial distribution of crucial trace elements in the ore and waste material. These analytical techniques allow spatial analysis at a micro scale, i.e. the possibility to map the spatial distribution of elements at trace concentrations in the sample. The principal advantage is the high spatial resolution and consequent facility for analysing individual mineral grains, which becomes more and more important when finer grained and more complex ore bodies are mined, and the need to identify and extract raw materials present in small quantities in ore and waste products is pronounced. In calculating the reserves of ore deposits, the contents and nature of minor components in both ore and mine waste should be taken into consideration to increase mining efficiency and to utilise the ores more fully. The techniques listed above are available, but not yet fully adopted by the mining companies.

Geophysical methods are widely used in exploration but only to a limited extent in production (e.g. gamma-gamma log) even though they offer a huge potential. In rock mechanics, both geological and geophysical methods are used but the measurements of intact rock strength, fracture properties and stress state require techniques of their own. Continuous measurement techniques are available (such as CSIRO HI, doorstopper and MWD) but the mining industry is slow to adopt them.

Geometallurgical analysis techniques can be divided into two classes: 1) mineralogical methods and 2) geometallurgical tests. The purpose of using mineralogical methods is to map the mineralogical variation and interpret the metallurgical response from this data. Geometallurgical tests are small-scale laboratory tests which measure the metallurgical response directly.

In recent years there has been a strong development in utilising mineralogical information in geometallurgy also at Swedish mines. The most important parameters are modal mineralogy (i.e. mineral composition of the ore) and mineral textures. In most ore types, mineral composition can be determined relatively fast and at low cost using a combination of quantitative X-ray diffraction and element-to-mineral conversion, developed at Luleå University of Technology. In complicated cases, SEM-based automated mineralogy (e.g. QEMSCAN, MLA, IncaMineral) must be used.

The quantification of mineral textures is more challenging and this is the focus of much research around the world. Quantification can be performed using image analysis tools on different kinds of images (optical, hyperspectral, X-ray) of macroscopic (e.g. hand sample) or microscopic (e.g. thin-section or polished section) specimens. The density or frequency of microcracks can be measured using X-ray tomography or a method based on fluorescence-polarisation-microscope techniques on samples impregnated with dyed epoxy.

A big challenge in geometallurgy is how to use the deposit information to reliably forecast how the ore will behave in processing. Since geometallurgical tests are lacking in several areas (like flotation) a more promising route is to link the mineralogical information with mineral processing. This requires good quality and detailed mineralogical information on both the ore and the process streams. The latter is required in order to build a mineral processing model and the former for providing the required information for the feed stream of such a model.

Different levels of models are used, from mineral via mineral-by-particle-size to mineral-by-size-and-liberation. They all have their benefits but the mineral liberation level offers the highest flexibility and portability for the process and for the variability in the ore. The liberation level requires not only automated mineralogy to be used in the characterisation but also robust tools for mass balancing, modelling and simulation. Mass balancing and simulation tools operating on the liberation level are quite rare and still in the early stages of development. Finally, the spatial ore data with forecasted metallurgical response is integrated and used in production design, planning and management. Integrated systems for dealing with the whole geometallurgical data are virtually lacking.

Knowledge of the resources in mining operations is currently in many ways incomplete. Gaps exist in data collection, subjective characterisation and between different disciplines. Cross-disciplinary usage of data is limited. For example, geological and rock mechanical models are separate and use very little data from each other. In addition, some of the relevant data is underused or is lost during data processing.

In mining operations in general, the data collection and usage is very ineffective and subjective. It is not uncommon for drill core logging to be done twice: first for geological purposes and then for rock mechanical measurements.

In order to avoid subjective characterisation, automatic, online and less time-consuming methods are needed in tunnel mapping and for characterisation of drill cores and chips.

Data gaps exist due to the current lack of reliable online sensing techniques. One identified problem associated with the introduction of new characterisation methods, such as hyperspectral logging, is that techniques are mineral- or rock-type specific and there is no guarantee that they will work in all types of ore deposits. Moreover, they are designed for producing only one type of information.

Extending mining to deeper levels probably generates rock mass stability problems, which in turn could cause safety problems, production disturbance and damage to structures and machines. This imposes higher demands on tools which are used in collecting information of the ore and the surrounding rock mass. The Nordic countries have a strong and innovative industry related to online analysis and measurement (e.g. Vattenfall, IMA Engineering, Specim and Outotec). However, the mining industry is conservative when it comes to adopting this new technology. The lack of compiled open source test data also leads to the unnecessary duplication of work at several sites.

4.2.3 Research and innovation needs, and strategies and actions

In order to mine Swedish deposits at increasing depths as well as near the surface with good resource efficiency, minimised environmental impact and increased productivity and safety, the research should be focused on optimising the methods providing reliable data in both the design and operational stages. The research should focus on the following main areas:

Short- to medium-term

- Apply new and existing resource characterisation techniques for online and in-situ measurement of geological, mineralogical, rock mechanical and metallurgical properties.
- Facilitate the use of new monitoring methods for rock mechanics by adapting the use of existing sensor techniques.
- Develop new resource management tools which enable real-time data integration, effective data visualisation, production planning and scenario analysis.
- Develop a tool for resource efficiency assessment and sustainability evaluation of existing and planned mining operations.

Long-term

- Facilitate the use of new online analysis tools, sensing methods and management tools, all integrated in a geometallurgical model and resource management system.

- Facilitate the use of micro-analytical tools for incorporating detailed resource information in long term production planning.
- Develop interdisciplinary tools for rock mass characterisation. A common visualisation platform based on an open source Virtual Reality technique could possibly be used.
- Develop and implement novel resource characterisation techniques.
- Develop MWD and AWD (measurement while drilling and assay while drilling) technology to deliver data for online process design, optimisation, prediction and planning for ore delineation, rock mechanics, drilling, continuous mechanical excavation, blasting, crushing and grinding or milling.

4.2.4 Expected impact

Technical

- Increased resource efficiency.
- Reduction of ore losses.
- Optimised mine-to-mill processes.

Economical

- More cost-effective production.
- New value-added products.

Environmental

- Reduced energy consumption.
- Reduction of deposited waste on surface.
- Efficient use of waste on surface as secondary raw material.
- Decrease in harmful emissions.
- Reduced CO₂.

Social

- Increased job satisfaction.
- Equal gender employment.

4.3 MINING

The agenda area *Mining* is based on the updated visions and ideas presented in SMIFU II³⁵.

4.3.1 Vision

The long-term vision for 2030 and beyond (Fig. 4-5) is to improve the competitiveness of the Swedish mining companies with more efficient and highly competitive mining processes, equipment and methods for underground as well as open pit extraction, more energy-efficient extraction and improved safety. The goals are set at zero accidents, no human exposure at the production face, and greater energy savings (by 30%), reduced CO₂ emissions (by 30%) and lower ore losses (by 30%). The long-term vision can be achieved through the following measures:

- Improved mining methods and processes.
- More continuous processes.
- Fewer man-hours per produced tonne.
- Fully remote-controlled mining operations.
- More energy-efficient extraction.

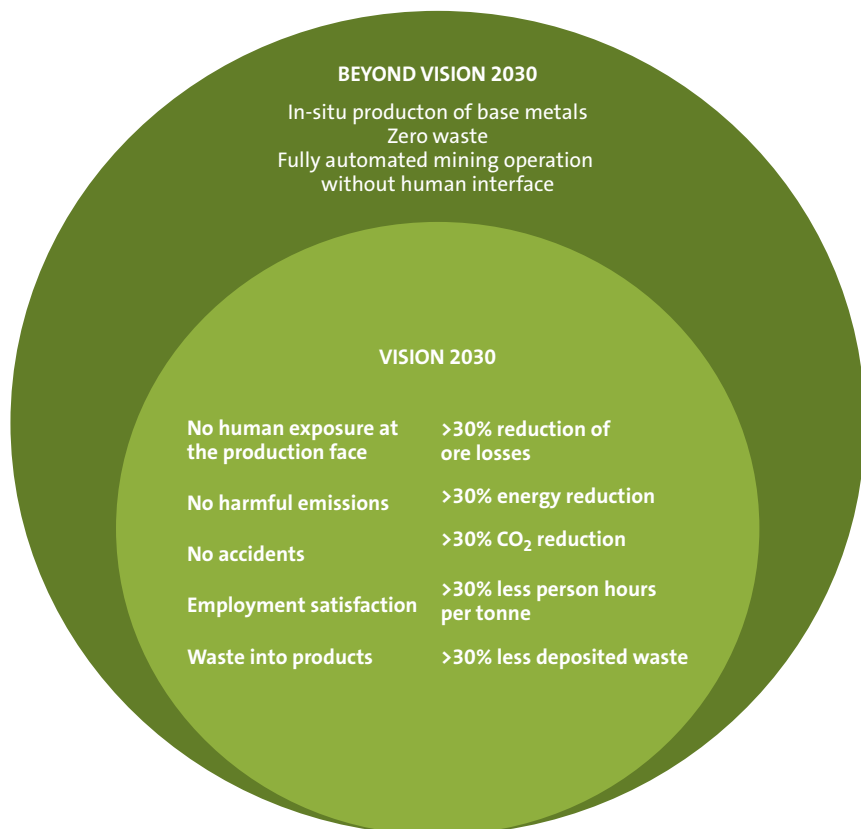


Figure 4-5. Vision 2030 and Key Performance Indicators for *Mining*.

- Decrease in seismic hazards and mitigation of the consequences of mining-induced seismic events.
- Decrease in uncontrolled rock falls.
- Cost-effective well-designed rock support systems that are able to sustain either large deformations or seismic conditions.
- An improved understanding of all major rock breakage and comminution processes.
- Increased ore recovery through an improved understanding of the behavior of the fragmented rock.
- Robust and reliable mining equipment.
- All relevant process information collected into one control system to achieve online monitoring, control and optimisation, and increased automation of the complete mining process.

The short-term goals (2013–2016) are to develop tools, methods and conceptual models that will facilitate the medium- and long-term objectives, which include implementation and validation.

4.3.2 State of the art

Underground as well as open pit mines are complex systems with interacting processes such as drilling, blasting, fragmentation, loading, hauling, hoisting, ground control, ventilation and logistics. By improving the extraction methods and processes, mining operations will reduce their environmental footprint, greenhouse emissions and production costs, and the Swedish ore reserves will increase. As an increasing number of deposits in Sweden (and in the rest of the world) are mined at great depth, efficient mining processes will be of utmost importance. Each unit operation (i.e. drilling, blasting, scaling, loading, hauling and rock support) of the mining process needs to be improved and optimised, and the full mining process needs to be controlled and optimised. Extending mining to deeper levels probably generates ground control problems, which in turn could cause safety problems, production disturbances, and damage to structures and machines. This imposes higher demands on the tools which are used in collecting information of the ore and surrounding rock mass.

Fragmentation is a crucial part of the mining process. The most common and important fragmentation method is blasting. During blasting the burden is detached from the host rock mass and fragmented. The blasting also induces damage to the remaining rock mass which may be the burden of a later part of the round (delayed parts of the same round or the next round) or the rock mass that forms the boundary of an underground excavation or a rock slope face. Damage to the remaining rock mass, i.e. the boundary of a future excavation, may seriously affect the mechanical properties and the behaviour and lead to an increased demand of rock support and an increased inflow of water. In the sublevel, block and panel

caving methods, the rock mass is provoked to fragment or cave by successive blasting of sub-vertical fans of blastholes (sublevel caving) or blasts on an undercut level (block and panel caving). The fragmentation may therefore be difficult to control and boulders may be formed as a consequence of the spontaneous fragmentation. In sublevel caving, the caved rock at the brow supplies a confinement to the burden which, for instance, may affect the wave reflection or refraction at the boundary between the burden and the fragmented rock (caved rock) and reduce the swelling volume and therefore the fragmentation of the burden. Hang-ups of boulders and back-break are examples of problems originating from the complex interaction of the fragmentation caused by blasting and the caving, and also by the confinement of the production fans caused by the fragmented material.

Fragmented rock can comprise particles from grain size to boulder size. The fragmentation process, the grain size distribution, the rock type and the mineral composition determine the properties and behaviour of the fragmented rock. The fragment size and the behavior of the fragmented material in terms of e.g. swelling is important for the handling and has a major impact on loading and unloading of buckets and cars. Therefore, automation of loading and hauling will be strongly influenced by the ability to control the size distribution of the ore, and frequent boulders will jeopardise any attempt to automate LHD (Load, Haul and Dump) operations. The fragment size distribution is also very important in the filling and drawing of orepasses and bins. The boulders may cause damage to the orepasses due to impacts. Many serious problems with hang-ups, jamming or other flow problems in orepasses are also related to the inability to control fragmentation and especially the occurrence of boulders. The gravitational flow and the draw point control are strongly influenced by the size distribution of the blasted rock.

The mechanisms and performance of the gravitational flow in sublevel caving need to be addressed in order to improve the flow, increase the ore recovery and reduce the dilution. The interaction between blasting and fragmentation in the caving mining methods needs to be further understood, and a reduction in the amount of non-detonated explosives (to reduce the environmental impact) is important.

Mining equipment operates in extreme environments, and equipment design, maintenance and operation need to be optimised in order to facilitate successful mining operations. The mining process in most mines is based on mobile equipment. Not only the availability and reliability but also the effective utilisation of the equipment are constrained by many factors which are mining system dependent as well as machine and maintenance dependent. Greater utilisation can be achieved by means of automation. However, this presumes that many of the mining-related disturbance factors can be removed or minimised.

High equipment availability needs to be supported by effective maintenance programmes. The programmes used today is often very general and not adapted to suit varying operational conditions, machine age etc. Reliability studies have, in a

broad sense, been carried out in connection with open pit and underground mining. Most of the studies focused on major production equipment and systems. The main concern of these studies has been the reliability and maintenance of equipment and their components and the influence on various parameters such as total capacity, effectiveness, machine stoppage rate, material flow, need for buffers etc. Specific studies have been made regarding the effects of operating environmental factors (dust, humidity, temperature, moisture etc.), the management of spare parts, maintenance methods and other parameters. Studies of the reliability of mine ventilation networks and fire escape routes in mines have also been reported. The reliability of total mining systems has also been studied. Such studies can be considered the most general cases of reliability analyses in mining engineering. The basic aim of these studies was to analyse the reliability of production delivery and continuity of operation. Efforts have focused on the development of reliability methods, on defining components, equipment and systems to be studied, and on linking failure rates, maintenance time etc. to statistical distributions. There is a lack of a unique comprehensive data collection (reliability, maintainability, risk, performance and cost) methodology for reliability studies in mining.

The increasing environmental concerns for the Swedish mining industry create a specific focus on energy reduction in the mining process. For underground mining the ventilation accounts for a major part of the total energy consumption and a significant part of the operating cost for a mine. Efficient ventilation is increasingly important in an arctic climate and for larger underground facilities where large capacities for pre-heating are required. Pre-heating is important in order to avoid the accumulation of ice in shafts but also to improve the working conditions in the mine. Different methods of heat exchange and flow control must be used for a more efficient use of air and energy. When mining depth increases, the temperature at the production levels will increase and the need for cooling will become an issue. Innovating and improving the ventilation design for complex mine systems will influence the workplace, production, cost and environmental impact.

Safe and stable underground constructions are a necessity to achieve optimal utilisation of mineral resources and efficient mining at great depth. Extreme deformations of drifts and stopes and an escalation of the occurrence of seismic events with increasing magnitude jeopardise safety and may lead to injuries, damage to equipment, ore losses and unplanned operational disturbances, and, in extreme cases, that whole areas of a mine have to be abandoned. Other examples related to stability are highly variable geological conditions and difficulties to design drifts, stopes and rock support. Furthermore, over-stressed, over-strained and non-functional ground support systems, expensive and time-consuming installation methods, and high material costs especially in seismically active mining areas are other areas that need attention.

Seismic networks now operate in numerous mines worldwide and the seismic events are detected and localised on a routine basis in almost every seismically

active mine. Therefore, there are now great possibilities for using the seismic data recorded in the mines in order to monitor changes in the local stress and geomechanical properties related to the mining. Despite the advances in mining seismology, the seismic risk is still considered unpredictable and remains one of the greatest challenges, especially in deep mines. New advances, based on high quality data and tools, are clearly needed to improve the mitigation of damage induced by seismic events.

The traditional deterministic methods used for underground mine design do not consider the inherent variability in the rock mass properties. Typically, the variability is considered by analyzing the worst case scenarios in a deterministic manner. However, the worst case scenario may result in designs which are overly conservative or, in some cases, not conservative enough. There is a need for probabilistic numerical methods which are more efficient and can produce results with an accuracy acceptable for the mine design.

The present design of rock support is based on the philosophy that the support should enable the rock mass to carry its inherent loads. The load imposed by the rock on the support depends on how the support deforms in relation to the rock, and the stiffness and load-bearing capacity of the rock support. Information about the interaction is only achieved through field tests, field observations and numerical studies. The design of rock support worldwide is generally controlled by the tradition and culture within the mining company or at the mine site. Many solutions are based on empirical relations from one or more mine sites combined with other engineering approaches. The fundamental understanding of the mechanisms triggering and leading to a certain chain of events is often over-simplified because of the need for quick solutions.

Comprehensive information from real seismic events and the corresponding rock mass–rock support system response (deformation, damage etc.) is sparse. Information can be obtained through thorough examination of seismic events with respect to source characteristics and damage to support and rock mass. Numerical studies can make a contribution, but models of rock mass and rock support have to be validated against the real behaviour.

Continuous excavation is a possible solution for some mining operations and this method can reduce human exposure at the face, reduce environmental impact and increase the possibility for automation. Continuous excavation machines are divided into two major groups: part face and full face. The first group contains roadheaders and continuous miners. The second group includes tunnel boring machines (TBM) and mobile tunnel miners (MTM). The main alternatives for continuous cutting in mine development and ore production are MTMs and roadheaders. Roadheaders have undergone considerable development in the last ten years and can theoretically be used in underground mining in most cases. Major obstacles are ore formations composed of very strong rocks without cracks and joints supporting the cutting, and the need of a total change of mining system in

the introduction of continuous mechanical excavation. It is expected that the development towards cutting stronger rocks will continue, mainly through the development of sharper picks by using better materials and through improvements in cutter head and machine system design. It is also concluded that developments of MTMs are ongoing and at the same time represent an interesting alternative in certain underground environments.

The automation of mobile equipment is one way of minimising human exposure to high-risk areas and unfavourable climate, and of improving efficiency. A study has been made in SMIFU II on remote control and automation in mining production areas. All unit operations at the production area were included in the study. The conclusion was that 9% of the tasks that were analysed satisfy the vision of full automation and remote control while 91% do not. It should be stressed that all tasks in all unit operations have to be remotely controlled or automated for the vision to make sense. A considerable number of research centres worldwide operate in the field of mining robotics and automation. Additionally, a huge number of activities are in progress worldwide that relate to generic automation and mobile robotics. Most of the research conducted in these groups can be adapted to mine requirements and push the technological advances in this field. A proposed road map to reach the vision of no human exposure through fully autonomous mines is illustrated in Figure 4-6.

