

## STRATEGIC RESEARCH AND INNOVATION AGENDA FOR THE SWEDISH MINING AND METAL PRODUCING INDUSTRY (STRIM)

April 2013

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More organisations are expected to endorse the STRIM Agenda and to become actively involved in its implementation.

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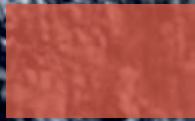
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# 1 Executive summary

THE STRATEGIC RESEARCH AND INNOVATION AGENDA FOR THE SWEDISH MINING AND METAL PRODUCING INDUSTRY (STRIM) is subdivided into seven main Agenda areas:

- Deep Innovative Exploration
- Mining
- Mineral Processing
- Recycling and Metallurgy
- Reclamation/Environmental Performance
- Attractive Workplaces
- Gender Equal Mining

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

We set the stage by explaining why the STRIM Agenda has been developed in Chapter 2. In Chapter 3, a common vision is set for the STRIM Agenda organisations. The seven Agenda areas related to primary and secondary resources are explained in some detail in Chapter 4. Each Agenda area has defined the research and innovation needs in the short (2013–2016), medium (2016–2020) and long (beyond 2020) terms. Each Agenda area also has a defined vision for 2030 and beyond, based on key performance indicators.



All Agenda areas have defined their 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 (Chapter 5). In Chapter 6, the proposed measures are shown in an extensive table for future implementation. The form of collaboration for execution is further defined in a national strategic innovation area – Mining – to be annexed to this STRIM Agenda. The ambition is also to implement the measures in various international initiatives described in Chapter 2.

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.



*“LKAB creates wealth by being one of the most innovative and resource efficient mining companies in the world.”*

LARS-ERIC AARO, CEO LKAB,  
ANNUAL REPORT 2012

*“Atlas Copco fosters a culture of innovation by ensuring competent people have the responsibility to understand customer needs and have the freedom to act. We also actively attract external innovators and cooperate with universities.”*

RONNIE LETEN, CEO ATLAS COPCO,  
ANNUAL REPORT 2012

*“The investment is paying off as we achieve genuine technological breakthroughs and bring advanced products to the market. We are pleased that 2012 was a particularly rich year for technological achievements.”*

JOE HOGAN, CEO ABB,  
ANNUAL REPORT 2012



## 2 Introduction

This 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 STRIM agenda is the international cooperative work on developing a programme for Sustainable Mining and Innovation for the Future (SMIFU)<sup>1</sup> 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 this 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 STRIM Agenda also extends the ambitions of SMIFU and broadens the scope to cover the entire primary resources value chain, as explained below, 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. It also addresses the secondary resources by proposing a research and innovation programme for recycling and how the mining and metal producing industry can contribute to a sustainable development of the society.

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

Society has always had, and will continue to have, a fundamental need for metals and minerals. An average citizen of the Western world consumes about

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<sup>1</sup> Lindqvist. P.-A., 2012. Sustainable mining and innovation for the future. Research, development and innovation programme. RTC, Luleå



## 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 hightech industry, a good infrastructure, stable political conditions, and stable political conditions – all of which are factors that will contribute to a competitive Swedish mining and supply sector. Sweden is in the forefront of efficient mining both underground and in open cast mining operations. It has leading global suppliers of underground equipment for the mining industry and one of the worlds leading companies in recycling of electronic scrap. In addition, Sweden has and 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 seven 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 (2013–2016), medium (2016–2020) and long (beyond 2020) 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 5). In Chapter 6, the proposed actions are listed for future implementation. The form of collaboration for execution is further defined in a national strategic innovation area – Mining – to be annexed to this STRIM Agenda. The ambition is also to implement the measures in various international initiatives described in Chapter 2.

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

1,700 tons<sup>2</sup> (Table 2-1) of minerals and metals in their lifetime (about 25 tons per year) which are used for roads, building materials, cars, refrigerators, computers, etc. A society without minerals and metal is unthinkable.

It is estimated that there will be an additional 3 billion members<sup>3</sup> of the middle-class by 2030, which will create a strong long-term need for supplies of raw material. Sweden has a unique opportunity to contribute towards the needs of the many. Sweden possesses untapped geological potential for a strongly 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 Mining Association recently released the sectors vision for growth<sup>4</sup> (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 industry, including technology providers, works on a truly global, international market. The world as well as the market conditions are

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

3 Kharas, H. 2011. The emerging middle class in developing countries. Working Paper 285 OECD Development Centre, Paris.

4 SveMin, Stockholm, 2012: The mining sector – an engine for growth in Sweden (in Swedish).

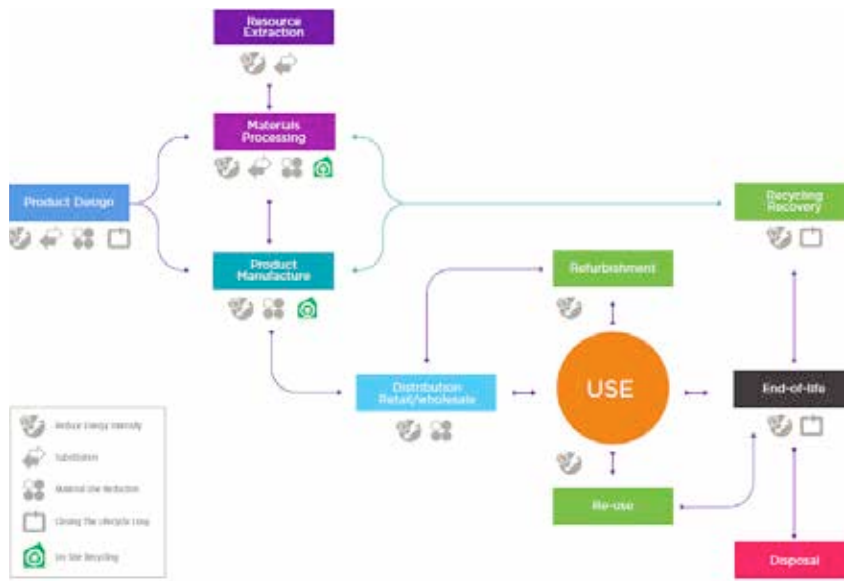


Figure 2-2. Raw materials in the value chain. Source: European Round Table, 2013. Raw Materials in the Industrial Value Chain. An Overview. Download from [www.ert.eu](http://www.ert.eu).

Figure 2-2. Raw materials in the value chain. Source: Raw Materials in the Industrial Value Chain. An Overview. European Round Table. Download from [www.ert.eu](http://www.ert.eu) 2013.

Commodity	Use	
Salt	14	Tonnes
Clays	9.7	Tonnes
Zinc	0.35	Tonnes
Aggregates	775	Tonnes
Petroleum products	350,000	Litres
Copper	0.6	Tonnes
Gold	81	Grams
Phosphate	10.6	Tonnes
Coal	267	Tonnes
Lead	0.387	Tonnes
Bauxite (Al)	2,710	Tonnes
Iron	14.95	Tonnes
Cement	33.1	Tonnes
Natural gas	163,000	Cubic metres
Other minerals and metals	30,335	Tonnes

constantly changing, and the only way to survive and prosper is through competitiveness. Competitiveness 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 science, 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.

For additional global competitiveness, the mining and metal producing industry must have a positive image and reinforce diverse 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 interfaces between human, technology and organisation with respect to safety, occupational health, ergonomics, management, workplace-culture, learning, career opportunities, diversity and gender equality, etc. By taking these considerations into account, the industry will create attractive organisations that are both more efficient and more innovative, as well as flexible to societal change and technological development.

In the Government's research and innovation bill<sup>5</sup> 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.
- 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.

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”<sup>6</sup>. 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, shared commitment and the embryo for a Strategic Research and Innovation Agenda to meet this vision. The areas of focus defined were resource characterisation, safer, leaner and greener mining, and attractive workplaces. The feasibility stage of the project was later continued on commercial premises and the results of this stage<sup>7</sup> (Fig. 2-3) also form the core of this *Strategic Research and Innovation Agenda for the Swedish Mining and Metal Producing Industry (STRIM)*. Safer, leaner and greener mining, developments in mineral processing and laying a foundation for attractive workplaces are areas covered in this new research, development and innovation programme for 2013–2016. Three additional core areas of the programme are 1) deep 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).

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<sup>5</sup> Prop. 2012/13:30

<sup>6</sup> Bäckblom, G., Forssberg, E., Haugen, S., Johansson, J., Naarttijärvi, T., Öhlander, B., 2010. Smart Mine of the Future. Conceptual study 2009–2010. RTC, Luleå.

<sup>7</sup> Lindqvist, P.-A., 2012. Sustainable mining and innovation for the future. Research, development and innovation programme. RTC, Luleå.



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

The mining sector is directly responsible for one of the core pillars for the functioning of the society in the past, in the present and for 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).

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](http://www.bergforsk.se)) as well as the European Technology Platform on Sustainable Mineral Resources (ETP SMR, [www.etpsmr.org](http://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](http://www.vinnova.se)). A programme was developed, jointly funded by the government (via Vinnova) and the mining industry in the range of SEK100 million. The previous Strategic Mining Research Programme for 2006–2010 received a favourable evaluation from the independent reviewers<sup>8</sup>. 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 2008<sup>9</sup>. 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.



Figure 2-3. The SMIFU II final report on Sustainable mining and innovation for the future: Research, development and innovation program, was published by RTC in October 2012 and forms the backbone of this Strategic Research and Innovation Agenda for the Mining and Metal Producing Industry (STRIM).

<sup>8</sup> 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

<sup>9</sup> COM (2008)699

- 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 and Luleå University of Technology have been very successful in these calls and are currently active partners as coordinators or WP-leaders in two FP7 flagship projects related to raw materials: *Promine*<sup>10</sup> and *I<sup>2</sup>Mine*<sup>11</sup>. The Geological Survey of Sweden (SGU) is currently involved in several FP7 projects, some of them directly related to raw materials, such as EURARE.

In the research and innovation proposal advanced by the Swedish government in 2008<sup>12</sup>, 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)<sup>13</sup> 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.

In November 2012 the Nordic Council of Ministers announced a new Nordic initiative related to raw materials called NordMin. NordMin will be administered from LTU and will serve as a network of excellence within the full value chain of raw materials. NordMin will involve academia, industry and research institutes

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<sup>10</sup> <http://promine.gtk.fi>

<sup>11</sup> <http://www.i2mine.eu>

<sup>12</sup> Proposal. 2008/09:50

<sup>13</sup> <http://www.ltu.se/centres/camm>

in Sweden, Norway, Finland, Denmark, Iceland and Greenland. The current decision covers operation for the three-year period 2013–2015 with a total of DKR 30 million in funding. The Swedish mining industry and LTU will also support leverage with the EU, where Arctic Policy, for example, would present opportunities for extending the NordMin initiative.

The European Union has, since the publication of the RMI 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 and the Geological Survey of Sweden are particularly involved (outside regular calls) and where we see that future EU support for any RDI action related to raw materials will be realized:

- The European Innovation Partnership (EIP)<sup>14</sup> on Raw Materials. This EIP will contribute to the mid- and long-term security of 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 EIP has the overall target of reducing Europe's import dependency on the raw materials that are critical to Europe's industries.
- The ERA-NET called ERA-MIN<sup>15</sup> a joint action between eleven European research agencies (Vinnova and the Swedish Geological Survey are the Swedish partners) to define a roadmap for joint calls along the value chain of raw materials including primary resources, recycling, substitution, education and legal framework and international collaboration.
- The SPIRE consortium<sup>16</sup> where the European process industry including for example mining, minerals and steel join forces to increase energy and resource efficiency. The expectation is that SPIRE will be a Private Public Partnership in the order of €2–3 billion.
- A future Knowledge Innovation Community (KIC) on raw materials<sup>17</sup> under the auspices of the European Institute of Technology (EIT), in which the focus will be on innovation, education and business creation within the area of raw materials.

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

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<sup>14</sup> <http://ec.europa.eu/enterprise/policies/raw-materials/innovation-partnership/indexen.htm>

<sup>15</sup> <http://www.era-min-eu.org>

<sup>16</sup> See [www.spire2030.eu](http://www.spire2030.eu)

<sup>17</sup> <http://eit.europa.eu/about-us/strategy/>



## 2.2 CURRENT STATUS

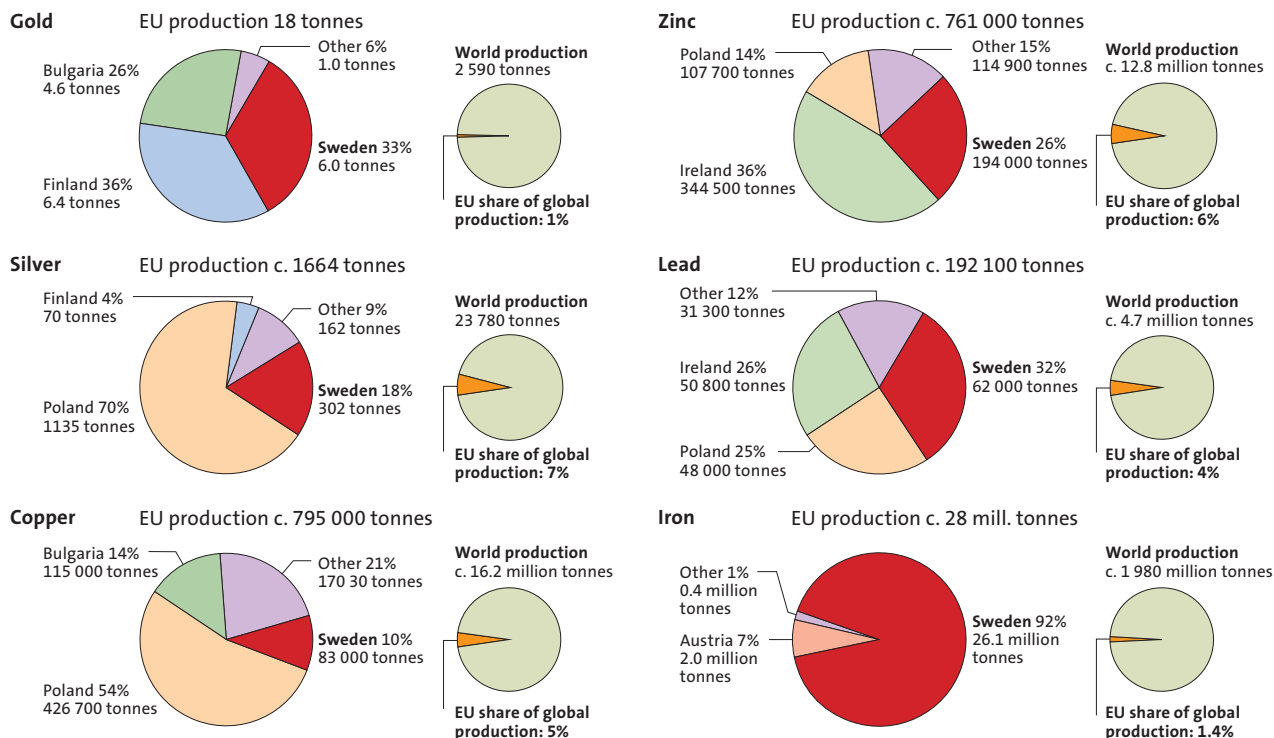
In a global comparison, the Swedish mining companies are relatively small. However, as a result of forward-looking research and development they are competitive and, in many cases, at the forefront of global technology and environmental issues. In a European perspective, the Swedish mining companies account for a large part of the EU27 production of metals, and are for many of them market leaders (Figure 2-4).