A mine is a very large-scale, complex system that incorporates the need for real-time acquisition of thousands of signals, the analysis of the signals, the calculation of optimal control strategies and, finally, the distribution of the planned control strategy in thousands of control loops. Such a control scheme, which can

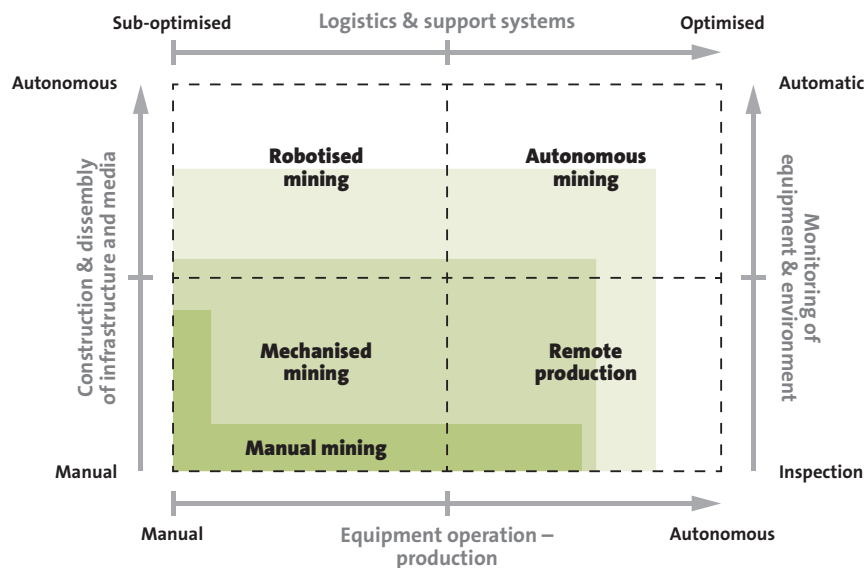


Figure 4-6. Road map to reach the vision of fully autonomous mining operations without human presence in the production areas. The darker green box illustrates the current status. The lighter green box illustrates the first steps that need to be taken concerning the following objectives: 1) Production, 2) Construction and disassembly of infrastructure, 3) Monitoring of equipment and the mine environment and 4) Logistics and support systems. Source: Andersson et al. 2011. SMIFU WP1, Final report, Nordic Rock Tech Centre.

also be called dynamic real-time optimisation, has to be applied throughout the mine area in order to improve the entire process and fine-tuning it. Studies in the LKAB Kiruna mine and the mines of KGHM in Poland have concluded that only the central ore transport process (from ore passes or LHD dumping points via trains or conveyors to skip-hoisting up to bins on the surface), have the relevant control systems integrated with each other (Kiruna). In general, there is a considerable lack of connectivity and integration among the rest of the mining systems and processes, including the different machines and equipment utilised. Moreover, there are numerous distributed stand-alone control loops, equipped with local onboard control systems, and usually with an operator panel or workstation to manually execute the different tasks and fine-tune the operational parameters. In these cases, there is a requirement of a constant and extended, and in many cases ad-hoc, manual human intervention for enabling the integration or connection of the overall processes and operations.

The increased scale and complexity of control applications has brought about the demand for a focus on distributed and networked compositions of heterogeneous and semi-autonomous processes. These new types of systems are, in fact, collections of many sub-systems that need to be integrated, optimised and controlled to achieve the planned objective.

4.3.3 Research and innovation needs, and strategies and actions

In order to mine Swedish deposits both at increasing depths and near the surface with minimised environmental impact and increased productivity and safety, the research should be focused on optimising the mining processes and methods. The research activities should aim at improving and optimising all separate parts of the production process, as well as finding solutions that enable an optimisation of the complete process. The research should focus on the following main areas:

4.3.3.1 Efficient unit operations for mining

The following RDI areas have been identified for further work:

Short- to medium-term

- Develop the unit operations to improve productivity, resource efficiency and to facilitate automation.
- Improve the efficiency of materials handling and mass movement.
- Develop the blasting process in order to optimise the use of explosives and its effect on fragmentation.
- Develop the understanding of detonation and its connection to drill accuracy and rock mass properties.
- Improve the understanding of fragmentation.

Long-term

- Optimise all steps of the extraction process (e.g. drilling, blasting, materials handling, mass movement and rock support).
- Develop continuous excavation methods adapted to Swedish mining conditions.
- Minimise the environmental effects by:
 - reducing the amount of mine waste.
 - developing more selective mining methods.
 - developing a near-face processing scheme.

4.3.3.2 Improved ore recovery, fragmentation and breakage of hard rock

The following RDI areas have been identified for further work:

Short- to medium-term

- Study problems related to increased mining depth.
- Increase understanding of the gravity flow by full-scale gravity flow studies
- Increase understanding of numerical models and conceptual studies of fragmentation and breakage of hard rock.
- Laboratory tests of physical material properties, possibly physical model scaled tests.
- Develop cutting tool design with focus on tools that require low cutting forces when cutting hard rock formations.

Long-term

- Increase ore recovery and reduce waste rock dilution.
- Improve the understanding of draw control and gravity flow in caving mines with increasing stresses and potentially increasing volumes involved.
- Improve detonation of explosives (e.g. avoid dead pressure), blast damage and deep mining related issues such as blast-hole stability.
- Improve the understanding of the behaviour of the fragmented rock. This is essential for the automation of continuous mechanical excavation and ore bucket loading, and also important in the design and control of underground ore shafts. In addition, this work will support the development of sublevel caving. In this respect, compaction under high static and dynamic loads and dilation (swell) during large deformations is of interest.
- Develop a full understanding of breakage mechanisms under cutting tools and apply this knowledge to improving continuous mechanical excavation processes.
- Develop Measurement While Grinding (MWG) and full-body modelling of mills with grinding charges to be able to continuously measure and dynamically control comminution circuits (jointly with mineral processing).

4.3.3.3 Rock mechanics, support and mining seismology

Increasing safety and decreasing the production disturbances will be accomplished by improving the understanding of mining seismicity and developing novel numerical analysis approaches, rock support design methods and ground control strategies. It is important that laboratory and field tests, monitoring and evaluation of real seismic events, and the numerical analyses are done hand-in-hand. The approach used in the research should strive towards achieving a fundamental understanding of the mechanisms and processes involved in order to develop methods that can be used in several mines with different geological environments, different dimensions and different mining methods.

Short- to medium-term

- Improve the understanding of the
 - correlation between seismic hazards and mining depth.
 - difference in characteristics of different types of seismic events (shear events, strain burst, tensile cracks, collapse etc.).
- Develop rock mechanics block models with “graded” rock engineering properties of the rock mass in a similar fashion as mineral resource block models.
- Develop effective rock reinforcement systems in squeezing and bursting ground conditions.
- Develop an effective methodology to test the capacity of the rock support system including both surface support and reinforcement.
- Improve numerical modelling capabilities, which describe well-constrained failure and post-failure deformation mechanisms.
- Improve numerical modelling capacities which can handle rock fracturing, deformation and ejection under static and seismic conditions.
- Develop monitoring technology on a mine scale to observe the states of failure and post-failure at, and in the proximity of, an excavation. Both scaled physical models and full-scale underground tests should be considered.
- Effective probabilistic numerical modelling techniques with the capability to identify the ground control problems associated with mining at great depth.
- Evaluate the performance of rock support systems and the rock mass–rock support system interaction.
- Improve the understanding of the rock mass and rock support performance by monitoring and damage mapping.
- Give a clearer understanding of the effectiveness of the rock support systems by detailed numerical analyses.
- Develop knowledge about the factors governing the interaction and performance through large-scale field tests and the development of novel laboratory testing methods.
- Improve the productivity of equipment for rock support.

The research in mining seismology should go hand-by-hand with the research in rock mechanics as the mining goes deeper.

Long-term

- Improved understanding of rockburst mechanisms by thorough investigation of seismic hazards, and evaluation of the rockburst mechanisms.
- Develop interpretation methods that can assist in judging whether failure surfaces and fallouts are formed.
- Develop methods that can be used in rock support design under squeezing and bursting ground conditions.

4.3.3.4 Energy and infrastructure

The following RDI areas have been identified for further work:

Short- to medium-term

- Improve and develop ventilation, for instance by optimising heat exchange and flow control.
- Develop new power sources.
- Develop mining processes, mine layout and infrastructure, and tools that enable minimised transports, efficient flows and efficient process control.
- Innovative processes such as near-to-face processing and continuous excavation needs to be considered and developed in order to reduce energy per produced tonne.

Long-term

- Reduce the environmental impact and the overall energy consumption.

4.3.3.5 Mining equipment reliability and machine design

The following RDI areas have been identified for further work:

Short- to medium-term

- Failure and maintenance data collection and analysis.
- System reliability analysis of operating environment.
- Condition-based maintenance.
- Operator training and procedures.

Long-term

- Design for reliability.
- Maintenance programme design and optimisation.
- Models and equipment prototype design.

4.3.3.6 Integrated process control and automation

In order to achieve an optimised mining process with a high degree of digitisation and automation, the technology for communication and process control must be available, and applied to the mining process using the knowledge on all unit operations and the behaviour of the rock material. Research should focus on the development of and the application to mining of:

Short- to medium-term

- Improved communication networks, localisation systems and navigation systems enabling automation and integrated process control.
- Automated inspection, reporting, image analysis and processing.
- Information gathering systems.
- Mining equipment monitoring.
- Sensors.
- Production prediction systems, calculation and prediction of KPIs in real time.
- Traffic management systems.
- Integration of maintenance systems into scheduling models.
- Human interaction in automated systems.

Long-term

- Improve and optimise the overall mining process including the utilisation of mining equipment and automation:
 - developing dynamic simulation models and optimisation tools as well as the acquisition and communication of real-time data (integrated process control).
 - model-based integrated decision-making and monitoring support systems.
- Mobile machine monitoring and remote diagnostics.
- Augmented reality.
- Field robotics in order to facilitate autonomous mining.
- Sensors for mine environmental characterisation (identification of fall-outs, road condition, gas detection etc.).

4.3.4 Expected impact

Technical

- Reduction of ore losses.
- Optimised mining processes.
- More continuous processes.
- Integrated process control and one control room.
- Minimised human exposure at the production face.
- Increased conversion of waste into products.
- Increased degree of automation.
- Safer mining with fewer accidents.

Economical

- Reduction of man-hours per tonne.
- More cost-effective rock support.

Environmental

- Reduced energy consumption.
- Reduction of deposited waste on surface.
- Decrease in harmful emissions.
- Reduced CO₂.

Social

- Increased job satisfaction.

4.4 MINERAL PROCESSING

4.4.1 Vision

The resource efficiency within mineral processing will be significantly improved by 2030, resulting in added value from high value or more refined products and new by-products, in lower energy consumption and related CO₂ emissions as well as reduced metal losses. Innovative process design and control optimisation of comminution and physical separation processes using advanced analytical methods and online sensor technology will lead to intelligent production systems (Fig. 4-7).

4.4.2 State of the art

Within mineral processing, different unit operations for comminution and physical separation are combined into a multi-stage beneficiation process in order to provide an ore concentrate or to produce an industrial mineral product with defined application properties. Available processes and technologies have matured during recent decades but are still far from optimal. Therefore, the major challenge in mineral processing research and development still lies in improving the overall resource efficiency for particular ore deposits, i.e. enhanced recovery of valuable minerals with reduced energy consumption and water demands. New challenges arise from the future exploitation of deposits with complicated ore properties. Considering the general trend towards lower grades, fine-grained ores and a more complex mineralogy, enhanced mineral liberation and separation processes are required.

Mineral liberation is achieved by grinding the ore to fine particle sizes. The comminution stage is usually not only the most energy-intensive step within mineral processing plants, but is also crucial for all subsequent steps in mineral beneficiation, as a sufficient liberation of valuable minerals is the key prerequisite for any downstream separation process. However, the selection and operation

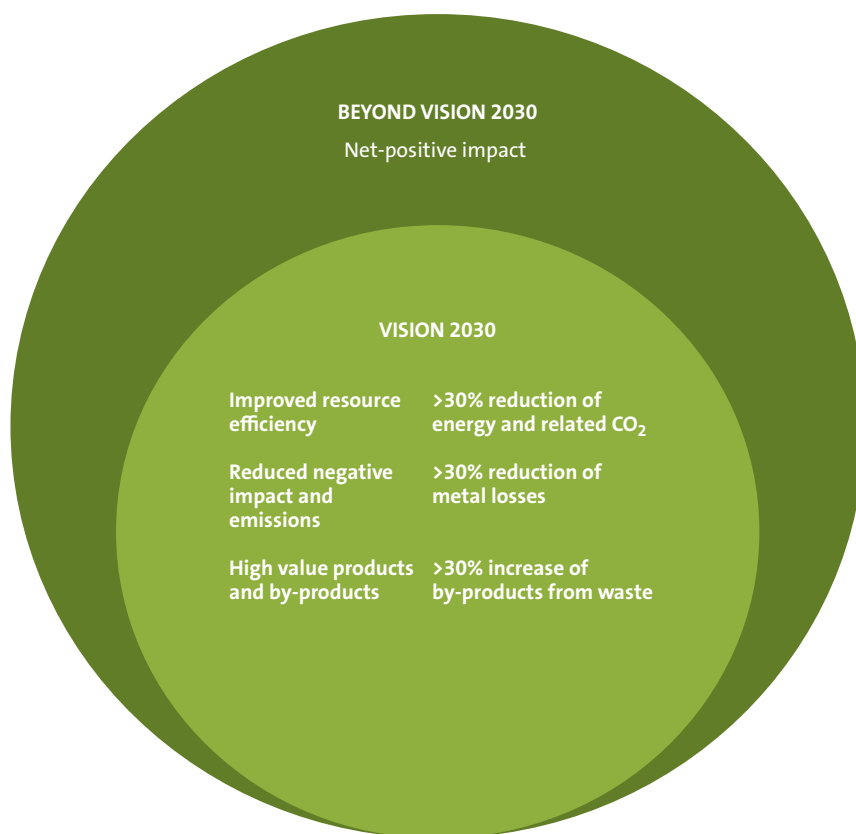


Figure 4-7. Vision 2030 and Key Performance Indicators for *Mineral Processing*.

of comminution devices today are often not optimal due to limited ore characterisation, particularly when ignoring the variability in liberation size within an ore body. With respect to the introduction of new mill types, the first steps have already been taken during recent years through the adaption, for instance, of high pressure grinding rolls and stirred media mills to ore comminution. In comminution modelling, the approaches used today need to be extended in order to take into account mineralogy and texture.

Within ore concentration processes, the recovery and selectivity of physical separations need to be further improved. For instance, the efficiency of flotation separation depends on suitable particle size ranges. In the flotation of base metal ores, about 10% of the value minerals in the feed are lost in the very fine and in the coarse fractions. In the case of flotation of oxide and silicate minerals, the losses are generally higher. Coarse mineral particle recovery is limited due to an increased probability of detachment with increasing size and density, whereas the very fine and lighter particles do not manage to penetrate the fluid flow around the air bubbles, thus decreasing the likelihood of collision. Some basic approaches exist to adjust the flotation process to fine particle flotation, involving high in-

tensity dispersion and mixing, while low intensity flotation with larger sized air bubbles is generally intended for coarse particle flotation.

One way of reducing the amount of ore that needs to be processed is by physical separation to remove liberated gangue already at coarser particle sizes, e.g. by sensor-based sorting, gravity separation etc. Although the benefits of pre-concentration are obvious, these technologies have at present only been implemented at a few mining sites. Also other approaches to improve the entire process, using for example more efficient classification steps within comminution circuits or the successive concentration and size reduction, have not gained general acceptance up to now due to higher complexity.

Agglomeration (pelletising, briquetting, sintering) of ore concentrate requires extra energy, but agglomerates create less dust and are thus more suitable for transfer and shipping, and agglomerates may be necessary in some processes. Agglomeration can also be conveniently combined with the mixing of several materials, e.g. mineral concentrate and different additives. At present, the pelletising of ore concentrates is mainly limited to iron ore, resulting in energy savings and improved performance in metallurgical processing. However, the demand for agglomeration processes can be expected to grow in the future when treating other ores as well as recycled materials.

4.4.3 Research and innovation needs, and strategies and actions

Resource efficient mineral processing involves increasing the recovery of valuable minerals and metals while reducing the losses, as well as the reduction of energy, water and other auxiliaries. In order to meet the demands of a circular economy, efficient processes for improving the quality of the products, i.e. concentrate grades and impurities, need to be developed in order to compensate the lower quality of recycling material. Due to the integration between beneficiation plants and smelters, also the processing of secondary materials, for instance metallurgical slags, becomes relevant. In the long term, research is needed to:

- Develop and implement energy-efficient processes, particularly for ore comminution.
- Develop efficient separation processes for treating finely dispersed, polymetallic ores as well as removing impurities.
- Improve and optimise mineral beneficiation processes towards better resource-efficiency and sustainable production, e.g. by reduction of waste rock and tailings, and reduction of process water as in dry processing.
- Develop suitable pre-treatment processes for separation close to the mining production face.
- Develop new processing routes for efficient separation of minerals and metals from by-product and waste streams from existing beneficiation as well as extraction plants.

RDI strategies related to mineral processing are proposed in the fields of comminution and physical separation and agglomeration, as well as their combined consideration in a systems approach in order to optimise entire processing plants. The research needs and suggested short-term and medium-term actions presented below involve both fundamental and applied research.

4.4.3.1 Comminution of hard rocks

For more efficient crushing and grinding, the currently existing processes need to be optimised or novel technologies have to be provided. Research should aim to:

- Enhance mineral liberation by adjusting the target particle size and the breakage mechanism for grinding to ore texture and mineral associations.
- Improve comminution technologies and machinery for hard ore comminution with regard to energy for grinding and wear characteristics.
- Develop measurement technology and advanced models for optimising design and control of comminution processes.
- Investigate alternative fragmentation methods and mill types for the efficient grinding of coarse and fine particles (considering dry and wet grinding).

4.4.3.2 Physical separation

Improvements in technology are particularly required to better deal with separation at coarse and very fine particle sizes.

- Investigate processing routes for bulk sorting prior to the actual concentrator plant, considering unit operations for separation at coarser particle sizes.
- Develop improved reagent schemes and hydrodynamic concepts for flotation to recover valuable minerals from fine and ultra-fine as well as coarse particle size fractions, particularly for cold flotation.
- Develop processing routes for the effective separation of complex ores and removing impurities.
- Develop dry processing technologies particularly for finer size ranges (classification as well as sorting, magnetic, electric and gravity separation).
- Investigate the stability and degradation of flotation reagents and their effect on downstream processing.

4.4.3.3 Process design and analysis

In addition to the optimisation of single unit operations or processing stages, investigations also need to be made of potential improvements along the whole processing chain. This comprises the introduction of new conceptual process designs and methodology development.

- Develop hybrid flow sheets based on successive separation and size reduction to improve the efficiency of comminution circuits.
- Optimise the whole chain of ore fragmentation (blasting, mechanical cutting, crushing and grinding) in combination with pre-concentration processes.
- Develop geometallurgical models together with innovative analysis methods for resource characterisation.
- Develop process designs for flexible plant operation in order to process different ores and ore domains.
- Develop strategies and models for the efficient management and treatment of process water.

4.4.4 Expected impact

Technical

- Providing designs for energy-efficient comminution.
- Providing innovative measurement solutions and mill models for reduced wear and enhanced mill control.
- Providing solutions for enhanced coarse and fine particle separation.

Economical

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

Environmental

- Reduced CO₂ emissions due to decreased energy consumption.
- Less water usage due to dry processing and reducing the tonnage in downstream processes.
- Less material to be deposited.
- Stabilisation of waste products to reduce their hazards or harms.

Social

- Improved social acceptance of mineral processing plant operation due to higher resource efficiency and less emissions and waste.
- Increased awareness of civil society of how the mining industry can improve the quality of life in society.
- Education: generation of new knowledge through research.

4.5 RECYCLING AND METALLURGY

4.5.1 Vision

Through combined novel pre-treatment and metallurgical operations fully utilise ore concentrates, scrap and residues from ore and metal treating industries in order to maximise the economic outcome and minimise environmental impact for the whole process chain.

To reach the vision, actions will be needed in several areas, including measures to stimulate collection, development of more suitable material combinations for recycling, design of the final product etc. These issues are covered within other research programmes, e.g. Re:Source. This part of the STRIM agenda deals with metallurgy in general and the interconnected recycling of metals, especially focused on the metals and processes complementing the strategic innovation programmes Metallic materials and Re:Source.

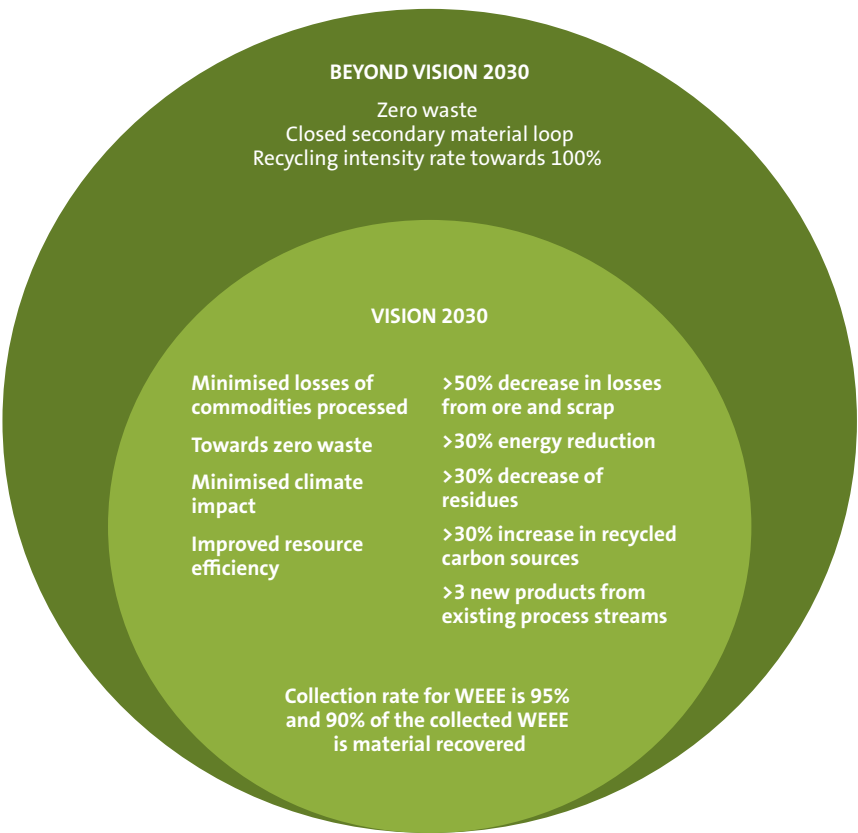


Figure 4-8. Vision 2030 and Key Performance Indicators for *Recycling and Metallurgy*.

4.5.2 State of the art

4.5.2.1 Industrial practice and business structure

Sweden is one of the leading countries in Europe when it comes to the mining of metals, both iron, base metals (copper, zinc, lead) and precious metals as silver and gold. Part of the ore is used for metals extraction within Sweden, but a considerable amount of the ore is also exported, especially iron ore upgraded into fluxed iron ore pellets.

The metal extraction is carried out in processes with very high demands on low emission levels and low energy consumption in process systems which are competitive in an international comparison. Raw materials used for the production of metals consist of ore, scrap and metal-containing residues in the form of dust, sludge, fines etc. in varying proportions depending on the process. Metals contained in scrap is extracted in specially designed processes as the electric arc furnace (EAF) process for smelting steel scrap and the Kaldo process used by Boliden for treating scrap from used electric and electronic appliances. Also processes originally designed to mainly treat concentrates or pellets use a considerable amount of scrap for cooling purposes. The highly interconnected processes for extraction of base metals from both ore and scrap, and the very big importance of the recycling part are illustrated in Figure 4-9, showing the share of production of Cu, Au, Ag, Pb and Zn within Boliden in Sweden emanating from ore and scrap.

Recycling of metals from rich material streams has been and will be an attractive and economically viable business. Extraction of metals from scrap can always be performed with lower total energy consumption and usually also lower

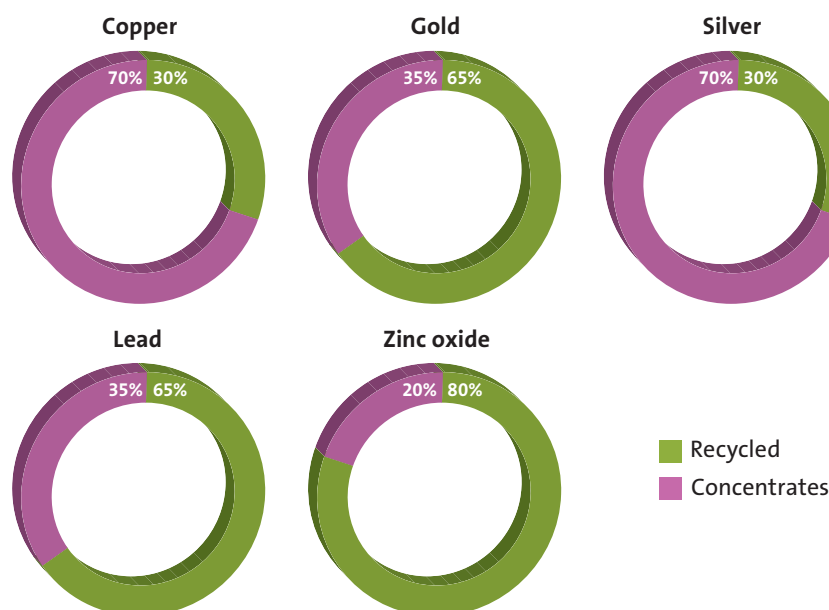


Figure 4-9. Production of base metals and precious metals by Boliden in Sweden in year 2011, as well as the share of the production originating from recycled material and concentrates.

total environmental impact compared to production from ores. The recycling chain consists of collecting, fragmenting, sorting and upgrading through physical processing steps, followed by the extraction of the metal contained in the various process streams using hydro- or pyrometallurgical methods. The separation of metals into the different material streams is, however, not complete which partly results in complex scrap concentrates, usually containing several metals in various concentrations, entering the extraction processes.

Base metals are usually extracted from concentrates produced from complex sulphidic ores that contain other valuable metals and impurities. Valuable metals as Au, Ag, Pt, Pd and Ir, and impurities such as As, Sb, Bi etc. that cannot easily be removed completely during the physical beneficiation of the ores, may either follow the main product stream (as gold that follows copper until the final refining step by electrolysis) or be enriched in residue streams, i.e. dust and sludge from the gas cleaning operations or in the slag formed by oxides. The content of some of the minor elements, e.g. As, Bi and Sb, in copper extraction in many cases limits the extent of impure raw materials, ore concentrate and scrap that can be used in the processes as these elements are detrimental for the final refining of copper in the electrolysis. Some of these impurities are also considered to be strategically critical metals in Europe. In the processes for base and precious metals extraction from sulphidic ores and recycled materials, Boliden is today in Sweden extracting Cu, Pb and Pb alloys, Au, Ag, crude Se, Zn, Pt-Pd-Rh, part of the Ni and crude copper-telluride as intermediate products. Several of these elements are mainly recovered from scrap as can be seen in Figure 4-9. An increased extraction of some of the minor elements into product streams as a bleed from the main product streams would, in addition to a recovery of these metals, also increase the capacity to treat new and complex raw materials, and thereby to increase the raw material base, making some of the known mineralisations into ores.

There exist already today processes and business structures for collecting, handling, marketing and processing of most, by the tonnage, larger metals contained in scrap. New processes for extracting more metals from the scrap has to be designed so that they do not jeopardise existing and well-functioning extraction processes of the main metals contained in the scrap. In Sweden, there are a few large scrap treating companies, e.g. Stena Metall AB, Kuusakoski Sverige AB, SIMS Recycling Solutions and Ragn Sells AB, delivering scrap to the smelters. The recycling industry is, however, also characterised by a large number of smaller companies that are active within the sector.

The process steps for extracting metals from ores, scrap and residues are for many metals highly interconnected. Residues containing metals or reductant/fuel of economical value are recycled within the processes to the extent possible today. Zinc which is contained in the galvanised scrap smelted during steelmaking is recovered within the base metal industry. Intermediate products from the production of one base metal are used in the production of another base metal. An

increased extraction of metals that are not fully recovered today necessitates an understanding of all parts of these interconnected production chains. A holistic approach is therefore necessary where ore based metallurgy and recycling are dealt with simultaneously. It is believed that a more flexible use of existing process steps, complemented with improved pre- or post-treatment of scrap, ores and residues through hydrometallurgical or physical separation methods, has a potential to substantially increase the amount of recycled scrap as well as the capacity to process more impure scrap and ores.

Modern processes for the extraction of metals have been developed to a state where the utilisation of supplied or produced energy is very high. Heat contained in hot gases is recovered in waste heat boilers, and most smelters have a capacity to deliver both electricity and hot water in considerable amounts to the surrounding society if the need exists. There exist, nevertheless, process streams that are not fully utilised, especially gas streams with lower heat content and slag. There are several metal containing material streams, also containing organic materials, which could be further utilised for reduction and energy recovery, thereby replacing mined fossil reductants such as coal and coke.

All metallurgical processes generate more or less residue materials such as slag, dust and sludge. The largest in volume is usually slag. The slag produced has in many cases excellent technical properties for certain construction applications. However, tightened environmental regulations and practice connected to the environmental goals formulated by the government increases barriers for the use of residue materials in applications outside the plant. There is, thus, still a need to increase the knowledge regarding how a slag can be adapted to both strict environmental and technical demands connected to the intended application of the slag. Impurity elements with high vapour pressures are often enriched in dust and sludge from the cleaning of process gases to an extent which hinders the recycling within a plant. There are thus still considerable amounts of metal and carbon units that are deposited and which could contribute to better raw material efficiency if ways to recycle these materials were available.

Swedish iron ore products are characterised by high iron content and low gangue content, but contain impurities such as V and P in an amount that can introduce difficulties in the processing of the final steel, but could also be a resource for the extraction of V and P. The majority of the iron-ore concentrates are processed into pellets with designed properties for the use in a blast furnace or DRI (Direct Reduced Iron) process. Mining of new ore bodies will, to some extent, change the gangue composition which has to be considered in the upgrading and in the design of the slag chemistry in the produced pellet. The oxidation of the magnetite in the concentrate is an exothermic reaction, resulting in a very energy efficient process. However, both the exothermic nature of the process and demands on decreased emissions of e.g. NO_x, also introduces higher demands on the control of the gas circulation, the oxygen content in the recirculated gases,

the mass and heat transport within the pellet bed, and the temperatures in the different zones of the furnace. This necessitates access to new innovative measurement techniques for crucial process parameters, and more accurate models for the sintering process. The base for a more precise overall process model is a better understanding of the reactions occurring in a single pellet, including slag formation and heat and mass transfer within the pellet. Tighter regulations on process emissions have also introduced a need for tools to better evaluate the environmental consequences of different process alternatives, e.g. through implementation of the gained knowledge into better overall models for the pellet sintering process. Measures to deal with increased V and P contents in process streams at the steel plant are crucial to ensure a long-term sustainable use of these iron ores in the steel industry.

4.5.2.2 Research

In the on-going SIP-STRIM programme, one research project focuses on metal containing organic fractions from the recycling industry for use as a reductant within the base metals industry. There are also several pre-studies with a connection to *Recycling and Metallurgy* within SIP-STRIM dealing with the supply of raw materials, mining of metal mine water, electrolytic extraction process, coating of iron ore pellets for direct reduction, recycling of fines from scrap fragmentation and recycling of dust from steel production using hydrometallurgical methods.

Research related to recycling within the metallurgical industry and with focus on the metallurgical processing has also recently been dealt with in some larger research programmes. The Steel-Eco cycle financed by MISTRA has contained projects on, among other things, how to find ways to better utilise slags from the steel industry, the use of waste from the recycling industry for preheating scrap, the recovery of metal content in slags, how to increase the yield of alloying elements and finding better sorting techniques for shredded scrap. The recently finalised Steel research programme, financed by VINNOVA, contained one project on products from slag for the construction industry. This research on the use of steelmaking slag has continued within the Strategic innovation programme “Metallic materials”, partly devoted to use of slags for water cleaning purposes. The former Mining research programme, financed by VINNOVA, contained a project (Wise process routes) which focused on strategies to treat materials containing Sb, both from the mining and the smelting point of view.

A new Strategic innovation programme dealing with recycling, Re:Source, has recently started. In comparison to the area of Recycling and Metallurgy within SIP-STRIM, the research agenda for Re:Source is much broader, covering almost all material streams, not only metal containing material streams, and covering also societal aspects of recycling. The programme for Re:Source may, nevertheless, also contain aspects of metal recycling giving possibilities for collaboration between Re:Source and SIP-STRIM as well as “Metallic materials” as well as with

initiatives from MISTRA, e.g. the programme “Closing the Loop”, where recycling of material streams are dealt with.

The very high dependence within EU on imported raw materials has recently been in focus. Increased production of metals through recycling is within Europe considered one important way to decrease the import dependence. The question has been highlighted within the Raw Materials Initiative. A number of actions are presently on the way, including the network ERAMIN, a KIC on raw materials, and several calls within this area within Horizon 2020 etc. For several of the metals of strategic importance for Europe, the base metals industry has the potential to play an important role for Europe’s supply, from both ores and recycled scrap.

4.5.2.3 Connection to other business sectors and their strategic research programmes

The research agenda for *Recycling and Metallurgy* within STRIM concentrates on the metallurgy and recycling within the base metals industry as well as on the sintering of iron-ore pellets, i.e. research more or less connected to the mining industry. The recently approved SIP Re:Source will in addition to a broad perspective on recycling also focus on new business models and the collection of the scrap etc. The connection to the present agenda is within metallurgical process solutions for recycling. The strategic agenda for the steel industry, *Metalliska material*, will cover all aspects of the hot processing into steel, from both ores and scrap, but with an emphasis on the material properties of steel.

Some of the residue materials from the steel industry is or could be raw materials for the base metals industry, e.g. the dust containing zinc which is produced in the steelmaking. The scrap used in the production of steel partly emanates from the scrapping of products which also yield scrap fractions that contain base metals. For both the steel industry and the base metals industry it is increasingly important to be able to guarantee the quality of slags used in applications outside the plant (e.g. for road construction) from both a product property and a leaching perspective. Therefore, although the processing of base metals and steel differ considerably, common interests exist within several areas. In addition to those presented above, improved process modelling and measurement techniques to increase the yield in the processes should be mentioned.

The iron ores produced within the mining industry are upgraded into more highly valued products, such as the pellets used in the blast furnace for ironmaking. Another product is the pellet used in the production of direct reduced iron, DRI, e.g. in processes using natural gas for reduction. As very pure steel scrap becomes less available, it is urgent for the scrap based industry to have access to DRI as a scrap replacement in the production of many of the more advanced steel grades. With access to cheap natural gas, this alternative becomes more interesting and could contribute to lower emissions of greenhouse gases. This is another area of common interest between the mining and steel industries.

4.5.3 Research and innovation needs, and strategies and actions

As described earlier, one larger project and several pre-studies have been performed within the context of Metallurgy and recycling within SIP-STRIM. The actions given below are an expression of the areas for research and development prioritised by the industry. The participating companies have been Boliden, LKAB, Stena Recycling and Kuusakoski, and the participating research organisations have been LTU, SP and Swerea MEFOS.

The majority of the Swedish iron ore is processed into added value pellet products. To aid in the development of new products, in adapting processes for variable raw materials, the use of new heating devices, and towards decreased emissions, research and innovative solutions are needed within several areas. Models based on fundamental properties and chemistry of the materials, models that are also implemented in overall process models, will aid in optimising gas utilisation, decreasing the energy need, and predicting consequences of changed fuel in the processes. Development of new process models should also be complemented with new innovative measurement techniques for on-line measurement of important process parameters. Two important impurity elements for the steel industry is the vanadium and phosphorus contained in the ore. New innovative methods to extract vanadium and phosphorus from the residues generated in the steel industry would be of high value, not only for the steel industry but would also strengthen the competitiveness of the iron ore mining industry.

Recycling of the metals contained in collected material streams, where the recycling can be carried out in an economically viable way, using existing technique and knowledge is already done. However, many of the material streams have a very complex composition and one challenge for the future is to increase the yield of the metals which are already recovered. Another challenge is to recover additional elements contained in the material streams (ore, scrap and residues) that are not extracted today but instead lost in by-products or waste streams. The composition of ores and scrap gradually changes as lower grade ores and scrap from new consumer products are used as raw material. There are also large mineral deposits, that have been known for a long time, which cannot be turned into ores with conventional mineral processing methods due to their complexity and fine-grained structure.

Future processes have to be adapted to variable raw material compositions. The access to new measurement techniques, for instance the online XRF measurement technique, could then be an asset. There is also a large flexibility in the existing processes which is not fully utilised today. Due to increased recycling, some elements may be enriched in e.g. slag. Aluminium and chromium have already increased in the slag and are expected to increase which gives rise to changed properties of the slag and, thereby, possibly increased metal losses to the slag. This may also jeopardise the slag properties as a product.