With research and development in well-selected areas for research, development and innovation, 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 (2012) fifteen metal mines in operation in Sweden, producing around 67 million tonnes of ores, but the number of mines could increase to 30 by the year 2020 and to 50 by 2030. The production of ore is expected to triple by 2030. In 2010, the Swedish mining and mineral industry employed 8,400 persons. Export volumes in the sector are steadily increasing, and amounted in 2011 to 12% of all goods export, i.e. SEK 145 billion. The share of the Gross National Product in 2010 was 0.85%. During 2011, the sector made investments of approximately SEK 9.3 billion. With the expected growth, the

Figure 2-4. Sweden's share of EU27 mine production of selected metals (source SGU periodiska publikationer 2012:2).

### Sweden's mine production for 2011 in relation to EU27 and the world



mining industry would by 2025 account for 3–5% of GDP and over 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%<sup>18</sup>. 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 persons of which almost 16,000 were employed in Sweden. In 2012 they invested more than SEK 5 billion in research and development or around 3% of the turnover. The Swedish mining cluster with mining companies, service providers and technology providers is shown in Figure 2-5.

It must be remembered, however, that successes in the past are no guarantee for long-term success in the future. International competition is fierce, not only in terms of products but also with respect to competence. The OECD reports<sup>19</sup> 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, even before the current 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 specialized. 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. LTU and Swerea MEFOS are renowned for their research in recycling and steel. On top of this, there are excellent operators of blast furnaces (SSAB), 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:

Figure 2-5. The Swedish Mining Cluster.



<sup>18</sup> 2012: The mining sector - an engine for growth in Sweden (in Swedish). SveMin, Stockholm. Download from www.sveMin.se  
<sup>19</sup> 2013: Mineral resource trade in Chile: contribution to development and policy implications. OECD TAD/TC/WP(2012)16/FINAL

- 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 account 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 propose 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 is 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 industry (the translation from Swedish into English has been made by the authors).

The organizations behind this Strategic Research and Innovation Agenda for the Swedish Mining and Metal Producing Industry (STRIM) supports the vision of the Swedish mineral strategy: *“Through a sustainable utilization 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 strategy is divided into five main action areas:

- 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.

We will especially contribute under action 8: *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 characterized 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 share the vision of the Swedish government and support the action whereby Vinnova is tasked, in collaboration with the Swedish research council, with conducting a subject overview of the mining and minerals area. The overview should include a bibliometric evaluation and a mapping of historical as well as future research actions within the mining and minerals area. This mapping should, among other things, identify actions associated with recycling and substitution, which should be reported during 2013 as a support for the work within the European innovation partnership for raw materials. The Swedish strengths and challenges within mining and minerals research in an international perspective should be identified and the strategic benefits of actions carried out should be evaluated. The investigation should also include a proposal for how forms of collaboration between research players within the mining and minerals area could be improved. We hope that this task will lead to an improved funding structure for both fundamental and applied research, for research areas of relevance to the Swedish mining, minerals and steel sectors.

We also welcome the actions defined under heading 9: *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 industry is authored in close collaboration between the industry and academia, and here we anticipate close collaboration with organisations on a local, regional and national level to put the Agenda into action.



### 2.2.2 A Swedish Innovation Strategy

The Swedish government published the Swedish Innovation Strategy<sup>20</sup> in 2012. As with the Europe 2020 strategy<sup>21</sup> the national strategy specifies the visions with the 2020 horizon. 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 2-6 illustrates how the Swedish mining industry contributes to the overall aims of the national innovation strategy. The goals and sub-targets set by the mining 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 6) are also measures of how the sector contributes to the sub-targets set in Figure 2-6.

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<sup>20</sup> Publication N2012.33

<sup>21</sup> COM(2011) 808 final

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

Figure 2-6. 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><b>Goal:</b> Capacity building is a key action area of the STRIM and is implemented for 2013-2016 in the SIO for mining and metallurgy.</p> <p><b>Subtarget:</b> People have the knowledge, skills and expertise to contribute to innovation.</p> <p><b>Subtarget:</b> People have the courage and willingness to contribute to innovation as an entrepreneur, manager, and employee.</p> <p><b>Subtarget:</b> Swedish metal extractive and producing industry is attractive on an international level and welcomes diversity and mobility.</p>	<p><b>Goal:</b> 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><b>Subtarget:</b> Education and research in mining and metallurgy at universities with world-class quality and relevance contribute to innovation.</p> <p><b>Subtarget:</b> World-class research institutes in mining and metallurgy established in Luleå meet knowledge and development needs in businesses and society.</p> <p><b>Subtarget:</b> Strong Swedish research nodes in mining and metallurgy have strong positions in global knowledge networks such as EIT KIC RM.</p>	<p><b>Goal:</b> 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><b>Subtarget:</b> Regulations, market conditions and norms that promote innovation within exploration, mining, processing and recycling.</p> <p><b>Subtarget:</b> Functioning access to capital that invests in the mining sectors capacity for innovation and growth.</p> <p><b>Subtarget:</b> Sustainable and predictable legislation for the metal extractive and producing industry.</p>
INNOVATIVE BUSINESSES AND ORGANISATIONS	INNOVATIVE PUBLIC SERVICES	INNOVATIVE REGIONS AND ENVIRONMENTS
<p><b>Goal:</b> Metal extractive and producing businesses and organisations in Sweden have world-class innovation capacity.</p> <p><b>Subtarget:</b> Businesses in Sweden grow by offering innovative solutions on global markets.</p> <p><b>Subtarget:</b> Mining and metallurgical sector in Sweden grow by offering innovative solutions on global markets.</p> <p><b>Subtarget:</b> Using the potential in social innovation and social entrepreneurship to contribute to attractive workplace and mining regions.</p>	<p><b>Goal:</b> Innovative and collaborative geological survey organisation that has a high degree of quality, service and availability.</p> <p><b>Subtarget:</b> Environmental protection agency and the Geological Survey of Sweden contribute in developing innovative ways of meeting societal challenges.</p> <p><b>Subtarget:</b> Regional authorities works systematically with innovation in order to create growth in the mining sector.</p> <p><b>Subtarget:</b> Efficient public sector support for innovation with a focus on SMEs in the metal extractive and producing sector.</p>	<p><b>Goal:</b> Luleå's regional innovation environments in the mining and metallurgical sector have international appeal.</p> <p><b>Subtarget:</b> Mining regions are increasing their innovation capacity based on their unique conditions.</p> <p><b>Subtarget:</b> Regional mineral strategies for innovation are grounded in combined regional leadership.</p>

## Five initiatives enables the growth vision for the Swedish mining industry

<b>Competence</b> 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.	<b>Transport</b> A national plan of the rail-road infrastructure which supports the mining industry's need for good transportation.	<b>Permit handling</b> A common action plan with concerned authorities for increased discipline and higher pace of handling of permits within the boarders of current environmental legislation.	<b>Research and Development</b> 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.	<b>Energy</b> 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 2-7. 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).