The final slag from base-metals production has, until recently, had a good market for construction purposes as aggregate in road-building, insulation material etc. Today, the marketing of this slag faces increasing difficulties, especially connected to the governmental environmental objective Giftfri miljö (A non-toxic environment). Base metals extraction that lack a viable way to use the final slag might not be possible. There is an urgent need for intensified research on the environmental properties of slag, adaption of the slag to comply with environmental demands, and new applications for the use of the produced slag.

An increase of the energy efficiency in the processes through energy recovery from hot gases and slag, which is not done today, is partially a question of having a market for the recovered energy. With a market at hand, there are possibilities for an increased energy recovery. Research on the possibility of replacing mined fossil reductants with metal and carbon containing waste streams is on the way, but a need for further in-depth studies might be required.

To increase the metal recovery from ores and increase the recycling of metals it is necessary to have a holistic perspective where the whole recycling chain is considered as well as the interaction with ore based metal production and the advantages from a combination of ore and scrap based production. Suitable pre-treatment methods, as bio- or hydrometallurgical processing, should be considered as a supplement to existing processes.

Research to utilise metal containing residue streams by increasing the understanding of the generation and how metal content can be enriched should be encouraged. Examples are dust and sludge from gas cleaning that contain metals only in minor amount in the primary and secondary raw materials. Research and development will then be needed within the following areas:

- New innovative pyro-, hydro- or biohydrometallurgical processes to extract the metals.
- New knowledge on the distribution of elements between different process streams and their capacity to accept different elements.
- New innovative techniques to utilise carbon containing waste streams.
- New innovative separation techniques or combinations of separation techniques to more efficiently separate the metals contained in complex material streams.

Already existing collaboration with universities and research organisations in the Nordic countries, Europe and North America should be further strengthened. A closer collaboration with the strong developing countries in Asia is foreseen.

Targeted materials

New as well as existing metallic concentrates, scrap and residues from the process industry as well as iron containing pellets for use in the steel industry.

Type of activities

Full-, pilot- and laboratory-scale experiments, process modelling, education and knowledge transfer.

Objectives

- To enhance the extraction of metals from complex scrap, ores and residues, including extraction of elements contained in existing material streams but so far not extracted as well as securing the quality of products and by-products and securing a viable use of the by-products, through
 - technology development,
 - measures to increase the quality of material streams,
 - developing the necessary methods and knowledge needed to increase the type of material streams used,
 - education,
 - knowledge dissemination.
- To fully utilise the energy content in raw materials, including sources with low energy content, and to increase the utilisation of metal containing organic sources.
- To secure the knowledge base for production of existing as well as new high quality iron-ore based pellets with a minimum of environmental impact due to e.g. emissions.

Technology

- Adapting processing of iron-ore into pellets for increased product quality and simultaneous optimised gas and energy utilisation for minimised emissions, based on fundamental knowledge coupled to the processing and implemented in process models.
- Develop and adopt measuring techniques for online measurements to control material streams.
- Develop new innovative methods to extract phosphorus and vanadium from residues generated in the steel industry.
- Develop knowledge and technology to use slag products in new applications.
- Develop knowledge and technology to increase the yield in existing processes, considering the whole value chain for the raw materials.
- Develop the technology needed to extract more elements from material streams already processed.
- New and improved methods for the recovery of energy from low heat value sources.

Enhanced quality of material streams

- Optimise the existing process chains for simultaneous extraction of metals from ore concentrates and scrap, including the whole system from exploration,

concentrating of ores and scrap, and processes for extraction of the metals, e.g. through improved process modelling.

- Develop methods to enhance the metal content in and secure the quality of all by-product streams to increase the possibility to extract more metals from the material streams.
- Dissipate knowledge about recycling possibilities and limitations to the designers of consumer products (design for recycling).
- Introduce new methods to more efficiently control the processes through new measurement techniques.
- Develop the knowledge necessary to secure the product quality of the slag produced at the same time as processing consequences of varying slag composition can be controlled or purposely adjusted.

New material streams

- Waste to raw material: Develop methods to utilise waste materials from own processes or across business sectors to enhance effectiveness and the recovery of metals, e.g. the use of organic-containing waste materials as reductants or fuels in the extraction of metals.

Education

- Strengthen Swedish education of engineers and PhDs within all areas related to metallurgy and recycling.
- Carry out project assignments and thesis work in collaboration between universities and the companies connected to the research agenda.
- Introduce the knowledge gained within the research into the study materials at universities.

Knowledge dissemination

- Dissipate knowledge to increase the understanding of both benefits and limitations for recycling to plant people, designers, researchers and society.
- Dissipate knowledge about the need for metals, how they are produced and what the alternatives are.
- Exchange personnel between academy and industry.
- Collaborate and exchange with universities, research organisations and industries in other parts of the world.

4.5.4 Expected impact

Research within the given areas has the potential to have a large impact on a more efficient extraction of metals from ore concentrates, scrap, residues and waste, and result in increasingly environmentally safe use of generated residue materials.

Technical

- Optimised use of upgrading, pre-treatment and smelting operations.
- Advise for design of products to enhance recycling possibilities.
- Increased efficiency in process routes.
- New processing routes for complex ore and scrap materials.
- Adaption of slag properties with respect to new and existing uses for the slag products.

Economical

- Improved competitiveness of the industry through more efficient use of existing process streams.
- Known and new mineralisations are turned into ores.
- New, so far unused process streams are becoming economically viable.
- A market for by-products and slag.

Environmental

- Lower amount of materials deposited.
- Decreased dependency on raw material availability.
- More environmentally friendly residue streams.
- Decreased energy consumption.

Social

- Increased employment opportunities.
- Higher awareness of sustainability issues connected to metallurgy and recycling among plant people, designers, recycling industry and society as a whole.

Table 4-3 summarises the actions needed to reach the goals set up within agenda area *Recycling and metallurgy* in the time frames of short-term needs, medium-term needs and long-term needs.

Table 4-3. Summary of the actions needed to reach the goals set up within *Recycling and Metallurgy* in the time frames of short-term needs, medium-term needs and long-term needs.

Area	Action	Time frame
Technology	Adapting processing of iron-ore into pellets for increased product quality, and simultaneous optimised gas and energy utilisation for minimised emissions, based on fundamental knowledge coupled to the processing and implemented in process models.	Short- to medium-term
	New improved methods for recovery of energy from low heat value sources .	Medium-term
	Develop new innovative methods to extract phosphorus and vanadium from residues generated in the steel industry.	Medium- to long-term
	Develop the technology needed to extract more elements (e.g. Sb, Ni, Sn) from material streams already processed.	Medium- to long-term
	Develop and adopt new methods for online measurements.	Medium- to long-term
	Develop knowledge and technology to increase the yield in existing processes.	Long-term
	Develop knowledge and technology to use slag products in new applications.	Short- to medium-term
Enhanced quality of material streams	Develop methods to enhance the metal content in by-product streams.	Medium-term
	Optimise the existing process chains for simultaneous extraction of metals from ore concentrates and scrap.	Medium-term
	Introduce new methods to more efficiently control the processes and quality of material streams through new measurement techniques.	Long-term
	Develop the knowledge necessary to secure the product quality of the slag produced at the same time as processing consequences of varying slag composition can be controlled or purposely adjusted.	Short-term
	Dissipate knowledge about recycling possibilities and limitations.	Short- to medium-term
New material streams:	Waste to raw material. Develop methods to utilise waste materials from own processes or across business sectors to enhance effectiveness and recovery of metals, e.g. the use of organic-containing waste materials as reductants.	Short-term

4.6 RECLAMATION AND ENVIRONMENTAL PERFORMANCE

4.6.1 Vision

The vision is that the environmental footprint of mining is sustainable and accepted by the society. There are no harmful emissions, and a large part of the mine waste is used as a resource. Added values at closed mines include preserved biodiversity and improved possibilities for cultural heritage and other activities such as reindeer herding, tourism and out-door recreation. Visions and key performance indicators are presented in Figure 4-10.

Medium- to short-term

- A sound understanding of which new prevention methods are promising and worth scaling up to full-scale applications.
- New and innovative prevention methods have been tested in the field in full-scale applications offering good demonstration possibilities. Research results allow predictions to be made of long-term performance of the different methods.
- Sustainable emissions to recipient waters and air, both during production and after mine closure.

Figure 4-10. Vision 2030 and Key Performance Indicators for Reclamation and Environmental Performance.



Long-term

- The environmental footprint of mining, such as emissions to water and air, is sustainable.
- Energy consumption and CO₂ emissions have decreased by over 30%.
- Mine waste, including the Fe sulphides, is to a large extent used as a resource.
- Remediated industrial areas and waste deposits can be left without continued maintenance.
- Plans and possibilities for post closure added values, such as greater biodiversity and increased possibilities for outdoor life and recreation, are common at abandoned mine sites.
- The metal extractive and production industries operate together with other businesses for sustainable development.

4.6.2 State of the art

There has been a tremendous development in reducing the environmental footprint of mining during recent decades, but mining operations may still have detrimental effects on soil, water and biota. Mining operations generally require large

areas of land, and associated conflicts arise that are primarily related to competing land use. The mining industry is also a major energy consumer, and a substantial amount of fossil fuel is used. Leakage of the nutrient nitrogen from undetonated explosives and from cyanide leaching for gold extraction is common. Emissions of NO_x, SO_x, Cl and F to air also occur from transports. Dust and noise problems are common at mine sites. However, these effects only occur as long as a mine is active. The major potential long-term environmental effect of mining is the formation of acid rock drainage (ARD) in sulphide-bearing mine waste, mine voids and open pits, which may go on for hundreds of years. This is common in base metal and gold mining but does not usually occur in iron oxide mining.

Iron oxide ores have a high metal content, but volcanogenic base metal deposits contain only a few percent of the valuable metals. Thus more than 90% of the ore will be regarded as waste after processing. Porphyry copper ores often have an average copper concentration of less than 1%. Gold is mined in deposits with a grade as low as a few grams per tonne. Most of the excavated ore material will thus be treated as waste. The global production of mine waste is estimated at more than 20,000–25,000 million tonnes of solid waste per year.

Acid rock drainage (ARD) may form in waste deposits and on pit walls containing Fe-sulphides such as pyrite and pyrrhotite when exposed to oxygen. This ARD is often rich in sulphate, heavy metals and metalloids. Conventional mining generates two main types of waste, both of which may contain sulphide minerals: waste rock (dominated by coarse material) that is removed to reach the ore, and finely ground tailings that are generated during ore processing. Waste from Cu, Zn, Pb and Au mining usually contains Fe-sulphides, in contrast to waste from Fe-oxide mining.

The primary approach to the prevention and mitigation of ARD is to minimise the supply of the primary reactants for sulphide oxidation or to maximise the amount and availability of acid-neutralising reactants. These methods involve minimising the oxygen supply through decreasing oxygen diffusion or advection/convection, minimising water infiltration and leaching (water acts as both a reactant and a transport mechanism), minimising, removing or isolating sulphide minerals and maximising the availability of acid-neutralising minerals and pore-water alkalinity. Most remediation methods aim at reducing the amount of oxygen reaching the sulphides in the waste, thereby preventing the formation of acid mine drainage. The most common remediation solution is different types of coverings for the waste, often some sort of soil cover (dry cover) or water cover. Soil coverings usually contain a sealing layer with low hydraulic conductivity, which results in a high degree of water saturation, and above that a protective layer which protects against root penetration, frost effects and drought. Sealing layers are usually constructed by using a natural soil, in Sweden generally clayey till. The function of such conventional soil covers is reasonably well understood, but there is an urgent need for research into the use of alternative materials such

as industrial and municipal waste for mine waste remediation. This would solve two waste problems at the same time, and soil and till quarrying would decrease. The function of the alternative materials must be studied in detail before they can be used on an industrial scale.

Future research plans should involve studies of the use of incineration ashes, waste from wood and paper industries, waste from other industries, sewage sludge, and combinations of these materials, for the construction of sealing layers and other applications in mine waste remediation.

Another potential prevention option that requires further research is to inhibit the sulphide oxidation by stimulating the formation of coatings on the reactive mineral surfaces, thereby decreasing oxygen availability. It could also be possible to remove the source, i.e. iron sulphides, from the mining waste with the aim of reducing the total amount of ARD-producing waste and remediation efforts needed.

Paste is a technique for the disposal of tailings, and is defined as dewatered tailings with non-segregating nature. It is often used for backfilling but when used for surface disposal it has potential environmental benefits such as reduced land use, increased water reuse, reduced dust formation and reduced inundation risks. Paste surface disposal may result in more efficient water management but there is a risk for increased elemental concentrations in re-circulated process water. Paste or cemented paste instead of conventional slurry disposal may decrease oxidation rate and acidity and concentrations of heavy metals in leachate waters. Paste disposal and co-deposal of waste rock and tailings improves the opportunities to form the shape of the landscape, which may give post-closure added values.

Methods that ensure safe disposal over very long periods of time are particularly important. Neutralising ARD by liming is common practice, but this is a short-term solution that results in increased amounts of waste, although of another type.

4.6.3 Research and innovation needs, and strategies and actions

Research focusing on preventing the formation of acid rock drainage (ARD) in mine waste has a high priority, but research on mitigating immediate short-term problems such as dust, the release of nitrogen and metals to recipient waters during production, and emissions of NO_x, SO_x, Cl and F to air is also important. There is a need of research on resource efficient water management at mine sites. Fundamental research on surface reactions on Fe sulphides in different physiochemical environments is needed, but otherwise most research is of an applied nature. Research on the short- to medium-term should focus on:

- Waste management.
 - Characterisation and management of desulphidised tailings – a new paradigm for waste management.

- Utilisation of mine waste as a resource, including the development of processes that can convert what traditionally is considered as waste into products.
- Paste disposal of mine tailings.
- Dust prevention.
- Drainage water treatment.
 - New technologies for the reduction of nitrogen, sulphur, metal and metalloids emissions into the environment and for the recovery of metals from drainage waters.
 - Innovative methods for monitoring, modelling, predicting and following up the effects of water use on emissions to recipient waters and process water composition.
 - Methods to assess and predict what is sustainable water quality.
- Treatment of emissions to air.
 - New technologies for reducing emissions of NO_x, SO_x, Cl and F to air.
- Mine closure and remediation.
 - Prevention of ARD by innovative remediation methods including an increased use of waste from other industries and the society.
 - Inhibition of sulphide oxidation.
 - Development of post-closure added values.
 - Methods for safe disposal of the waste formed when bioleaching is used.
- Energy efficiency.
 - Improved energy control systems. Utilisation of thermal heat.

4.6.4 Expected impact

Technical

More efficient methods for reducing the environmental impact of mining will be developed. Environmental issues are discussed and integrated at all stages along the value chain from exploration via mining and processing to waste management and reclamation at mine closure.

Economical

The costs for remediation and environmental control will decrease if efficient methods are developed. The need for maintenance and monitoring for a long time after mine closure will decrease, and thus also the costs. It will be faster and easier to acquire permits to start new mines and expand existing mines if the environmental impact of mining is sustainable and there is a social license to operate.

Environmental

An obvious result of this research is that the environmental impact of mining will decrease and that mining eventually will be sustainable.

Societal

The demand for metals and minerals in society will increase. Within the European Union, much larger quantities of metals are used than are mined. It is important to increase the level of mining in the EU in a sustainable way, without having a negative impact on the environment. This is necessary for a social license to mine. Otherwise, there will be a strong public opinion against mining. Improved environmental performance is a prerequisite for future mining within EU.

There are many possibilities for developing added values after mine closure. Remediated waste rock deposits and tailings impoundments may be utilised for outdoor life and recreation. Abandoned mine sites may be important tourist attractions. Careful planning during reclamation may result in increased biodiversity at old mine sites.

4.6.5 Development of the research agenda

Compared to the research agenda for the first STRIM period, the section *Reclamation and Environmental Performance* has been developed and broadened. Research on the prevention of formation of ARD, the most serious environmental challenge for the mining industry, still has a high priority but methods for treatment of emissions to water and air are now more clearly included in the research agenda. Innovative methods for monitoring, modelling, predicting and following up the effects of water use on emissions to recipient waters and process water composition are also a part of the agenda. Developing the utilisation of mine waste and mine waters is also stressed.

4.7 ATTRACTIVE WORKPLACES

4.7.1 Vision

The long-term vision (beyond 2030) is the zero entry mine where all machines are self-regulated or remote-controlled from remote operations control centres (ROCs) above ground (Fig. 4-11). The new ROCs are designed to promote co-operation and creative problem solving in multi-skilled teams of men and women. Diversity has replaced conformity and this is a good base for creating “production scouts” – miners that are always ready and interested in improving the mining processes.

In a shorter perspective, there are still many workers underground. There are new methods for iterative mine planning that take work environment and safety into account and reduce common initial design errors when mines are planned. Production is organised by the new concept Lean mining, which is based on a more holistic approach on production teams and broad professional skills among management and miners. Mining work has been transformed into being attractive to both men and women, not only because of the wages, but also because it is a very interesting occupation that offers good potential for personal and professional development in a safe and sound working environment (Fig. 4-11).

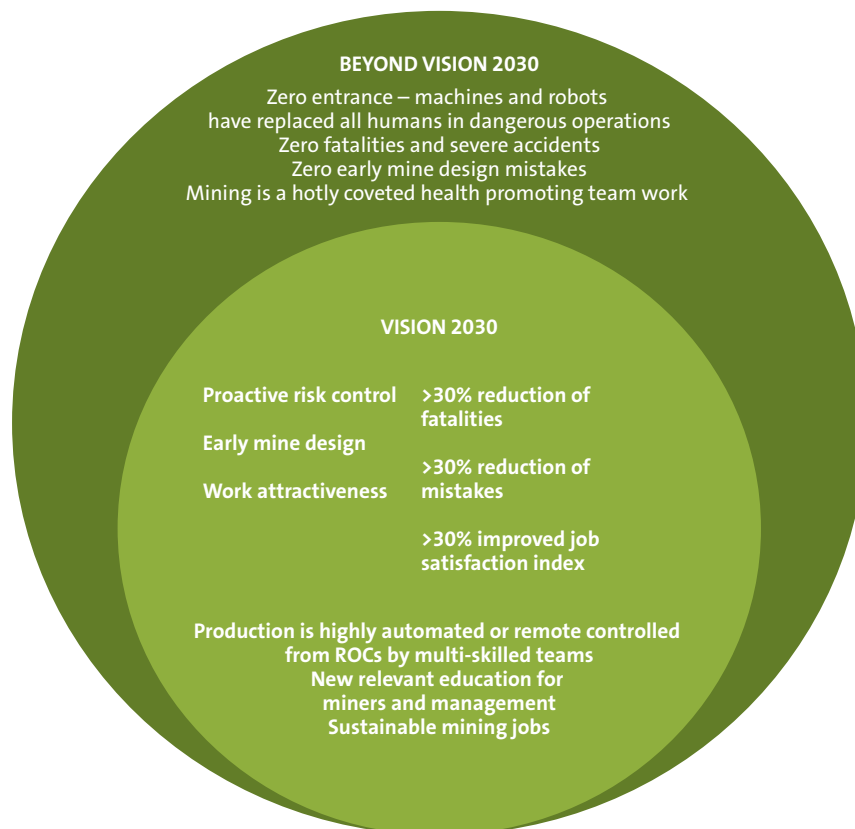


Figure 4-11. Vision 2030 and Key Performance Indicators for Attractive Workplaces.