### 2.2.3 A vision of growth for the Swedish mining industry

The Swedish Mining Association's recently released vision for the mining sectors growth<sup>22</sup> is shown in Figure 2-7. 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 alone may need to recruit about 5,000 people in the coming years. The vision presents a forecast showing that the mining industry may before 2025 have to recruit 10,000 to 15,000 personnel in order to cope with the expansion. The need is to be assessed at all levels. 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 mining.

<sup>22</sup> , 2012: The mining sector – an engine for growth in Sweden (in Swedish). SveMin, Stockholm. Download from [www.sveemin.se](http://www.sveemin.se)

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 recently presented Swedish Mineral Strategy<sup>23</sup> also 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 strategy<sup>24</sup>. 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 to create 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 in 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”<sup>25</sup>*

Metals can in theory be recycled countless times, with significant savings in energy and reduction of waste compared to primary processing. In addition recycling contributes to savings of scarce resources<sup>26</sup>. Although high recycling rates are achieved today for many metals, there is a loss of metals in the collection and processing chain, thus there is 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 considerable potential to decrease both energy consumption and losses of metals to waste. As examples the introduction of heap leaching of ores and crude concentrates can be mentioned. Furthermore, a systematic analysis of 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 cited above shows the

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23 2013. Sweden's mineral strategy for sustainable use of Sweden's mineral resources for growth in the whole nation. (In Swedish). Regeringskansliet

24 2012. Regional mineral strategies for Norrbotten and Västerbotten (In Swedish)

25 2013. Raw Materials in the Industrial Value Chain. An Overview. European Round Table. Download from [www.ert.eu](http://www.ert.eu)

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



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 productivity<sup>27</sup>. 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.

Increased resource and energy efficiency are some of the key drivers for the previously mentioned SMIFU project, as well as the SPIRE project.

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 is more like 6%. This can be exemplified by the company LKAB, which currently uses 4 TWh of energy annually. 50% of the energy is supplied by electricity and the remaining part by fossil fuels<sup>28</sup>. The growth of the company would require the consumption of 7 TWh of energy in year 2020, unless measures are taken to make the processes more efficient. Of special importance for improved energy efficiency for the Swedish mining companies are actions in connection with underground ventilation and improved energy efficiency in 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.

This Strategic Research and Innovation Agenda for the Mining and Metal Producing Industry (STRIM) thus emphasizes energy efficiency as an overarching goal. Key performance indicators are given in Chapter 4 for Agenda actions related to energy efficiency.

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<sup>27</sup> McKinsey Global Institute 2011: Resource revolution. Meeting the world’s need of energy, material food and water needs.

<sup>28</sup> 2012: LKAB Energy and Climate Strategy 2012-2030. LKAB.

## Examples of drivers (non-exhaustive) shaping the environment in which the mining and metals sector will operate (World Economic Forum 2010)

Economic	Environmental	Social	Technological	(Geo)political
<ul style="list-style-type: none"> <li>• Global economic growth</li> <li>• Emerging middle classes</li> <li>• Developmental states of economies</li> <li>• Access to capital</li> <li>• Financial openness</li> <li>• Global wealth distribution</li> <li>• Fiscal policy</li> <li>• Form of capitalism</li> </ul>	<ul style="list-style-type: none"> <li>• Climate change policy</li> <li>• Water availability</li> <li>• Effects of climate change/environmental degradation</li> <li>• Price of CO<sub>2</sub></li> <li>• Price of water</li> <li>• Global industry adaptation of environmental standards</li> <li>• Ecosystem valuation</li> <li>• Biodiversity regulation</li> </ul>	<ul style="list-style-type: none"> <li>• CSR expectations</li> <li>• Income inequality</li> <li>• Population growth</li> <li>• Consumer behaviour</li> <li>• Indigenous expectations</li> <li>• Skills gap</li> <li>• Health and safety expectations</li> </ul>	<ul style="list-style-type: none"> <li>• Automation of operations</li> <li>• Substitutions for minerals</li> <li>• Energy innovation</li> <li>• Resource scarcity</li> <li>• Low carbon technologies</li> <li>• New uses for materials</li> </ul>	<ul style="list-style-type: none"> <li>• Geopolitical instability</li> <li>• Level of state intervention in business</li> <li>• Degree of trade liberalisation</li> <li>• Resource nationalism</li> <li>• Resource management</li> <li>• Protectionism</li> <li>• Energy security policy</li> <li>• Corruption</li> <li>• Global governance</li> <li>• Quality of public governance</li> <li>• Geopolitical power shifts</li> </ul>

### 2.3 INTERNATIONAL OUTLOOK

In order to understand how the mining and metals sector may evolve over the period prior to 2030, the vision date set in this agenda, it is necessary to identify the social, technological, economic, environmental and geopolitical drivers that shape the environment in which the sector will operate. The World Economic Forum identified over 60 drivers in a report published in 2010<sup>29</sup> (Figure 2-8).

Based on the growth and jobs strategy, Europe 2020, and later clarified by the EU Council in the regulation of establishing Horizon 2020<sup>30</sup> – The Framework Programme for Research and Innovation (2014–2020), the following societal challenges have been highlighted as particularly important:

- Health, demographic change and wellbeing.
- Challenges for European bioeconomy: Food security, sustainable agriculture, marine and maritime research.
- Secure, clean and efficient energy.
- Smart, green and integrated transport.
- Climate action, resource efficiency and raw materials.
- Secure societies: Protecting the freedom and security of Europe and its citizens.

It is of interest to note that the European Commission identifies raw materials as being a societal challenge. Section 2.2.3 describes the actions regarded by the Swedish mining industry as being of particular importance in this respect. It should also be emphasized that any national action in research and innovation

Figure 2-8. Drivers shaping the future mining and metals sector until 2030 according to World Economic Forum (from WEG, Mining & Metals Scenarios to 2030, WEF, 2010).

<sup>29</sup> Mining & Metals Scenarios to 2030, WEF, 2010

<sup>30</sup> COM(2011) 808 final

within the raw materials sector should strive for leverage based on Nordic and European initiatives such as Horizon 2020. Based on the fact that raw materials are identified as a societal challenge, it is anticipated that measures will be taken within the framework of Horizon 2020 and the Swedish mining industry is willing to take a lead in responding to any such measures.

A strategic research and innovation agenda for the Swedish mining industry should also look into the state of the art in other parts of the world where research and innovation within the sector are at the forefront such as in Australia and Canada. The SMIFU II project<sup>31</sup> mapped the state of the art within all areas covered by the project. The full documentation of all scoping studies conducted within the SMIFU II project covers 1,800 pages and is available for the consortium in prioritizing further actions in forthcoming national as well as international RDI programmes. In addition to the international initiatives described in the SMIFU II materials, it is worth mentioning the *Deep Exploration Technologies Initiative*<sup>32</sup> in Australia which addresses actions described in this Agenda in section 4.1.

The European Technology Platform on Sustainable Mineral Resources has been in operation since 2005. Since its initiation, the Swedish mining industry and Luleå University of Technology have been active in developing prioritized measures within ETP SMR and have also been instrumental in developing the strategic research agendas of the ETP SMR. The current SRA of ETP SMR is under revision and it is anticipated that the updated version will be published during spring 2013. The 2009 version of the SRA is available on the Internet<sup>33</sup>.

In 1998, the National Mining Association and the U.S. Department of Energy developed *The Future Begins with Mining: A Vision of the Mining Industry of the Future*. This document defined a long-term vision of the U.S. mining industry and established long-term goals for the industry. Based on this, an *Exploration and Mining Technology Roadmap*<sup>34</sup> was published in 2002.

## 2.4 RELATIONSHIPS TO OTHER RESEARCH AND INNOVATION AGENDAS

The STRIM Agenda has furthermore been defined against the other agendas presented below, where we see a potential for future collaboration on a project basis:

### IoT Agenda (Forsknings och Innovationsagenda IoT för Sverige)

Internet of Things (IoT) is a collective phrase for the development of sensor- and computer-based machinery, vehicles, consumer goods, household equipment,

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31 Lindqvist. P.-A., 2012. Sustainable mining and innovation for the future. Research, development and innovation programme. RTC, Luleå

32 <http://detcrc.com.au>

33 <http://www.etpsmr.org/index.php?option=comcontent&view=article&id=14&Itemid=13>

34 <http://www1.eere.energy.gov/manufacturing/resources/mining/pdfs/emroadmap.pdf>

clothes and other items. Sensor- and computer-based mining equipment is a key development area for the mining and supplier industry and thus any co-ordinated actions within this field should be a joint effort between the STRIM Agenda and IoT.

### **Process-IT Innovations**

Process-IT Innovations 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 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.

Also, collaboration for European leverage is seen as an activity in which strong collaboration is called for.

### **The Agenda for gender aspects in the mining industry (Bryta malm och könsmonster)**

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 organizational research as a field of excellence in the Swedish mining sector. The gender agenda is integrated into the STRIM agenda (see section 4.7)



**The Agenda for the Swedish steel industry  
(Nationell samling för metalliska material)**

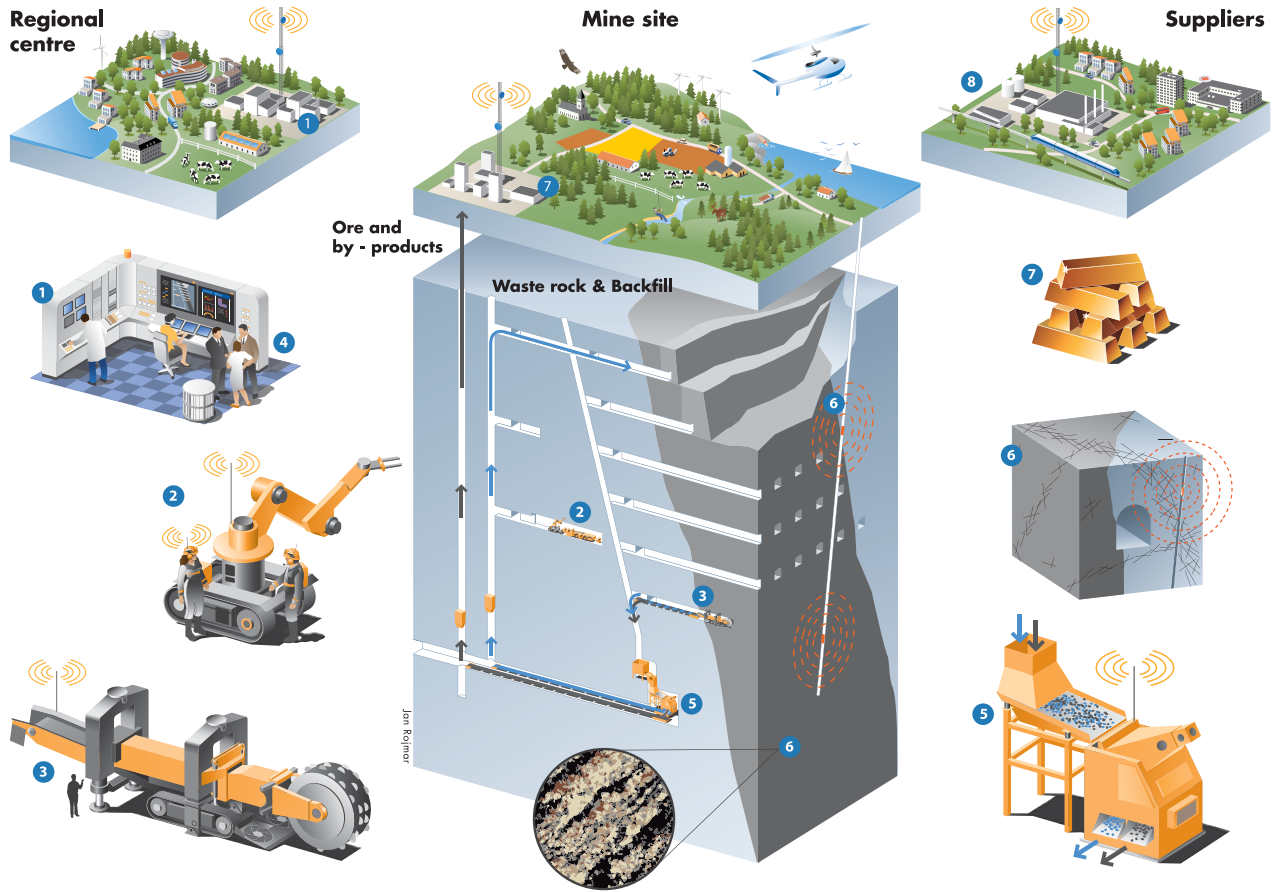
The Swedish steel agenda has been developed by Jernkontoret – the Swedish Steel Producers Association. The STRIM Agenda areas Metallurgy and Recycling have been evaluated against the agenda for the Swedish steel industry (see section 4.4).

**Programme SIO Waste (working title)**

The programme proposal SIO Waste is under development and is led by SP Technical Research Institute of Sweden. The vision of SIO Waste is 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. A successful programme will create innovations, employment opportunities and increase export of both technology and knowledge. This will contribute to sustainable development of the society and the industry.

The programme will gather all relevant Swedish clusters, for example Waste Refinery, The Research Program Towards Sustainable Waste Management, Post-graduate school Polytechnic Waste Research in Sweden POWRES, Avfall Sverige – Swedish Waste Management and Recycling Association. The programme application will be sent to the SIO programme call opening in September–October 2013.

The two programmes SIO Mining and Metallurgy and SIO Waste will collaborate within the areas of re-use and recycling of metal components in WEEE (waste electric electronic equipment) and residues from waste-to-energy. Collaboration will include both common RDI projects and a dialogue regarding future development of respective programmes.