4.7.2 State of the art

Many problems associated with the work environment in existing mines can be traced to insufficient initial physical planning and design. Since mining is characterised by huge investments and long-term operations, it is very important to have a well-designed physical production system. If initial mistakes are made, the personnel will have to live with the negative consequences for many years to come. The initial design phases of every major development project are therefore critical for establishing a safe and attractive work environment in a mine. There is a need to further develop a general iterative industrial planning and design method with available and relevant work environment tools, and to apply them in a mining context.

Health and safety are very high on the agenda, and are also strong driving forces behind the ideas of automation. The number of accidents and injuries is still too high, especially among contractors. Safety issues are an important research field for the whole sector, but are most obvious with respect to underground work and different levels of automation and remote control. It is also important to develop new methods for monitoring and control of the work environment, which comprises noise, dust, poor illumination, fire, explosive and toxic fumes and gases etc. in order to avoid disease, injuries and fatalities. By using advanced sampling strategies (based on statistics and science) with portable, more accurate and reliable measuring devices, better control can be achieved and more efficient countermeasures can be taken. There is also a need for better safety routines and a more proactive way of handling production and safety risks. When an accident or a fire occurs, there must be clear action plans and well-rehearsed procedures for fire and rescue operations. In order to create a safe working environment, with respect to fire, both for miners and first responders, plans and procedures need to be supported by sufficient technology. Initial fires need to be detected early and faults that could cause fire should be detected at routine maintenance and improved safety inspections.

But an attractive workplace is so much more than health and safety. There is also a need for an improved learning work organisation based on autonomous production groups with a good balance between demands and self-control (for groups and individuals). It is necessary to understand mining production in a holistic perspective in order to create efficiency flexibility in the production system. A sound base for such an organisation is probably Lean production but developing it is a real challenge. On the one hand, certain basic conditions are good – we can see that the mining industry has a long-term philosophy and a stable customer demand that matches the quality of products. On the other hand, we have the problem of establishing a stable, predictable continuous production flow.. The future research question is: how does one formulate a roadmap for Lean mining based on Lean-oriented basic principles but adapted to the conditions that the mining industry offer. A question that will require special attention is the use

and integration of contractors in the work organisation, and health and safety management systems.

A key component in future mining is to develop the concept of remote operations control centres (so called ROCs) where operators receive online processed information on the rock, from personnel as well as from the machinery and equipment that enable the checking and fine-tuning of the complete operation (process control and product control). This will make it possible for the personnel to actively steer and control the production instead of just passively reacting to deviations and alarms from an automated production process.

A key issue for the entire industry is the ability to recruit and keep skilled staff. Modern production is technically so advanced that the proportion of unskilled labour will decrease significantly or disappear. There will be fewer workers with higher individual wage costs. A general change to which it is important to adapt is globalisation. The major companies are global and act on a global market. Projects compete globally, and staff must be able to move and operate in several countries. Other requirements to be considered are the new technologies, automation, remote control, new machinery and especially new ways of organising and conducting business. To cope with the future labour supply, we need to increase the attractiveness of working in the sector and create career paths.

We also need to identify future skill requirements and shape future education programmes for management and workers, develop a strategy for recruiting more women, develop a mentor system so that professional knowledge is transferred between generations and to develop virtual reality for training and simulation, in particular for operations conducted in hazardous environments. Relevant competence development is a prerequisite for successful development along the whole value chain.

4.7.3 Research and innovation needs, and strategies and actions

Research on attractive workplaces includes the relationship human–technology–organisation, and specifically studies of how to create sustainable and attractive work places. Research should furthermore develop an innovative, efficient and competitive mining culture based on Lean mining by focusing on work environment, and health and safety issues.

Medium- to short-term

- Develop new methods for monitoring and controlling the work environment.
- Formulate a roadmap for Lean mining.
- Develop guidelines for attractive work places in deep mining.
- Develop a holistic framework for automation.
- Review the health and safety impact of automation.
- Review health and safety conditions for contractors in the mining business.
- Develop sufficient technology for fire and rescue operations.

Long-term

- Develop a holistic concept for the zero entry mine including those working in remote operations control centres.
- Develop efficient tools for proactive fatal risk control.
- Develop new tactics and methods for remote-controlled fire and rescue operations.
- Develop new education programmes for management and workers.
- Develop efficient programmes for development of attractive societies.

4.7.4 Expected impact

Technical

- Improved health and safety conditions in mining.
- A significant reduction in the number of severe and fatal accidents.
- A significant reduction in the number of occupational diseases.

Economical

- Reduced cost for a high turnover of miners and staff.
- Greater efficiency at work.
- Reduction of different types of waste.
- Less stand-stills due to fires.

4.8 GENDER AND DIVERSITY IN MINING

The agenda area *Gender and Diversity in Mining* is based on gender and organisational research, to meet the future challenges of capacity building as well as productivity, for an internationally competitive and socially sustainable mining industry. The agenda also establishes critical, integrated and applied gender research in the Swedish mining industry as a field of excellence (Fig 4-12).

4.8.1 Vision

In 2030, Swedish mining is well known for being world-class at breaking ore and gender patterns, creating and sustaining gender equal organisations and workplace cultures based on diversity for efficiency, productivity and innovation as well as prosperous regions and attractive mine communities in collaboration with local players in society. In 2030 the Swedish mining sector is:

- World leading in mining and gender equality.
- Competing with attractive, gender equal and culturally diverse workplaces for efficiency, productivity and innovation.
- Generating prosperous mine regions and socially sustainable development in communities characterised by openness and tolerance for all women and men.

The long-term goal for the Swedish mining industry is to be world leading in efficient and innovative gender equal mining. The short-term goal (2017–2020) is to

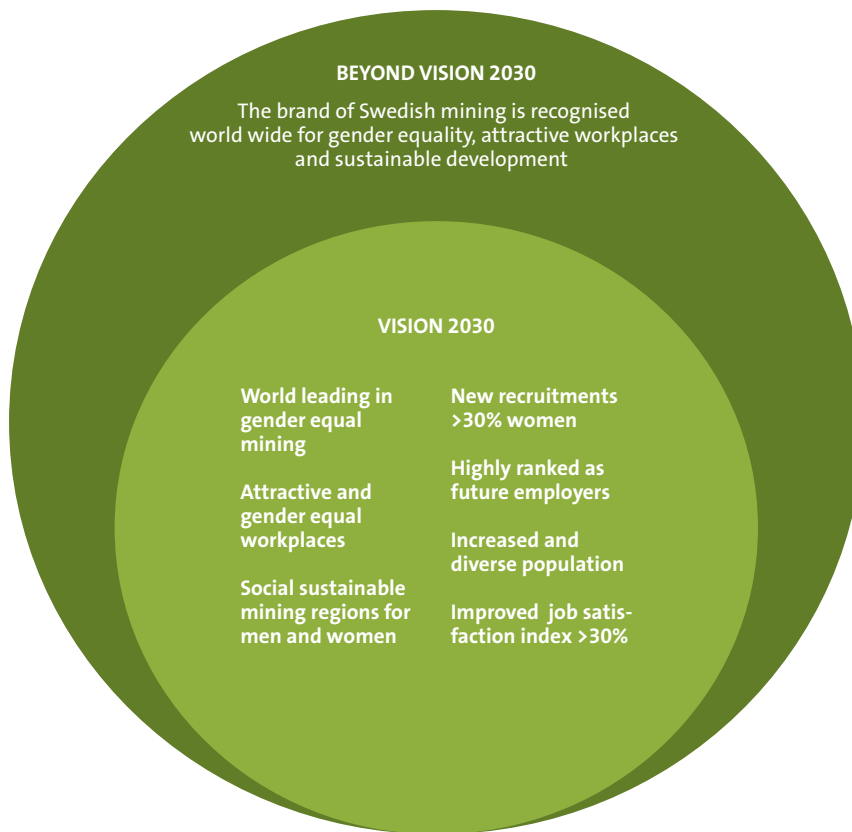


Figure 4-12. Vision 2030 and Key Performance Indicators for Gender and Diversity in Mining.

institute new knowledge and research on gender, diversity and gender equality in the mining sector that will facilitate the long-term vision and goals. It involves theoretical deepening, need-driven development of methodologies and evaluation of best practices. An interactive structure for knowledge exchange and collaboration for all players of the mining sector is necessary for successful implementation.

4.8.2 State of the art

Global competitiveness, new technology, and the implementation of lean and safe mine production place the mining industry in need for skilled personnel and expertise. A challenge for the future is to engage new target groups, especially young people and women, to education and jobs in the male dominated sector. For future capacity building, diversity and gender equality initiatives are an underestimated potential for additional global competitiveness, also in achieving a mining sector that is viable and sustainable for Sweden. Social sustainable development is about building technology, communities, organisations and clusters where humans are at the centre of development and innovation – where no groups are disadvantaged by formal and informal structures. Diversity and gender issues

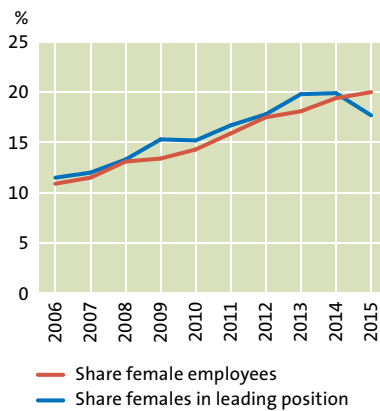


Figure 4-13. The development of the gender mix of employees in LKAB during the last decade shows a steady increase in female employees.

often focus on under-representation and whether minority groups or those considered “non-traditional” are included, respected and valued. Equally important is to understand the structures and existing norms within the majority, and how the meaning of being “different” is constructed and interpreted. From this point of view, a critical gender perspective on Swedish mining is central. Today the overall gender pattern of the mining sector is characterised, more or less, by male stereotypes – in all parts of the business clusters, in society and mining communities as well as in education, research and innovation.

4.8.2.1 Industry and companies

The mining industry stresses the importance of diversity and gender equality. Companies are proud to say that at some divisions or specific work teams there are now a mix of people, for example numerous nationalities and gender balance. The companies’ diversity policy typically addresses prevention of discrimination based on gender, ethnicity, religion, sexual orientation and age etc., but also point at the gender imbalance as the most pressing issue and suggests strategies to recruit more women.

The mining industry is a typical and “classic” male dominated sector. For a long time, men constituted the main body of the employees, about 90–95%, but over the last 15 years the proportion of women has increased. Within the mining sector the percentage of women in white collar is 26% and in blue collar 15% (SGU, 2014). This development mainly reflects recent strategic recruitment of women. Since then, two expanding companies went bankrupt and therefore it is expected that the proportion of women will decrease accordingly. Moreover, there are many small companies in the mining sector, suppliers, contractors and entrepreneurs, where most of the employees are men. Here we find construction contractors, equipment manufacturers and transport companies, which also are traditionally male sectors of working life. External and temporary staff is also more common at mining sites. This group is often invisible in a company’s gender statistics, yet nearly all are men. In trade unions, women are more common than before but men are still in high positions as leaders and chairmen. The mining trade unions have a central place in the Swedish labour movement, but at the same time a history of inequality and focus on men and masculinities. To sum up, there is still an obvious numerical gender imbalance within mining companies, and the male stability is a pattern for the industry in total.

Men and masculinity is also a common theme in traditions and norms of mining work. Although the industry has developed in many ways, old beliefs about a close relationship between mining and masculinity are still evident. Corporate cultures as well as workplace cultures highlight men and masculinity. There is also an idealisation of a certain type of masculinity embedded in the old manual, heavy and dangerous mining work and “macho-masculinity”. Research shows that this stagnation can create problems for companies as well as individuals in terms of

work practices and efficiency, learning and development, e.g. informal opposition to new technologies and safety procedures. In addition, in gender unequal male work contexts, a resistant attitude and “feminisation” of new technologies as automation, computerisation and robotisation and also a direct resistance to women and gender equality are often seen. Taken together this implies problems with organisational development and recruitment. This is one reason why mining companies of today are interested in more knowledge about gender issues – or more precise: knowledge on *how* to break gender patterns.

4.8.2.2 Society and mining communities

Breaking gender patterns is also important in communities around the Swedish mining industries. In Kiruna, Gällivare and other mining communities the situation is paradoxical. In regressive times for the industry, these rural areas suffer from emigration, stagnation and cuts in the public sector. In progressive times the shortage of public service, housing, factory buildings and labour is a problem and the mining companies have difficulties to recruit locally. It is a complex demographic challenge to get people, especially young women, who are willing to live and work in these communities. A contributing factor may be that mining communities, more than others, have a history, culture and working life which, somewhat simplified, can be described as traditional, unequal, gender segregated and male-centred. A gender-divided economy with a low degree of variation is vulnerable in many ways, especially a labour market that centers on mining which so clearly reflects the ups and downs in the global market. If women continue to move out to the same extent as today, some communities may be reduced to mining areas with “fly-in/fly-out-personnel”. The mining communities want to avoid a service sector of low paid women that serve a mining-population of well-paid weekly commuting men. There is a risk that the future holds “more of the same” and the same social problems. A key challenge is to break up the gendered structure of the industry and in the local labour market, as well as to integrate flexibility to change.

4.8.2.3 Research and education

Luleå University of Technology is leading in mining research in Sweden and *Future mining* is a prioritised strategic research and innovation area. However, LTU has for many years struggled with recruitment problems to mining programmes and courses. Both men and women choose other lines of academic education, despite the expected good labour market in the mining sector and LTU’s excellence in mining research in close collaboration with the industry.

As a male dominated university, LTU works to increase the proportion of women with initiatives at all levels, both among students, researchers and teachers. One problem is the horizontal segregation of gender where too few women hold a professorship. In technical faculty, where most of the mining research

is, only about 15% of the professors are women. In addition to this, we also see a horizontal segregation within technological research. Interdisciplinary technical areas (e.g. human work science), prevails a reasonable gender balance, while more “hard tech” areas, such as most mining research, is dominated by men. There are many different reasons why men and women are segregated into different programmes and research areas at LTU as well as the low proportion of women professors. One explanation is the stereotypical symbolic link between technology and masculinity. LTU’s geographical location and its technical and applied profile serve as another. Research shows that gender has significance for doctoral students’ and teacher’s careers. It seems easier for men to get time and money to research and get access to sponsors, networks and innovation. Further explanation may be found in the values of what is considered important for society and industry. Like most of LTU’s prioritised strategic research and innovation areas (as well as many national and regional innovation systems and clusters), LTU’s large mining projects and programmes CAMM, STRIM, NordMin, EIT Raw Materials and similar are male dominated and built on cooperation with players in the industry and mine communities, that also are male dominated.

4.8.3 Research and innovation needs, and strategies and actions

The industry faces challenges not only regarding breaking ore but also breaking gender patterns. The Swedish mining industry has for a long time been centered on men and associated with male-dominated activities. If nothing is done also future innovation, research and development are most likely to be tapered similarly. In order to secure safe, lean and innovative mining and attractive workplaces, there is a need for more research and solid understanding of what the gender structures looks like, how gender inequality operates, at what costs and, most importantly, how problematic gender positions and patterns can be challenged and changed – and how diversity and gender equality can be constructed. Along the line of research areas these actions are suggested:

- Form visions, policies and financing that enable research that can contribute to a more gender equal, diverse and socially sustainable development of the mining industry.
- Develop systematic gender divided statistics in industry, clusters, education and academia etc.
- Evaluate the mining companies’ diversity and gender equality related activities to support best practice.
- Develop versatile and gender aware strategic recruitment, promotion and retention practices in the mining industry.
- Encourage collaboration between industry and society for attractive, diverse and gender equal mining communities that are also flexible to change.

The research should, together with theories on diversity, gender, work and organisation, draw on theories like “undoing gender” and “degendering” and “gender toning down”. One main area of research should be to explore the relationship between the global mining industry, work organisations (mining companies, entrepreneur companies), mining labour unions, other actors, surrounding local communities and the regional context when it comes to gender, diversity and gender equality. Of special interest is also to address the flexibility and resilience to changes that must come with an industry that fluctuates due to changes in the global market. Another main area is to find ways to challenge existing attitudes and culture, including social constructions of gender (e.g. working class masculinity) and gender patterns in the mining sector – and how to use gender equality as a tool for competitiveness. It is important that this research is done in close collaboration with the mining companies as well as with other actors. Another area of research is interactive design of the gender equal mining workplaces of the future using, for example, “design teams” comprising both male and female mining professionals. Some suggested themes for research are:

- Gender patterns and diversity in the innovation system of mining.
- Key roles of middle management and workplace cultures for a gender equal mining industry,
- Gender patterns among mining entrepreneur companies.

The actions and tentative areas above are a result of interactive collaboration between researchers at LTU and actors from LKAB and Boliden AB as well as the County Administrative Board of Norrbotten, the township of Kiruna etc.

4.8.4 Expected impact

Research and actions within the described areas has potential for a large impact on the Swedish mining industry’s global competitiveness and for a vital and socially sustainable mining work sector in Sweden. The research will also contribute to a general and deeper understanding of problematic structures, as gender patterns, in working life and how to change these.

Technical

- Improved implementation of new technology.
- Improved implementation of lean and safe production.
- Creativity and innovativeness in organisational and technological development.

Economical

- Improved competitiveness through diverse capacity building.
- Flexibility to change and development within the industry.
- Flexibility to societal progression, locally and globally.

- Reduced vulnerability due to a gender-segregated economy and labour market.
- Sustainable economic growth in rural regions in Sweden.

Social

- Improved competence recruitment – thanks to possibilities to attract all sorts of skilled people to the industry, both men and women.
- Safe, healthy and attractive mining workplaces based on modern leadership.
- Enable more women to stay in mining regions.
- Additional employment opportunities for men and women.
- Prevent fly-in-fly-out societies.
- Attractive, sustainable and creative mining communities for men and women.
- Entrepreneurial cultures in the mining communities.

4.9 SOCIAL LICENSE TO OPERATE

The contribution of the mining and metal producing industries to sustainable development has become an increasingly debated issue over the last decades. Sustainable development is a complex concept, and concerns not only how the mineral resources are managed, the mining rents re-invested or how negative environmental impacts are mitigated. It also has broad environmental, economic and social dimensions, and the mining industry needs to consider the wider impacts of its operations on the local and regional communities. These include, for instance, local employment and income generation, distributional effects, land use conflicts, indigenous rights, migration patterns, demographics, cultural heritage, etc. The agenda area *Social license to operate* comprises research and innovation on the nature and the significance of the mining industry's community-wide footprints as well as on the different company strategies and policy instruments that can be implemented to address the associated challenges.