Important features of sustainable mining and innovation for the future.  
 From RTC Rock Tech Centre, August 2012.





## 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 antropogenic 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](http://www.etpsmr.org)) and also actively participating 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 initiative by the Nordic Council to create a Nordic Centre of Excellence in Raw Materials at LTU (NordMin) is an important milestone along this path. LTU also has the ambition to be a leading partner in the foreseen Knowledge and Innovation Community on Raw Materials.
- 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](http://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.
- Foster international co-operation for example through EU grants, but also through direct commercial co-operation with partners outside Europe in a fashion already implemented through the Bergforsk subsidiary RTC. Research shall, from a holistic perspective, be conducted within essential parts of the research and innovation area covered by the Agenda.

*“Selecting the right research and development projects is crucial and we are continuing to invest significant resources in this field. Thomson Reuters named us as one of the world’s 100 most innovative companies in 2012, which is a significant acknowledgment of our efforts. Innovation is central to the long-term development of the Group.”*

OLOF FAXANDER, CEO SANDVIK,  
ANNUAL REPORT 2012

*“The most critical aspect of Boliden’s competitiveness is stable production processes as they provide the basis for value generation and for high safety levels and good environmental performance”*

LENNART EVRELL, CEO BOLIDEN,  
ANNUAL REPORT 2012







## 4 Agenda

The Strategic Research and Innovation Agenda for the Swedish Metals Extractive and Producing Industry (STRIM) is subdivided for simplicity into seven main areas:

- Deep Innovative Exploration.
- Mining.
- Mineral Processing.
- Recycling and Metallurgy.
- Reclamation/Environmental Performance.
- Attractive Workplaces.
- Gender Equality in Mining.

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

In the work with the STRIM agenda the content has been revised and merged with a separate agenda for gender equal mining (see chapter 4.7). The main part of the agenda constitutes a revised version of the SMIFU II report (chapters 4.2-4.6). The Deep Innovative Exploration agenda (chapter 4.1) has been added to include the complete primary resources value chain.

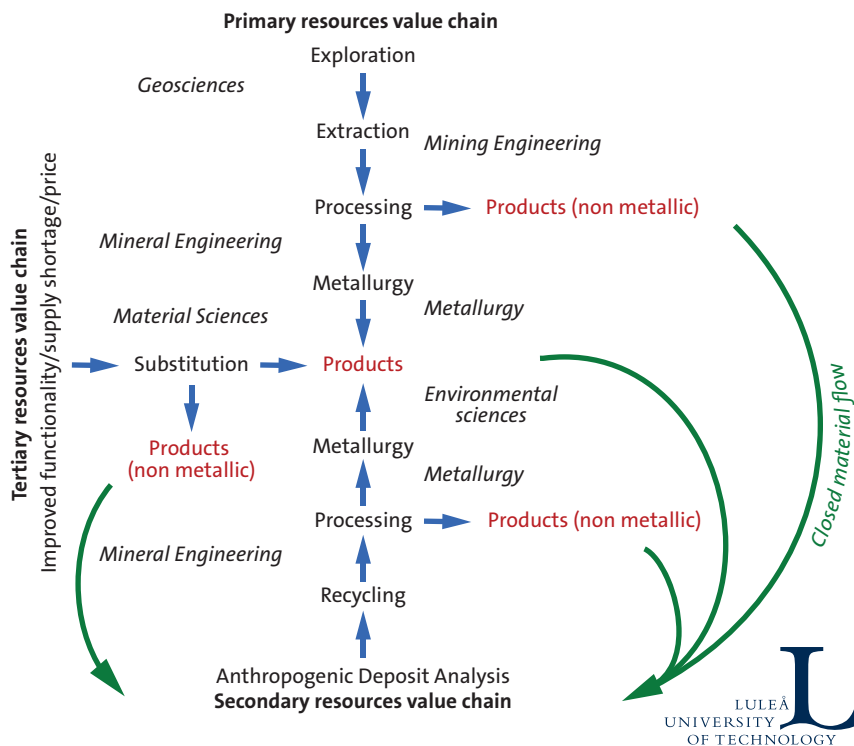


Figure 4-1. Raw material value chain. This agenda addresses the primary and secondary value chains. Secondary value chain also includes mine waste and tailings from processing. All value chains lead to products (red) utilizing research and innovation within the different steps defined (black). The research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

## 4.1 DEEP INNOVATIVE EXPLORATION

The proposal is made for a Deep Innovative Exploration Agenda owing to the need to improve the supply of metals and minerals from domestic resources.

### 4.1.1 Vision

Deep innovative 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 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 is to a large extent



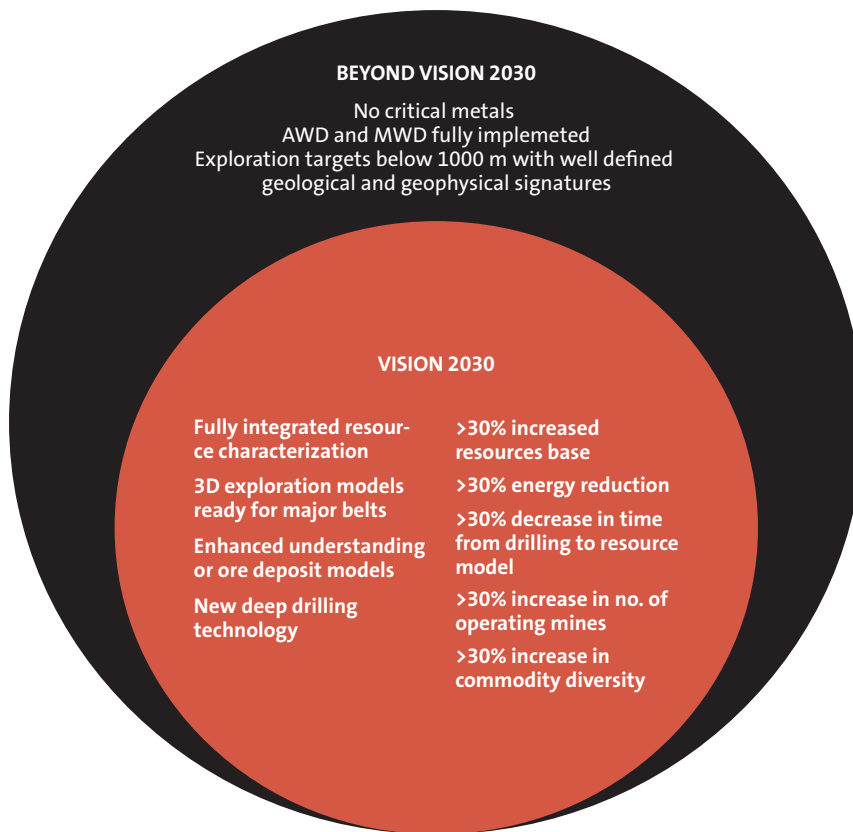


Figure 4-2 Vision 2030 and Key Performance Indicators for deep innovative exploration. AWD – analyze while drilling, MWD – measure while drilling.

due to the lack of many commodities in European crust, i.e. the geological potential is lacking. However, this is mainly based on models that rely on the current 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 will exhaust known mineral resources without exploration. 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 15 billion in 2010. In Europe, the exploration expenditure was about USD 415 million, which corresponds to less than 3% of the global expenditure. The amount of money invested in exploration per square

kilometre is also much lower in Europe compared to elsewhere in the world. With this relationship there is no indication that Europe's import dependence will decrease. On the contrary, 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. Europe has a very good potential for the extraction of "critical metals", and is a leading technology provider for underground mining.

In Europe, especially in the central and southern parts, competition for land is a major concern for the extractive industry. At the same time, there are fewer and fewer new "world class" discoveries being made on the surface, and exploration will in the future be focussed 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 "blind" and 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, to implement a better understanding for where the mineral deposits have been formed in Sweden and finally to build up knowledge and develop skills among 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 innovative exploration should target commodities that already exist in Sweden in general. Specific focus should be centred on ferrous, base, precious and critical commodities, bearing in mind that within the timeframe of the project the criticality aspect for some currently critical materials may change.

The deep innovative exploration agenda encompasses six main areas:

- New drilling technology for deep (+1,000 m) drill holes "*Technology*"
  - Deep + 1,000 m drill holes with master drill hole.
  - Fan- and/or cone-type drilling patterns at depth, developed MWD.

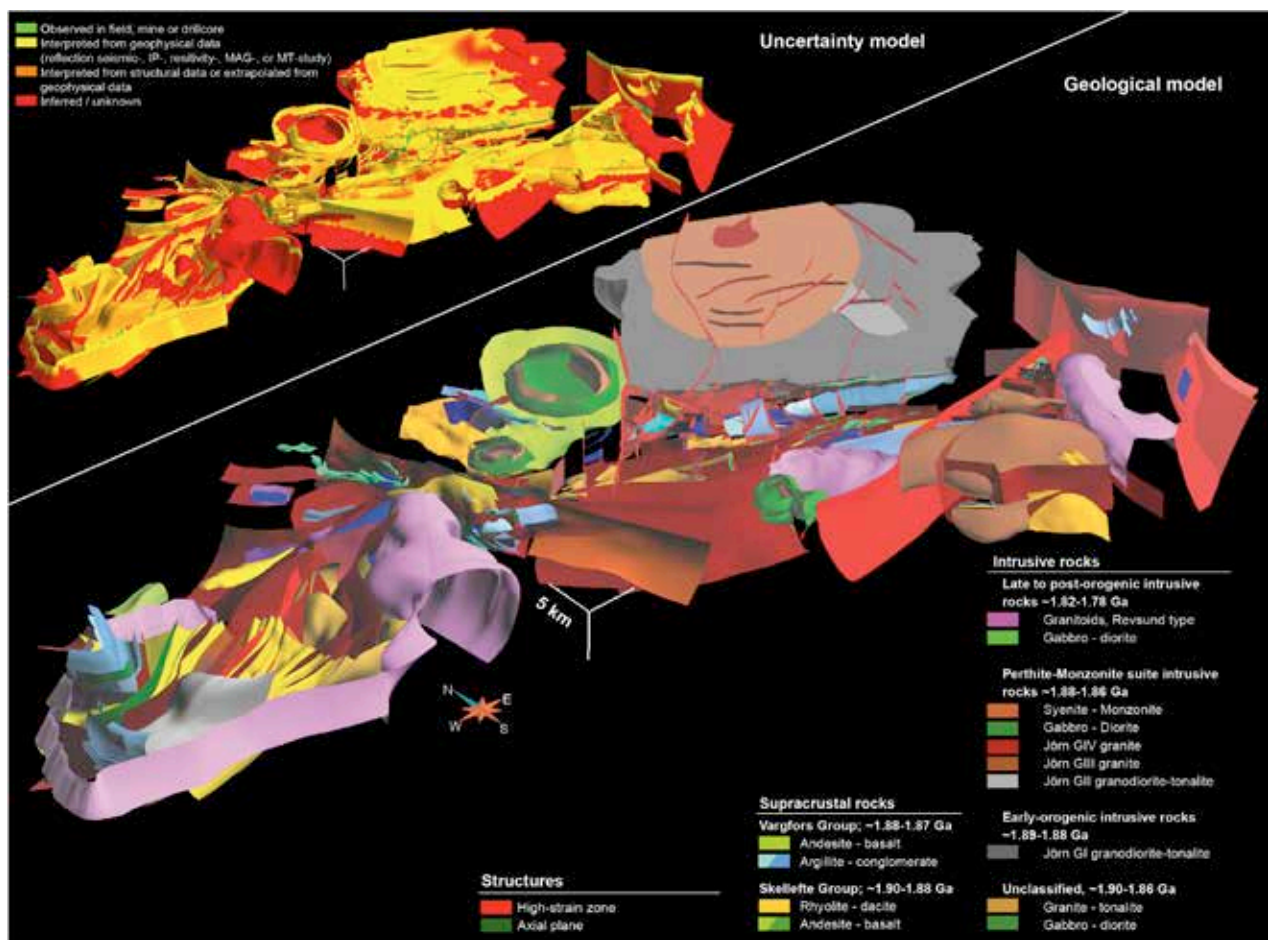


Figure 4-3. 3D-model and uncertainty model of the Skellefte district (from Bauer unpublished).

- 4D modelling of resources “*Location*”
  - Three-dimensional models of the Swedish crust in all areas of high potential for deep mineralization with a target depth of 4–5 km.
  - Models of the evolution and formation of geology and mineralization over time: Four-dimensional modelling.
- Development of new, deep penetrating geophysical techniques “*Penetration*”
  - Develop new seismic 3D tomography 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 methods with improved resolution at depths below 1,000 m.
- Conceptual modelling of deposit types “*Formation*”
  - Establish genetic models for major ore types in Sweden. Target: genetic models for deposits of critical minerals with economic potential.

- Define exploration targets for the most pertinent ore types in Sweden at depth. Target: increased investment in deep exploration in Sweden.
- Building knowledge and developing skills in Europe “*Education*”
  - Define a knowledge base of metals and minerals in Sweden. Target: implement the learning of economic geology based on Swedish resources in Swedish universities.
  - Training of Swedish industry, improving skills in the staffs of industry and survey organisations for future forefront predictive targeting of resources in Sweden.
- Integration of data into real-time geometallurgical tools “*Integration*”
  - Developing tools for data collection while drilling; 3D camera, scans, analysis while drilling (AWD), downscaled XRF, 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 and non-technology-based actions.

Technology based:

- 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 visualization 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.

*Non-technology based:*

- 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.

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.

#### **4.1.3 Research and innovation needs and strategies and actions**

Short-term needs 2014–2016

- Based on the results of current 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 making technical specifications for new exploration technologies. Launch a technology-based project on new drilling and geophysical techniques.
- Build visualization centres and publish predictive models for Sweden 3D.

Medium-term needs 2017–2020

- Intensive field work, pilot actions on new exploration techniques, feeding 3-4D models with data and further adjustment of acquisition parameters. Testing genetic models with predictive models in the test areas.
- Potential verification of 3D models and new geophysical equipment by deep drilling in test areas. Start to utilise results in training across Europe.

Long-term needs, 2020 and beyond

- Training of decision makers for better resource governance, actively promote results among exploration industry at large. Proven new deep drilling and deep geophysical techniques.

#### **4.1.4 Expected impact**

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.

*Economic*

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

## Social

- Fewer problems with access to space in densely populated areas.
- Lead to 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, potential and predictive models will lead to improved governance of Swedish resources.