4.9.1 Vision

The long-term vision is that the activities of the mining and metal producing industry, including its economic, social and environmental footprints, are perceived as acceptable and legitimate by key stakeholders as well as the general public. In 2030 the Swedish mining and metal producing industry is a role model for other countries that aim at enhancing the industry's contributions to important social, economic and environmental goals at the local, regional and national levels. The mineral products emanating from Swedish mines and metal smelters have a CSR-label (corporate social responsibility label), thus further contributing to the competitive strength of these companies.

Short- to medium-term

- Strong social science and humanities research environments on mining and sustainable development have been established, and they contribute signifi-

cantly to our understanding of the mining industry's community footprints, its political and institutional context, and the identification of policy instruments and management tools promoting best-practice.

- Sustainability indicators for the Swedish mining have been developed and operationalised, and these indicators can be tested, evaluated and baseline values established. These indicators address community values in addition to mitigation of negative impacts.
- Various impact assessment tools and deliberative approaches that can support different decision-making processes (e.g. the permitting of new mines, the introduction of new environmental regulations) have been developed and documented, and can be tested and evaluated.

Long-term

- Expedient stakeholder management tools have been fully integrated in all mining and metal producing companies operating in Sweden, and are perceived as legitimate.
- The sustainability indicators are fully accepted by key stakeholders and the general public, and are used by all mining companies operating in Sweden.
- Government decision-making at the local, regional and national levels concerning the adoption or implementation of different regulations, policies and guidelines is based on the use of comprehensive impact assessment tools. These impacts include community-wide footprints relating to regional development and employment, indigenous rights, diversity and cultural objectives, air and water pollution as well as any impacts on the competitiveness of the industry.

The vision will be achieved through: (a) an in-depth knowledge build-up concerning the social and economic footprints of the Swedish mining and metal industry, and (b) systematic evaluations and a scrutiny of different company strategies and public policies that could be adopted to increase the industry's contribution to all three dimensions of sustainable development.

4.9.2 State of the art

The global mining and metal-producing industries have undergone significant changes during recent decades. These changes indicate that the industry has had to devote increased attention to its wider impacts on local and regional communities. The mining ventures during the mid-1900s were less capital intensive than they are today, and the capital needs could typically be satisfied within the affected region. This significant local involvement was supported by high transport costs as well as by the relative simplicity of the required inputs. Moreover, the strong regional linkages gave primacy to the mining sector's contribution to the national income and export earnings, and any tax and royalty payments typically accrued to the national government rather than to the regional or local

governments. Although large mining investments were viewed as initial boosts to economic development, much less attention was devoted to what would happen after the initial investment. Consultations with affected citizens at the local level, including the recognition of indigenous rights, were also limited, and the social and environmental impacts of mining were largely neglected.

An important factor altering the industry's relationship with the economy has been technological change. A combination of scale economies and increased capital intensity has profoundly increased the capital requirements of a typical mining venture. This implies, in turn, that the magnitude of the regional-economic impact exerted by modern mining and metal-producing industries could be modest. Some regions may not have comparative advantages in either upstream or downstream activities. One reason is that the input into modern mining has to satisfy high standards in terms of know-how, and this cannot always be supplied by local firms.

Over time these structural changes have led to an increased demand from different stakeholders regarding a more inclusive mining development. The increased emphasis on the distributional and regional or local effects of mining ventures during the last decade is also very much attributed to: (a) an increased concern over the environmental effects of large-scale mining, which are generally most clearly felt at the local level; (b) a stronger pressure on the industry to make social contributions (e.g. culture, education) to adjacent communities; (c) a growing assertion of the rights of indigenous people and demands for more direct participation in decision-making processes; and (d) improved communication channels, which facilitate the sharing of experience between communities. The importance of these issues has been addressed in recent empirical research, often as case studies of single mining operations and communities, and this highlights the typically very context-specific impacts.

There is therefore a growing recognition that good business performance and good environmental and social performance need to go hand in hand. Ignoring the community-wide impacts of mining may increase the business risks for mining companies, and these risks could come in many forms. For instance, reliability in supply is a key for industrial competitiveness, and customers will generally not be forgiving in the presence of supply disruptions following tense community relations. In addition, customers, fund managers, banks and prospective employees do not only care about the industry's output, but increasingly also about how the products have been produced and how companies live up to social goals. For these reasons several companies and governments in mineral-rich countries embrace the need for mineral ventures to gain a "social license" to operate, i.e. a broad approval and acceptance of society towards these ventures that goes beyond the requirements of formal licenses.

In response to this challenge, a number of management tools, e.g. CSR, sustainable management systems, have been developed and adopted by mining companies. These are also endorsed by key organisations such as the International

Council on Mining & Metals (ICMM), which encourages partnerships with governments and non-governmental organisations.

While specific sustainability challenges are likely to differ between countries worldwide, not least between developed and developing countries, the above concerns are still relevant for the Swedish mining and metal producing industries. Swedish industry, including the mining sector, is often considered to be proactive in its adoption of CSR-related initiatives, especially in the areas of environmental and occupational health and safety and energy. This often manifests itself as a widespread corporate adoption of various international standards. Still, existing research indicates that there is room for a closer integration of all aspects of CSR into one comprehensive sustainable management system, which builds on a stakeholder-driven and value-based approach. It is also important to note that the Swedish mining and metal producing industry has grown more diverse over the last two decades, i.e. involving an increased number of international exploration and mining companies (with Swedish subsidiaries). The CSR and stakeholder management practices often differ substantially among these.

The mining investments taking place since 2005 have raised concerns about the long-run regional-economic impacts of the operations, not the least about how they may influence the local and regional labour markets in terms of skills, diversification, migration patterns etc. In Sweden, mining activities often take place in sparsely populated areas, which are characterised by a low population density, an ageing population and out-migration of young people. This makes the local labour markets very vulnerable to fluctuations in the demand for labour, i.e. labour shortages (or commuting) during boom periods and high unemployment during periods of weaker market conditions.

Research shows that the existence of fly-in fly-out (or rather drive-in drive-out) practices from other northern Swedish municipalities have caused a weaker customer base for the local service sectors, recreational areas etc., as well as less scope for funding municipal investments. This creates a dilemma affecting both the community and the mining company; in order to attract residents to the municipality and employees during boom periods, housing investments are needed but these are difficult to pursue if the in-migration rate is not increased and thus not helping to increase the tax base. Housing shortage limits the recruitment base, and will tend to make communities unattractive to live in, not least for the more skilled and specialised workforce. Moreover, in mining communities these challenges are related to the economic importance of the mining operations as such as well as to patterns concerning gender equality and social cohesion. The above makes it difficult to separate the social sustainability challenges of a local community on the one hand and mining company workplace policies and practices on the other. An increased understanding of the prerequisites for local social sustainability, the attractiveness of mining communities, diversity of lifestyles, and social inclusion and cohesion is therefore needed.

All in all, although mining operations may support a large number of direct and indirect jobs elsewhere (i.e. regionally or nationally) these may not necessarily result in breaking any negative population trends for smaller municipalities. Existing impact assessment methods have often not been able to fully address all relevant impacts; they are static and often build on a number of simplified assumptions (e.g. concerning labour supply responses). At the same time, there are also examples where the mining operations at, for instance, LKAB and Boliden have formed a test bed for the development of various technical innovations (e.g. ICT-solutions for underground operations, mining equipment) which, in turn, can be exported to other countries and regions. Such dynamic impacts supporting smart specialisation are overall poorly understood.

The wider community impacts have also concerned land use issues, and potential conflicts and synergies with other uses and interests. These include, for instance, tourism business, environmental organisations and the territorial and resource rights of the Sami population. The Swedish legislation provides few explicit guidelines on how to weigh, for instance, different national interests against each other (e.g. mining versus reindeer husbandry). The Swedish mineral strategy recognises the significance of land use conflicts, although so far the main response has been to call for public deliberations and consultations (“samråd”). While this planning tool has been found to be important, calls for more intense participation processes with increased resources have been common. Some Sami villages have been involved in several consultations (e.g. mining, wind power, forestry) at the same time, potentially making it difficult to exert real influence on the decision-making process. Many argue that there currently also is a lack of reliance on comprehensive impact assessment tools, e.g. social cost–benefit analyses, which can support regulatory decision-making by evaluating the aggregate and distributional consequences of different land use options.

While it is essential for the Swedish mining and metal producing industries to continually improve its environmental performance, concerns have been raised about how existing regulations affect the long-run competitiveness of the industry. The critique has in part been related to the stringency of the regulations, i.e. permit requirements (e.g. nitrogen oxide emission standards) that are perceived to impose excessive costs following changes in the production process. Still, the critique more often points at a lack of timely and predictable decision-making processes. The environmental permitting process (following the Environmental Code) has been claimed to be unpredictable, subjective, too slow and in lack of coordination across different regulatory authorities. The Swedish regulations have, however, also been criticised for being too lax. This concerns primarily the regulation of mining reclamation and waste (e.g. following a report from the Swedish National Audit Office).

However, previous research indicates that the relationship between environmental compliance and competitiveness is complex, and highly dependent on the

specific design and implementation of the regulations. This concerns the flexibility granted to the industry in terms of selecting the appropriate compliance measures, including the time granted to adapt to the new requirements. Different regulatory approaches may also differ in the extent on which they rely on cooperation and consensus between the relevant regulatory authorities and the industry. The above makes it difficult to identify best-practice regulations. Still, gaining experience from other countries should be able to shed light on environmental regulations that can be designed and implemented to provide scope for combining tough environmental requirements with maintained long-run competitiveness.

4.9.3 Research and innovation needs, and strategies and actions

The research and innovation activities should in different ways assist in identifying and developing management practices and institutional preconditions (e.g. legal rules, policy instruments, codes of conduct) that will help increase the Swedish mining and metal producing industry's contribution to sustainable development and assist the industry in gaining a social license to operate. This requires increased understanding about: (a) the economic, social and environmental footprints of mining development and operation in the country, and how these footprints may change over time under various political and institutional contexts, and (b) the impacts, efficiency and legitimacy of firm-level strategies and government policies.

While the agenda area embraces the economic, social and environmental dimensions of sustainable development, it also addresses important trade-offs and synergies among these dimensions. The significance of trade-offs (e.g. stringent environmental regulations versus competitiveness) and synergies (e.g. different industrial sectors jointly benefitting from mining operations) may differ in the short-run compared to the long-run (e.g. due to technological progress). This also concerns how the responsibilities for sustainable development could be shared between the mining industry and different public authorities (and ultimately the government). The issue of self-regulation versus government regulation is a complex, not least in the light of the cyclical nature of the minerals and metals markets and the income streams generated over time.

The research and innovation activities should focus on four main areas (see below), each involving short- and medium- as well as long-term challenges. Each of the areas provides plenty of scope for a variety of scientific disciplines and a multidisciplinary research approach. In all cases, there is a need for baseline assessments, which can be used to develop sustainability indicators, set targets and identify strategies and follow-up on any progress made.

4.9.3.1 Stakeholder management and communication strategies

An important overall objective is to explore how the Swedish mining and metal industry can develop relationships and interact with its stakeholders in an

action-oriented manner, and in this way create value beyond company profits. Additional research is needed on how different sustainable management systems unfold in practice, as well as how they can be translated into specific CSR objectives and implemented in the day-to-day activities of companies. An important task is to address the management practices of various kinds of companies, i.e. both exploration and mining companies, and both incumbent companies such as LKAB and Boliden and any Swedish subsidiaries to foreign-owned companies.

Short- to medium-term

- Review and analyse the Swedish mining and metal industry's existing CSR, stakeholder management and sustainability accounting practices.
- Identify industry-wide sustainability criteria for the Swedish mining and metal industry, and operationalise and test these for practical use.
- Develop strategic tools and guidelines for improved stakeholder assessments and community development practices.

Long-term

- Integrate and implement sustainability criteria, accounting systems and indicators into operational management systems (i.e. objectives, programmes, operational control, monitoring and measurement, audits).
- Develop a framework – including sustainability accounting practices – that can make possible and justify a CSR label on all mineral products emanating from Swedish mines and metal smelters.

4.9.3.2 Regional development: labour markets, migration and benefit-sharing mechanisms

The regional-economic impacts of mining are far from straightforward to assess, and future research needs to provide a greater empirical understanding of the wider impacts of mining operations in terms of migration patterns, indirect job creation and innovation spillovers, labour market behavior and recruitment challenges and needs. Sweden, with its large amount of register data, has unique conditions for studying such linkages as well as to follow the development over time and with a high degree of geographical resolution. Such empirical assessments also need to recognise that the labour market impacts of the mining and metal producing industry are likely to change over time, both due to cyclical fluctuations and due to long-term developments such as technological change and increased automation. Novel empirical research is also needed on the existing relationships between social sustainability, social cohesion and mining company workplace and practices, and how the industry and the communities cooperate to address regional development goals.

A comprehensive and solid empirical understanding of the regional-economic footprints of the Swedish mining and metal producing industry permits the

identification and evaluation of different types of strategies that can be used to strengthen these impacts, i.e. so-called benefit-sharing mechanisms. In this respect, comparisons of different experiences gained and strategies used in other countries may provide useful information. Particular emphasis should be on how to manage changing market conditions and the resulting fluctuating demand for labour.

Short- to medium-term

- Review and investigate current and future needs of labour recruitment in the Swedish mining and metal producing industry.
- Review and evaluate existing methods and scientific tools used in Sweden as well as internationally to assess the regional-economic impacts of mining operations (i.e. in terms of employment, income, spillovers), including the role of different types of benefit-sharing mechanisms.
- Analyse in detail the labour mobility and population change in local and regional labour markets impacted by changes in the Swedish mining and metal producing industries, in order to gain increased knowledge about the inter-relationship between the mining ventures and overall community development.
- Review and analyse important developments in social sustainability factors of the Swedish mining communities.
- Analyse the relationship between social sustainability factors in mining communities (e.g. satisfaction with built environment, social inclusion, sense of safety and security, sense of community belonging), and existing policies and practices within the mining companies concerning recruitment and personnel.

Long-term

- Identify and evaluate strategies and management practices aiming at meeting future demands for recruitment of qualified labour to the mining and metal sectors.
- Develop and put into use new improved methodological approaches to assess the regional-economic impacts of mining operations, including impacts and trade-offs associated with different types of benefit-sharing mechanisms.
- Identify and evaluate strategies on how to promote cooperation between the mining and metal industry and the local communities and regions.
- Formulate strategies for inclusive community investments as well as strategies for policies and practices concerning inclusion and well being of the workforce enabling the operation of the mines.

4.9.3.3 Managing land use conflicts: rights, public deliberation and trade-offs

Since issues of sustainability often involve conflicts in values between goals that people may consider important, there are no simple answers to the question of

how to resolve the often diverging views of the pros and cons of mining ventures. Land use conflicts raise questions about the efficient use of scarce resources but they also concern ethical issues such as fairness and participation in the decision-making process, as well as legal rights and cultural values. For instance, mining development outcomes may be difficult to match with local aspirations, including indigenous rights and concerns. Any meaningful decision-making institution and process must therefore be able to incorporate different modes of articulating such concerns, and this calls for the use of a mix of methods to resolve land use conflicts relying on deliberative processes, the recognition of rights and the valuation of impacts (i.e. cost-benefit analysis).

Much of this discussion concerns the legal framework for territorial planning, i.e. the Planning and Building Act, the Environmental Code and the sometimes complex relationship with the country's Mineral Act. It is often unclear how the mineral interest interacts with other land-use interests, and how they are considered or valued in relation to each other as well as over time. This calls for research investigating how the existing legal practices have come into actual use in real-life cases. The research also needs to address how the general public, Sami villages and interest groups gain information and participate in the planning decision-making process, as well as how a widened and more direct participation could affect planning outcomes and mining operations. Such research needs to build on an in-depth understanding of the causes of existing or potential mining conflicts.

Short- to medium-term

- Review the Swedish territorial planning and mining concession processes in relation to various types of mineral exploration and mining operations, as well as how the views of different stakeholders, e.g. interest groups, local population, reindeer husbandry and industrial sectors, have been addressed and evaluated in the legal rulings.
- Review the current use of public consultations ("samråd") and environmental impact assessments (EIA) in the case of mining operations, and investigate how such consultations can be improved to gain a social license to operate (e.g. by drawing on international experience).
- International comparison of the strategies (e.g. property rights, compensation mechanisms) employed to permit indigenous rights and mining operations to co-exist, taking into account the different circumstances in different legislations with a view for a best practice solution for the Swedish situation.
- Develop and test a social cost-benefit approach in the case of mining investments.
- Identify causes and challenges in land-use conflicts with respect to current legislation. How can the tool for the current national interests of land use (min-

eral resources, Natura 2000, reindeer husbandry etc.) be employed for mineral resource extraction and a sustainable future?

Long-term

- Identify and evaluate different types of strategies and regulations that could potentially improve the legitimacy and the efficiency of land use decision-making with respect to mining concessions.
- Identify and evaluate various strategies and regulations, e.g. compensation mechanisms, to address the co-existence of different national interests in mining areas.
- Complete a handbook for conducting cost-benefit analysis for mining development to support, for instance, legal rulings.

4.9.3.4 Environmental regulation, compliance and competitiveness

Research is needed on how environmental regulations (e.g. pollution control standards, reclamation funds, ecological compensation requirements) can be designed and implemented to promote continuous reductions of any negative impacts while at the same time taking into account the long-run industrial competitiveness of the Swedish mining and metal industry. This research can involve methodological developments on how to evaluate the efficiency and the competitiveness impacts of different types of regulations and public policies, as well as empirical evaluations of different types of existing and potential regulatory instruments.

In part these research endeavors will benefit from systematic comparisons of different countries' (past and present) regulatory approaches with respect to mining investments and operations. In addition, the research needs to address both the stringency of the respective regulations, and the ways in which these are designed and implemented in practice in terms of, for instance, compliance periods and flexibility.

Short- to medium-term

- Review and evaluate decision-making processes that underly the existing permitting conditions with respect to air and water pollution (including mining waste).
- International comparison of how significant mining countries (e.g. Australia, Canada) regulate, and have regulated the environmental impacts of mines and metal smelters, with a focus on standards and reclamation funding.

Long-term

- Develop different potential regulatory approaches (i.e. focusing on design and implementation) that can be used to improve environmental performance

without compromising fundamentally with the industry's long-run competitiveness.

- Develop different ways of regulating the rehabilitation of mining areas to secure that the necessary costs can be covered.
- Analyse best-practice regulations from an efficiency point-of-view, and the development of cost-benefit tools to assist the permit decision-making process (i.e. setting standards, the size of reclamation requirements etc.).

4.9.4 Expected impact

Economical

- The regional economic impacts of mining investments will be better assessed and will therefore support a more knowledge-based decision making at different levels of society.
- The industry provides more synergies and less conflict with other business sectors, in turn leading to a greater acceptance for the industry in the local community.

Environmental

- The environmental regulations and the industry's management practices address land use conflicts and pollution concerns in a transparent and legitimate manner leading to a high standard of environmental commitment.
- Future changes in the stringency, design and implementation of the mineral law and environmental regulations are conducted based on a thorough understanding of how these affect both environmental and economic outcomes.

Social

- Improved social acceptance for mineral exploration and mining operations in the local communities and among the general public in Sweden.
- Conflicts related to indigenous rights, cultural heritage, diversity of lifestyles etc. are clearly understood and dealt with in processes that are deemed by all involved as legitimate and efficient gaining support from a variety of impact assessment tools.



Remote operator station BENCHREMOTE
for surface drill rig SmartROC D65 .
Photo: Atlas Copco.



Malmtåget mellan Kiruna och Narvik,
vid Björnfjell.
Photo: G. Rúnar Gundmundsson, LKAB.

5 Internationalisation

The Swedish mining and metal extraction cluster is world leading in many areas, and are global forerunners in innovation and lean processing in the sector. However, this industrial sector is one of the most globalised, and in a global context Sweden is still a small player even if Sweden is one of the largest metal extractive countries within the EU. It is therefore important that SIP STRIM is actively engaged in creating leverage of national initiatives in research, innovation and education within the fields described in this agenda. An internationalisation strategy is therefore described below based on what is regarded as important in terms of:

- Research and innovation actions.
- Educational collaboration.
- Strategic alliances.

The European union has had a focus on raw materials since the publication of the Raw Materials Agenda in 2008. Today, Horizon 2020 contains a number of open calls and related relevant issues for SIP STRIM and the future programme is anticipated to also contain several calls related to raw materials. In the European context, Sweden is a leader in raw materials and should therefore engage heavily in the Horizon 2020 actions related to raw materials. It is seen as important from the point of view of competitiveness and growth for the Swedish industry sector that this engagement, where Sip STRIM should act as a catalyst and facilitator, is done in a coherent and strategic way. This means that industry, academia, research institutes, authorities and NGOs preferably should synchronise efforts to try to influence what is written in programmes and other policy documents related to raw materials.

5.1 THE EUROPEAN INNOVATION PARTNERSHIP ON RAW MATERIALS

The European Innovation Partnership (EIP) on Raw Materials²⁶ is a stakeholder platform that brings together representatives from industry, public services, academia and NGOs. Its mission is to provide high-level guidance to the European Commission, member states and private actors on innovative approaches to the challenges related to raw materials. By bringing together actors from the entire research and innovation value chain they aim at streamlining efforts and accelerating market take-up of innovations that address key challenges for Europe.

The EIP targets non-energy, non-agricultural raw materials. Many of these are vital inputs for innovative technologies and offer environmentally friendly, clean-technology applications. They are also essential for the manufacture of the new and innovative products required by our modern society, such as batteries for electric cars, photovoltaic systems and devices for wind turbines. With about 30 million EU jobs depending on the availability of raw materials, the EIP will have a clear, positive impact on European industrial competitiveness.

The EIP's Strategic Implementation Plan (SIP)²⁷ sets out specific objectives and targets. Actions to achieve these include research and development, addressing policy framework conditions, disseminating best practices, gathering knowledge and fostering international cooperation.

SIP STRIM and Bergforsk should monitor and actively be involved in initiatives related to the strategic action EIP RM. This should be done through active engagement in the High Level Group and its associated Sherpa team. Furthermore, it is important that the stakeholders try to implement the actions described in this agenda also in EIP's Strategic Implementation Plan through active involvement in the different operational groups of the EIP RM. Commitments are described below in the section Research and innovation actions.

5.2 THE ARCTIC DIMENSION

Sweden recently (2011) adopted an Arctic strategy²⁸. The purpose of this is to present Sweden's relationship to the Arctic, together with current priorities and future outlook for Sweden's Arctic policy, proceeding from an international perspective. The strategy begins with a summary, followed by an introduction to Sweden as an Arctic country. It further specifies how, and through which international cooperation bodies and bilateral channels, the Government should seek to achieve its objectives for the Arctic. It states, for instance, that "Swedish

26 <https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/european-innovation-partnership-eip-raw-materials>

27 <https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/strategic-implementation-plan-sip-o>

28 <http://www.openaid.se/wp-content/uploads/2014/04/Swedens-Strategy-for-the-Arctic-Region.pdf>

businesses are conducting extensive operations in the Arctic. Ore and mineral extraction is currently high on the global economic agenda, which has led to significant levels of investment in the Swedish mining industry”. Given the current focus on the Arctic, not only from Swedish authorities but also from EU, the Arctic Council etc., it is relevant to form alliances to develop R&I initiatives as well as educational programmes to help the Arctic develop in a sustainable way within the mining and metal producing industrial sector. The SIP STRIM programme could play a pivotal role in promoting Swedish interests in this case.

5.3 GLOBAL ACTIONS

The mining and metal producing industry is a truly global business, and even if Sweden is a major European player we are small on the global market on the mining side, but large with leading OEMs on the supplier side. It is therefore important to focus collaboration not only within Europe but also to form strategic alliances and collaborations outside Europe. Nordic Rock Tech Centre (RTC) was started by mining industry and Bergforsk to develop B2B concepts on the international market. It is essential to continuously support the efforts to involve Swedish industry in international projects, and support of RTC in various ways is therefore part of the STRIM agenda.

Business Sweden is a Swedish governmental organisation whose purpose is to help Swedish companies reach their full international potential. Since some years back, they have had the mining sector as one of their focus areas. It is therefore highly relevant with a collaboration between Business Sweden, Bergforsk, SveMin and SIP STRIM to include research and innovation activities in the ambitions to boost Swedish industry internationally. STRIM has been involved during the period 2013–2016 and will continue to be involved through the programme office.

One potential strategic action regarding internationalisation is to organise research and innovation trips within the framework of SIP STRIM. Such trips could be arranged to pertinent countries where cutting edge innovation is taking place in the sector. Countries like Australia, Canada and South Africa, and markets like South America are of particular importance here.

SIP STRIM should be engaged in educational activities (see below) and there is also an international dimension to education. It is the ambition of STRIM to further develop educational collaboration globally. STRIM should facilitate actions leading to involvement of Swedish industry, research institutes and industry in activities within education. This could mean the setting up of new MSc programmes in developing countries, joint PhD programmes and collaboration with developed countries, and also activities within the field of life-long learning and wider society learning where STRIM partners could play an important role.

5.4 RESEARCH AND INNOVATION ACTIONS

Horizon 2020

The current Horizon 2020 framework programme is a fantastic opportunity to leverage R&I results from STRIM projects. It is important that STRIM continuously engages in influencing call texts through available channels (e.g. ETP SMR and the national reference group for SC5) and monitors the development. STRIM should also facilitate for partners to engage in consortia answering to pertinent calls within H2020.

ERA-NET

There are currently ambitions to develop an ERA-NET on raw materials in Europe. Provided that Sweden (through Vinnova) will be involved, it is important that STRIM collaborates with Vinnova to define the content and also engages partners in applications for leverage funding from this ERA-NET if established.

NCM

The Nordic Council of Ministers has engaged in raw materials through the programme NordMin, which aims at creating added Nordic values from building Nordic networks related to raw materials. If this ambition is continued, STRIM should play an active role in facilitating for Swedish partners in activities related to raw materials also on the Nordic level.

EIT RM

The KIC on raw materials, EIT Raw Materials, was established in 2015 with one of six European co-location centres located in Sweden (Luleå). Swedish partners were pivotal in writing the winning proposal, and many of the partners that are foreseen to be active within STRIM activities will also be partners in the EIT RM. The EIT RM will launch a number of funded activities and SIP STRIM should facilitate active engagement from Swedish partners in all of these activities during the coming years. Activities within the EIT RM on pilot actions, demonstrators and test beds are seen as highly relevant for SIP STRIM projects.

5.5 EDUCATIONAL COLLABORATION

Marie Skłodowska-Curie actions (MSCA)

The Marie Skłodowska-Curie actions (MSCA) support research training and career development focused on innovation skills. The programme funds worldwide and cross-sector mobility that implements excellent research in any field. There are MSCA grants for all stages of a researcher's career, from PhD candidates to highly experienced researchers, which encourages transnational, intersectorial and interdisciplinary mobility. Several MSCA initiatives promote the involvement of industry etc. in doctoral and post-doctoral research. There are four main types of MSCA:

- Research networks (ITN): support for Innovative Training Networks that develop new researchers.
- Individual fellowships (IF): support for experienced researchers undertaking mobility between countries, with the option to work outside academia.
- Research and Innovation Staff Exchanges (RISE) for international and inter-sectorial cooperation.
- Co-funding of regional, national and international programmes that finance research training or fellowships involving mobility to or from another country.

SIP STRIM or Bergforsk should monitor the MSCA and through its international network try to engage partners in the various actions related to MSCA.

EIT RawMaterials

A large part of the EIT Raw Materials initiative deals with education, wider society learning, life long learning and MSc and PhD education. STRIM should work for an active participation of all STRIM partners in these different activities and also be a catalyst to involve industry in these issues. Especially an increased interactivity between industry and academia is seen as the right way forward. STRIM should also actively engage with the Northern CLC office to promote EIT labelling of educational programmes where STRIM partners have a leading role.

Nordic Mining School

The ambition to pool Nordic interest within raw materials education has been channelled through the Nordic Mining School (a collaboration between LTU and Oulu University) and activities with Nordic funding to broaden this collaboration to other HEIs in the Nordic countries. Emphasis should be on introducing more innovation, entrepreneurship and raw materials management into existing programmes and to establish common programmes in the form of double or even joint degrees.

Strategic alliances

SIP STRIM should work for establishing strategic alliances with schemes or programmes in other parts of the world with a set-up similar to SIP STRIM. It is seen as especially important to liaise with organisations and programmes in countries or regions in the forefront of innovation and research related to the mining and metal producing sector globally.



Borragegagat under jord.
Photo: Boliden AB

6 Expected impact

Below the expected impacts are subdivided per STRIM Agenda area into technical, economical, environmental and social impacts.

Agenda area	Technical impacts	Economical impacts	Environmental impacts	Social impacts
Exploration	<ul style="list-style-type: none"> • Providing Sweden with innovative, world-class technology for minerals exploration of deep ore bodies. • Providing Sweden with a first 3D model of the crust down to several kilometres, to be used for decision making on land planning issues. 	<ul style="list-style-type: none"> • Deeply located deposits can be defined and economically evaluated. • Improved self-sufficiency and a stable supply of base, critical and other metals for the Swedish and European economy. • Foster the development of Swedish-based downstream industries on domestic mineral resources. • Create wealth in many less densely populated areas of Sweden. 	<ul style="list-style-type: none"> • Definition of deeply buried resources to minimise the effect of mining. • Define where the mining potential is in Sweden for the coming century to be used as a tool for decision making on land use, protection etc. 	<ul style="list-style-type: none"> • Fewer problems with access to land in densely populated areas. • Increased employment opportunities in less populated and rural regions of Sweden with a good potential for the extraction of metals and minerals. • Training of decision makers on resource geography, and potential and predictive models will lead to improved governance of Swedish resources.
Resource Characterisation	<ul style="list-style-type: none"> • Increased resource efficiency. • Reduction of ore losses. • Optimised mine-to-mill processes. 	<ul style="list-style-type: none"> • More cost-effective production. • New value-added products. 	<ul style="list-style-type: none"> • Reduced energy consumption. • Reduction of deposited waste on surface. • Efficient use of waste on surface as secondary raw material. • Decrease in harmful emissions. • Reduced CO₂. 	<ul style="list-style-type: none"> • Increased job satisfaction. • Equal gender employment.
Mining	<ul style="list-style-type: none"> • Reduction of ore losses. • Optimised mining processes. • More continuous processes. • Integrated process control and one control room. • Minimised human exposure at the production face. • Increased conversion of waste into products. • Increased degree of automation. • Safer mining with fewer accidents. 	<ul style="list-style-type: none"> • Reduction of man-hours per tonne. • More cost-effective rock support. 	<ul style="list-style-type: none"> • Reduced energy consumption. • Reduction of deposited waste on surface. • Decrease in harmful emissions. • Reduced CO₂. 	<ul style="list-style-type: none"> • Increased job satisfaction.

Agenda area	Technical impacts	Economical impacts	Environmental impacts	Social impacts
Mineral Processing	<ul style="list-style-type: none"> • Providing designs for energy-efficient comminution. • Providing innovative measurement solutions and mill models for reduced wear and enhanced mill control. • Providing solutions for enhanced coarse and fine particle separation. 	<ul style="list-style-type: none"> • Reduced costs from less energy consumption in ore comminution. • Higher revenue from increased recovery of valuable minerals and metals. • Increased production due to reduced material amounts after pre-concentration. • Increased revenue by producing by-products. 	<ul style="list-style-type: none"> • Reduced CO₂ emissions due to decreased energy consumption. • Less water usage due to dry processing and reducing the tonnage in downstream processes. • Less material to be deposited. • Stabilisation of waste products to reduce their hazards or harms. 	<ul style="list-style-type: none"> • Improved social acceptance of mineral processing plant operation due to higher resource efficiency and less emissions and waste. • Increased awareness of civil society of how the mining industry can improve the quality of life in society. • Education: generation of new knowledge through research.
Recycling and Metallurgy	<ul style="list-style-type: none"> • Optimised use of upgrading, pre-treatment and smelting operations. • Advise for design of products to enhance recycling possibilities. • Increased efficiency in process routes. • New processing routes for complex ore and scrap materials. • Adaption of slag properties with respect to new and existing uses for the slag products. 	<ul style="list-style-type: none"> • Improved competitiveness of the industry through more efficient use of existing process streams. • Known and new mineralisations are turned into ores. • New, so far unused process streams are becoming economically viable. • A market for by-products and slag. 	<ul style="list-style-type: none"> • Lower amount of materials deposited. • Decreased dependency on raw material availability. • More environmentally friendly residue streams. • Decreased energy consumption. 	<ul style="list-style-type: none"> • Increased employment opportunities. • Higher awareness of sustainability issues connected to metallurgy and recycling among plant people, designers, recycling industry and society as a whole.
Reclamation and Environmental Performance	<ul style="list-style-type: none"> • More efficient methods for reducing the environmental impact of mining will be developed. Environmental issues are discussed and integrated at all stages along the value chain from exploration via mining and processing to waste management and reclamation at mine closure. 	<ul style="list-style-type: none"> • The costs for remediation and environmental control will decrease if efficient methods are developed. The need for maintenance and monitoring for a long time after mine closure will decrease, and thus also the costs. It will be faster and easier to acquire permits to start new mines and expand existing mines if the environmental impact of mining is sustainable and there is a social license to operate. 	<ul style="list-style-type: none"> • An obvious result of this research is that the environmental impact of mining will decrease and that mining eventually will be sustainable. 	<ul style="list-style-type: none"> • The demand for metals and minerals in society will increase. Within the European Union, much larger quantities of metals are used than are mined. It is important to increase the level of mining in the EU in a sustainable way, without having a negative impact on the environment. This is necessary for a social license to mine. Otherwise, there will be a strong public opinion against mining. Improved environmental performance is a prerequisite for future mining within EU. • There are many possibilities for developing added values after mine closure. Remediated waste rock deposits and tailings impoundments may be utilised for outdoor life and recreation. Abandoned mine sites may be important tourist attractions. Careful planning during reclamation may result in increased biodiversity at old mine sites.
Attractive Workplaces	<ul style="list-style-type: none"> • Improved health and safety conditions in mining. • A significant reduction in the number of severe and fatal accidents. • A significant reduction in the number of occupational diseases. 	<ul style="list-style-type: none"> • Reduced cost for a high turnover of miners and staff. • Greater efficiency at work. • Reduction of different types of waste. • Less stand-stills due to fires. 		

Agenda area	Technical impacts	Economical impacts	Environmental impacts	Social impacts
Gender and Diversity in Mining	<ul style="list-style-type: none"> • Improved implementation of new technology. • Improved implementation of lean and safe production. • Creativity and innovativeness in organisational and technological development. 	<ul style="list-style-type: none"> • Improved competitiveness through diverse capacity building. • Flexibility to change and development within the industry. • Flexibility to societal progression, locally and globally. • Reduced vulnerability due to a gender-segregated economy and labour market. • Sustainable economic growth in rural regions in Sweden. 		<ul style="list-style-type: none"> • Improved competence recruitment – thanks to possibilities to attract all sorts of skilled people to the industry, both men and women. • Safe, healthy and attractive mining workplaces based on modern leadership. • Enable more women to stay in mining regions. • Additional employment opportunities for men and women. • Prevent fly-in-fly-out societies. • Attractive, sustainable and creative mining communities for men and women. • Entrepreneurial cultures in the mining communities.
Social License to Operate		<ul style="list-style-type: none"> • The regional economic impacts of mining investments will be better assessed and will therefore support a more knowledge-based decision making at different levels of society. • The industry provides more synergies and less conflict with other business sectors, in turn leading to a greater acceptance for the industry in the local community. 	<ul style="list-style-type: none"> • The environmental regulations and the industry's management practices address land use conflicts and pollution concerns in a transparent and legitimate manner leading to a high standard of environmental commitment. • Future changes in the stringency, design and implementation of the mineral law and environmental regulations are conducted based on a thorough understanding of how these affect both environmental and economic outcomes. 	<ul style="list-style-type: none"> • Improved social acceptance for mineral exploration and mining operations in the local communities and among the general public in Sweden. • Conflicts related to indigenous rights, cultural heritage, diversity of lifestyles etc. are clearly understood and dealt with in processes that are deemed by all involved as legitimate and efficient gaining support from a variety of impact assessment tools.



Borragegatat under jord.
Photo: Fredric Alm, LKAB.

7 Actions to be implemented until 2020

The defined short-, medium- and long-term needs within each STRIM area defined under Chapter 4 are listed below. The short- and medium-term actions can be implemented during the period 2017–2020 and will form the basis for any strategic implementation on a national or international level. The actions are listed below for each STRIM area.

7.1 EXPLORATION

Area	Action	Time frame
Modelling	Geological modelling in the most ore potential areas of Sweden for new deep discoveries, i.e. Bergslagen, Gällivare, Kiruna.	Short-term
	Develop the ore genetic models by defining ore types in these areas with a focus on both main mined commodities and critical metals.	Short-term
	Pilot actions on new exploration techniques, feeding 3-4D models with data and further adjustment of acquisition parameters.	Medium-term
	Testing genetic models with predictive models in the test areas.	Medium-term
	Verification of 3D models.	Medium-term
	Predictive models for Europe 3D.	Long-term
Technology	Start technical specifications for new exploration technologies.	Short-term
	Development of broadband electro-magnetic sounding instruments.	Short-term
	Joint interpretation techniques for controlled source frequency domain EM, time-domain EM data and audiomagnetotellurics data.	Short-term
	Develop and test joint inversion strategies for multi-variable geophysical data types.	Short-term
	Launch a technology based project on new drilling and geophysical techniques	Short-term
	New geophysical equipment by deep drilling in test areas.	Medium-term
	Proven new deep drilling and borehole geophysical techniques	Long-term
Infrastructure	Building visualisation centres.	Short-term
	Start to utilise results in training across Europe	Medium-term

7.2 RESOURCE CHARACTERISATION

Area	Action	Time frame
Resource characterisation	Apply new and existing resource characterisation techniques for online and in-situ measurement of geological, mineralogical, rock mechanical and metallurgical properties.	Short- to medium-term
	Facilitate the use of new monitoring methods for rock mechanics by adapting the use of existing sensor techniques.	Short- to medium-term
	Develop new resource management tools which enable real-time data integration, effective data visualisation, production planning and scenario analysis.	Short- to medium-term
	Develop a tool for resource efficiency assessment and sustainability evaluation of existing and planned mining operations.	Short- to medium-term
	Facilitate the use of new online analysis tools, sensing methods and management tools, all integrated in a geometallurgical model and resource management system.	Long-term
	Facilitate the use of micro-analytical tools for incorporating detailed resource information in long term production planning.	Long-term
	Develop interdisciplinary tools for rock mass characterisation. A common visualisation platform based on an open source Virtual Reality technique could possibly be used.	Long-term
	Develop and implement novel resource characterisation techniques.	Long-term
	Develop MWD and AWD (measurement while drilling and assay while drilling) technology to deliver data for online process design, optimisation, prediction and planning for ore delineation, rock mechanics, drilling, continuous mechanical excavation, blasting, crushing and grinding or milling.	Long-term

7.3 MINING

Area	Action	Time frame
Efficient unit operations of mining	Develop the unit operations to improve productivity, resource efficiency and to facilitate automation.	Short- to medium-term
	Improve the efficiency of the materials handling and mass movement.	Short- to medium-term
	Develop the blasting process in order to optimise the use of explosives and its effect on fragmentation.	Short- to medium-term
	Develop the understanding of detonation and its connection to drill accuracy and rock mass properties.	Short- to medium-term
	Improve the understanding of fragmentation.	Short- to medium-term
	Optimise all steps of the extraction process (e.g. drilling, blasting, materials handling, mass movement and rock support have to be optimised).	Long-term
	Development of continuous excavation methods adapted to Swedish mining conditions.	Long-term
	Minimising the environmental effects.	Long-term
Improved ore recovery, fragmentation and breakage of hard rock	Studies of problems related to increased mining depth.	Short- to medium-term
	Full-scale gravity flow studies, possibly based on draw point or bucket monitoring or markers based on RFID technology.	Short- to medium-term
	Development of numerical models and conceptual studies.	Short- to medium-term
	Mine verification study.	Short- to medium-term
	Review of previous work and theory formulation.	Short- to medium-term
	Laboratory tests of physical material properties, possibly physical model scaled tests.	Short- to medium-term
	Increase ore recovery and reduce waste rock dilution.	Long-term
	Improve the understanding of draw control and gravity flow in caving mines with increasing stresses and potentially increasing volumes involved.	Long-term
	Improve the understanding of the detonation of explosives (e.g. avoid dead pressure), blast damage and deep mining related issues such as blast-hole stability.	Long-term
	Improve the understanding of the behaviour of the fragmented rock.	Long-term

	Develop a full understanding of breakage mechanisms under cutting tools and to apply this knowledge to improving continuous mechanical excavation processes.	Long-term
	Develop Measurement While Grinding (MWG) and full-body modelling of mills with grinding charges to be able to continuously measure and dynamically control comminution circuits.	Long-term
Rock mechanics, support and mining seismology	Improve the understanding of the correlation between seismic hazards and mining depth and difference in characteristics of different types of seismic events (shear events, strain burst, tensile cracks, collapse etc.).	Short- to medium-term
	Develop rock mechanics block models with “graded” rock engineering properties of the rock mass in a similar fashion as mineral resource block models.	Short- to medium-term
	Develop effective rock reinforcement systems in squeezing and bursting ground conditions.	Short- to medium-term
	Develop an effective methodology to test the capacity of rock support system including both surface support and reinforcement.	Short- to medium-term
	Improve numerical modelling capabilities, which describe well-constrained failure and post-failure deformation mechanisms.	Short- to medium-term
	Improve numerical modelling capacities, which can handle rock fracturing, deformation and ejection under static and seismic conditions.	Short- to medium-term
	Develop monitoring technology on a mine scale to observe the states of failure and post-failure at and in the proximity of an excavation. Both scaled physical models and full-scale underground tests should be considered.	Short- to medium-term
	Effective probabilistic numerical modelling techniques with the capability to identify the ground control problems associated with mining at great depth.	Short- to medium-term
	Evaluation of the performance of rock support systems and the rock mass – rock support system interaction.	Short- to medium-term
	Improve the understanding of the rock mass and rock support performance by monitoring and damage mapping.	Short- to medium-term
	Give a clearer understanding of the effectiveness of the rock support systems by detailed numerical analyses.	Short- to medium-term
	Develop knowledge about the factors governing the interaction and performance through large-scale field tests and the development of novel laboratory testing methods.	Short- to medium-term
	Improve the productivity of equipment for rock support.	Short- to medium-term
	Seismicity – by thorough investigation of seismic hazards, evaluation of the rockburst mechanisms.	Long-term
	Development of interpretation methods that can assist in judging whether failure surfaces and fallouts are formed.	Long-term
	Development of methods that can be used in rock support design under squeezing and bursting ground conditions.	Long-term
Energy and infrastructure	Improving and developing ventilation, for instance by optimising heat exchange and flow control.	Short- to medium-term
	Develop new power sources.	Short- to medium-term
	Develop mining processes, mine layout and infrastructure that enable minimised transports and efficient flows.	Short- to medium-term
	Innovative processes such as near-to-face processing and continuous excavation needs to be considered and developed.	Short- to medium-term
	Reducing the environmental impact (the overall energy consumption and optimising the mine infrastructure).	Long-term
Mining equipment reliability and machine design	Failure and maintenance data collection and analysis.	Short- to medium-term
	System reliability analysis of operating environment.	Short- to medium-term
	Condition-based maintenance.	Short- to medium-term
	Operator training and procedures.	Short- to medium-term
	Design for reliability.	Long-term
	Maintenance program design and optimisation.	Long-term
	Models and equipment prototype design.	Long-term

Integrated process control and automation	Improved communication, networks and localisation and navigation systems.	Short- to medium-term
	Automated inspection, reporting and image analysis and processing.	Short- to medium-term
	Information gathering systems.	Short- to medium-term
	Mining equipment monitoring.	Short- to medium-term
	Sensors.	Short- to medium-term
	Production prediction systems, calculation and prediction of KPIs in real time.	Short- to medium-term
	Traffic management systems.	Short- to medium-term
	Integration of maintenance systems into scheduling models.	Short- to medium-term
	Human interaction in automated systems.	Short- to medium-term
	Improve and optimise the overall mining process.	Long-term
	Optimise the utilisation of mining equipment and automation.	Long-term
	“Plug & Play” (common control and communication architecture).	Long-term
	Mobile machine monitoring and remote diagnostics.	Long-term
	Augmented reality.	Long-term
	Field robotics in order to facilitate autonomous mining.	Long-term
	Sensors for mine environmental characterisation (identification of fall-outs, road condition, gas detection etc.).	Long-term

7.4 MINERAL PROCESSING

Area	Action	Time frame
Comminution of hard rocks	Enhance mineral liberation by adjusting target particle size and breakage mechanism for grinding to ore texture and mineral associations.	Short- to medium-term
	Improve comminution technologies and machinery for hard ore comminution with regard to energy for grinding and wear characteristics.	Short- to medium-term
	Develop measurement technology and advanced models for optimising design and control of comminution processes.	Short- to medium-term
	Investigate alternative fragmentation methods and mill types for the efficient grinding of coarse and fine particles (considering dry and wet grinding).	Short- to medium-term
	Develop and implement energy-efficient processes, particularly for ore comminution.	Long-term
Physical separation	Investigate processing routes for bulk sorting prior to the actual concentrator plant, considering unit operations for separation at coarser particle sizes.	Short- to medium-term
	Develop improved reagent schemes and hydrodynamic concepts for flotation to recover valuable minerals from fine and ultra-fine as well as coarse particle size fractions, particularly for cold flotation.	Short- to medium-term
	Develop processing routes for the effective separation of complex ores and removing impurities.	Short- to medium-term
	Develop dry processing technologies particularly for finer size ranges (classification as well as sorting, magnetic, electric and gravity separation).	Short- to medium-term
	Investigate the stability and degradation of flotation reagents and their effect on downstream processing.	Short- to medium-term
	Develop efficient separation processes for treating finely dispersed, polymetallic ores as well as removing impurities.	Long-term
	Develop suitable pre-treatment processes for separation close to the mining production face.	Long-term

Process design and analysis	Develop hybrid flow sheets based on successive separation and size reduction to improve the efficiency of comminution circuits.	Short- to medium-term
	Optimise the whole chain of ore fragmentation (blasting, mechanical cutting, crushing and grinding) in combination with pre-concentration processes.	Short- to medium-term
	Develop geometallurgical models together with innovative analysis methods for resource characterisation.	Short- to medium-term
	Develop process designs for flexible plant operation in order to process different ores and ore domains.	Short- to medium-term
	Develop strategies and models for the efficient management and treatment of process water.	Short- to medium-term
	Improve and optimise mineral beneficiation processes towards better resource-efficiency and sustainable production, e.g. by reduction of waste rock and tailings, reduction of process water as in dry processing.	Long-term
	Develop new processing routes for efficient separation of minerals and metals from by-product and waste streams from existing beneficiation as well as extraction plants.	Long-term

7.5 RECYCLING AND METALLURGY

Area	Action	Time frame
Technology	Adapting processing of iron-ore into pellets for increased product quality and simultaneous optimised gas and energy utilisation for minimised emissions, based on fundamental knowledge coupled to the processing and implemented in process models.	Short- to medium-term
	Develop knowledge and technology to use slag products in new applications.	Short- to medium-term
	New improved methods for recovery of energy from low heat value sources.	Medium-term
	Develop new innovative methods to extract phosphorus and vanadium from residues generated in the steel industry.	Medium- to long-term
	Develop the technology needed to extract more elements (e.g. Sb, Ni, Sn) from material streams already processed.	Medium- to long-term
	Develop and adopt new methods for on-line measurements.	Medium- to long-term
	Develop knowledge and technology to increase the yield in existing processes.	Long-term
Enhanced quality of material streams	Develop the knowledge necessary to secure the product quality of the slag produced on the same time as processing consequences of varying slag composition can be controlled or purposely adjusted.	Short-term
	Dissipate knowledge about recycling possibilities and limitations.	Short- to medium-term
	Develop methods to enhance the metal content in by-product streams.	Medium-term
	Optimise the existing process chains for simultaneous extraction of metals from ore concentrates and scrap.	Medium-term
	Introduce new methods to more efficiently control the processes and quality of material streams through new measurement techniques.	Long-term
New material streams	Waste to raw material: Develop methods to utilise waste materials from own processes or across business sectors to enhance effectiveness and the recovery of metals, e.g. the use of organic-containing waste materials as reductants or fuels in the extraction of metals.	Short-term

7.6 RECLAMATION AND ENVIRONMENTAL PERFORMANCE

Area	Action	Time frame
Waste management	Characterisation and management of desulphidised tailings – a new paradigm for waste management.	Short- to medium-term
	Utilisation of mine waste as a resource, including the development of processes that can convert what traditionally is considered as waste into products.	Short- to medium-term
	Dust prevention.	Short- to medium-term
	Paste disposal of mine tailings.	Short- to medium-term
Drainage water treatment	New technologies for the reduction of nitrogen, sulphur, metal and metalloid emissions into the environment and for the recovery of metals from drainage waters.	Short- to medium-term
	Innovative methods for monitoring, modelling, predicting and following up the effects of water use on emissions to recipient waters and process water composition.	Short- to medium-term
	Methods to assess and predict what is sustainable water quality.	Short- to medium-term
Treatment of emissions to air	New technologies for reducing emissions of NO _x , SO _x , Cl and F to air.	Short- to medium-term
Mine closure and remediation	Prevention of ARD by innovative remediation methods including an increased use of waste from other industries and the society.	Short- to medium-term
	Inhibition of sulphide oxidation.	Short- to medium-term
	Development of post-closure added values.	Short- to medium-term
	Methods for safe disposal of the waste formed when bioleaching is used.	Short- to medium-term
Energy efficiency	Improved energy control systems. Utilisation of thermal heat.	Short- to medium-term

7.7 ATTRACTIVE WORKPLACES

Area	Action	Time frame
Attractive workplaces	Develop new methods for monitoring and controlling the work environment.	Short- to medium-term
	Formulate a roadmap for Lean mining.	Short- to medium-term
	Develop guidelines for attractive work places in deep mining.	Short- to medium-term
	Develop a holistic framework for automation.	Short- to medium-term
	Review the health and safety impact of automation.	Short- to medium-term
	Review health and safety conditions for contractors in the mining business.	Short- to medium-term
	Develop sufficient technology for fire and rescue operations.	Short- to medium-term
	Develop a holistic concept for the zero entry mine including those working in remote operations control centres.	Long-term
	Develop efficient tools for proactive fatal risk control.	Long-term
	Develop new tactics and methods for remote-controlled fire and rescue operations.	Long-term
	Develop new education programmes for management and workers.	Long-term
	Develop efficient programmes for development of attractive societies.	Long-term

7.8 GENDER AND DIVERSITY IN MINING

Area	Action	Time frame
Gender and diversity in mining	Form visions, policies and financing that enable research that can contribute to a more gender equal, diverse and socially sustainable development of the mining industry.	Short- to medium-term
	Develop systematic gender divided statistics in industry, clusters, education and academia etc.	Short- to medium-term
	Evaluate the mining companies' diversity and gender equality related activities to support best practice.	Short- to medium-term
	Develop versatile and gender aware strategic recruitment, promotion and retention practices in the mining industry.	Short- to medium-term
	Encourage collaboration between industry and society for attractive, diverse and gender equal mining communities that are also flexible to change.	Long-term

7.9 SOCIAL LICENSE TO OPERATE

Area	Action	Time frame
Stakeholder management	Review and analyse the Swedish mining and metal industry's existing CSR, stakeholder management and sustainability accounting practices.	Short- to medium-term
	Identify industry-wide sustainability criteria for the Swedish mining and metal industry, and operationalise and test these for practical use.	Short- to medium-term
	Develop strategic tools and guidelines for improved stakeholder assessments and community development practices.	Short- to medium-term
	Integrate and implement sustainability criteria, accounting systems and indicators into operational management systems (i.e. objectives, programmes, operational control, monitoring and measurement, audits).	Long-term
	Develop a framework – including sustainability accounting practices – that can make possible and justify a CSR label on all mineral products emanating from Swedish mines and metal smelters.	Long-term
Regional development	Review and investigate current and future needs of labour recruitment in the Swedish mining and metal producing industry.	Short- to medium-term
	Review and evaluate existing methods and scientific tools used in Sweden as well as internationally to assess the regional-economic impacts of mining operations (i.e. in terms of employment, income, spillovers), including the role of different types of benefit-sharing mechanisms.	Short- to medium-term
	Analyse in detail the labour mobility and population change in local and regional labour markets impacted by changes in the Swedish mining and metal producing industries, in order to gain increased knowledge about the interrelationship between the mining ventures and overall community development.	Short- to medium-term
	Review and analyse important developments in social sustainability factors of the Swedish mining communities.	Short- to medium-term
	Analyse the relationship between social sustainability factors in mining communities (e.g. satisfaction with built environment, social inclusion, sense of safety and security, sense of community belonging), and existing policies and practices within the mining companies concerning recruitment and personnel.	Short- to medium-term
	Identify and evaluate strategies and management practices aiming at meeting future demands for recruitment of qualified labour to the mining and metal sectors.	Long-term
	Develop and put into use new improved methodological approaches to assess the regional-economic impacts of mining operations, including impacts and trade-offs associated with different types of benefit-sharing mechanisms.	Long-term

Area	Action	Time frame
	Identify and evaluate strategies on how to promote cooperation between the mining and metal industry and the local communities and regions.	Long-term
	Formulate strategies for inclusive community investments as well as strategies for policies and practices concerning inclusion and well being of the workforce enabling the operation of the mines.	Long-term
Managing land use conflicts	Review the Swedish territorial planning and mining concession processes in relation to various types of mineral exploration and mining operations, as well as how the views of different stakeholders, e.g. interest groups, local population, reindeer husbandry and industrial sectors, have been addressed and evaluated in the legal rulings.	Short- to medium-term
	Review the current use of public consultations ("samråd") and environmental impact assessments (EIA) in the case of mining operations, and investigate how such consultations can be improved to gain a social license to operate (e.g. by drawing on international experience).	Short- to medium-term
	International comparison of the strategies (e.g. property rights, compensation mechanisms) employed to permit indigenous rights and mining operations to co-exist, taking into account the different circumstances in different legislations with a view for a best practice solution for the Swedish situation.	Short- to medium-term
	Develop and test a social cost-benefit approach in the case of mining investments.	Short- to medium-term
	Identify causes and challenges in land-use conflicts with respect to current legislation. How can the tool for the current national interests of land use (mineral resources, Natura 2000, reindeer husbandry etc.) be employed for mineral resource extraction and a sustainable future?	Short- to medium-term
	Identify and evaluate different types of strategies and regulations that could potentially improve the legitimacy and the efficiency of land use decision-making with respect to mining concessions.	Long-term
	Identify and evaluate of various strategies and regulations, e.g. compensation mechanisms, to address the co-existence of different national interests in mining areas.	Long-term
	Complete a handbook for conducting cost-benefit analysis for mining development to support, for instance, legal rulings.	Long-term
Environmental regulation	Review and evaluate decision-making processes that underly the existing permitting conditions with respect to air and water pollution (including mining waste).	Short- to medium-term
	International comparison of how significant mining countries (e.g. Australia, Canada) regulate, and have regulated the environmental impacts of mines and metal smelters, with a focus on standards and reclamation funding.	Short- to medium-term
	Develop different potential regulatory approaches (i.e. focusing on design and implementation) that can be used to improve environmental performance without compromising fundamentally with the industry's long-run competitiveness.	Long-term
	Develop different ways of regulating the rehabilitation of mining areas to secure that the necessary costs can be covered.	Long-term
	Analyse best-practice regulations from an efficiency point-of-view, and the development of cost-benefit tools to assist the permit decision-making process (i.e. setting standards, the size of reclamation requirements etc.)	Long-term