## 4.2 MINING

The agenda area Mining is based on the updated visions and ideas presented in SMIFU II<sup>35</sup>.

### 4.2.1 Vision

The long-term vision for 2030 and beyond (Fig. 4-4) 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 CO<sub>2</sub> emissions (by 30%) and lower ore losses (by 30%).

The long-term vision can be achieved through the following measures:

- Resource characterization that results in a “mathematical copy” of the rock mass, i.e. a detailed description of all the elements (rock material, joints, faults, mineralogy, geometallurgy etc.) constituting the rock mass.
- Improved mining methods and processes.
- More continuous processes.
- Fewer man-hours per ton produced.
- Fully remote-controlled mining operations.
- More energy-efficient extraction.
- Decrease in seismic hazards and mitigation of the consequences of mining-induced seismic events.
- Decrease in uncontrolled rock falls by 20% compared to 2010.
- Cost-effective well-designed rock support systems that are able to sustain either large deformations or bursting conditions.

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<sup>35</sup> Lindqvist, P.-A., 2012. Sustainable mining and innovation for the future. Research, development and innovation programme. RTC, Luleå

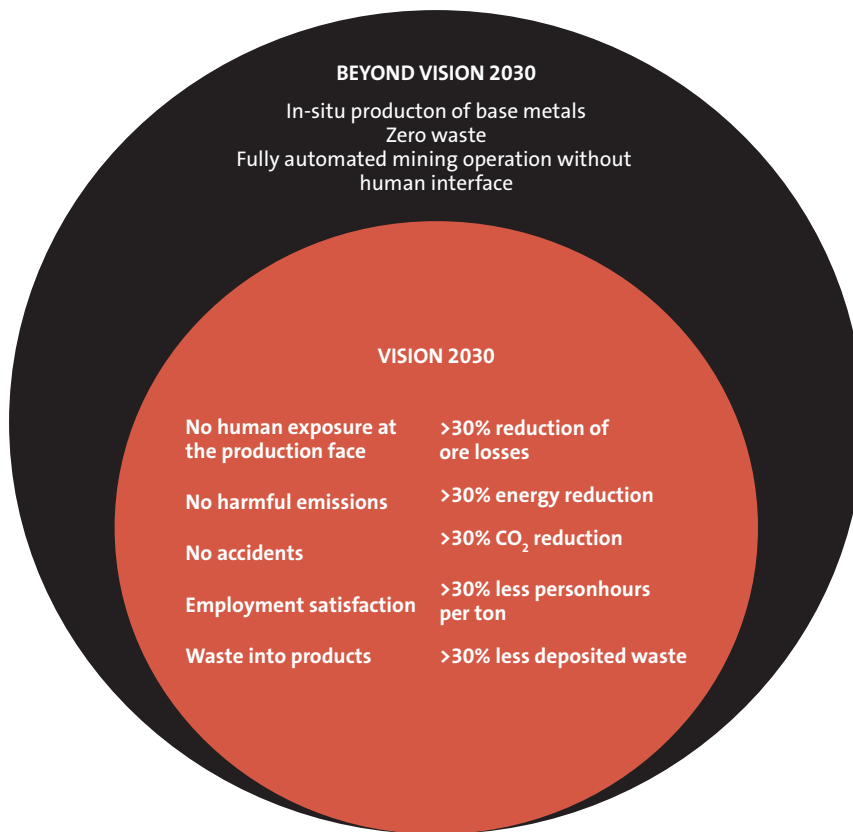


Figure 4-4. Vision 2030 and Key Performance Indicators for Mining.

- An understanding of all major rock breakage and comminution processes.
- Increased ore recovery through an understanding of the behaviour of fragmented rock.
- Robust and reliable mining equipment.
- All relevant process information collected into one control system to achieve online monitoring, control and optimization 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.

#### 4.2.2 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 greater depth, efficient mining processes will be of the utmost importance. At present, there is a lack of a systematic approach to the mining process. This leads to sub-optimized unit operations and low system efficiency. Each unit operation of the mining process needs to be improved and optimized, and the full mining process needs to be controlled and optimized.

A sound knowledge of the resource serves as a basis for effective extraction and use 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. Generally four kinds of data are collected and corresponding models are established: 1) geological, 2) geophysical, 3) rock mechanical and 4) geometallurgical (Table 4-1). Novel analysis techniques exist in all these areas. In geology methods such as digital photogrammetry, optical borehole imaging (OBI), drill core scanning by X-ray fluorescence and hyperspectral methods, measurement while drilling (MWD) and on-line analysis (analysis while drilling) are currently available, although the techniques are only being adopted by the mines at a very slow rate. 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

Table 4-1. Front and end-users of different data utilised in resource characterisation.

Area	Data	Front-user	Model	End-user
Geology	Lithology	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 behaviour	Engineering geologist	Geomechanical model	Mining engineer, Production engineer, Management
Geometallurgy	Comminution properties	Geologist, Geometallurgist, Minerals processing engineer	Geometallurgical model	Production engineer Management
	Concentration properties	Geologist, Geometallurgist, Minerals processing engineer	Geometallurgical model	Production engineer Management, Minerals processing engineer
	Tailing properties	Geologist, Geometallurgist, Minerals processing engineer, Environmental engineer	Geometallurgical model	Production engineer Management, Minerals processing engineer, Environmental engineer

stress state require techniques of their own. Continuous measurement techniques are available (such as CSIRO HI, doorstopper and MWD) but the mining industry is making slow progress in their utilization.

Geometallurgical analysis techniques can be divided into two classes: 1) mineralogical methods and 2) geometallurgical tests. The purpose of using the 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. Geometallurgical models and programs are still very few in the world and in Sweden the first efforts have been made in Kiruna by LKAB.

Knowledge of the resources in mining operations is currently in many ways incomplete. Gaps exist in data collection, subjective characterization and between different disciplines. Cross-disciplinary usage of the data is limited in mining operations. For example geological and rock mechanical models are separate and use very little data from each other. Also, some of the relevant data is underused or is lost during the data processing. For example, in the block model use is only made of the grade of elements considered valuable and rock density information. However, ore deposits commonly contain a number of valuable minor components, which may have a potential for extraction.

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 the subjective characterization, the future needs according to the industry are more digital tunnel mapping, and automatic, on-line, more objective and less time-consuming characterization methods.

Data gaps exist due to the current lack of reliable on-line sensing techniques. One identified problem associated with the introduction of new characterization 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 surrounding rock mass.

The Nordic countries have a strong and innovative industry related to on-line analysis and measurement (e.g. Vattenfall, IMA Engineering, Specim and Outotec). However, the mining industry is conservative in adopting this new technology. The lack of compiled open source test data also leads to the unnecessary duplication of work at several sites.

The mining process from in-situ rock mass to the final mill product with fully liberated value minerals consists of a chain of unit operations that all im-

pact, and are influenced by, the fragmentation. From a production point of view, fragmentation is a key parameter for the function of all major mining processes. Models in connection with blasting are either 'size distribution function'-oriented or material behaviour-oriented, based on artificial material solutions. Blasting is a crucial activity that affects the fragmentation to a considerable extent. 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) and the damage induced on the infrastructure by blasting is important. All this together contributes towards improving ore recovery and minimizing dilution.

The results of blasting in terms of the behaviour of the blasted rock also has a major impact on loading and haulage of the material, particularly the influence of large pieces or boulders. Deformation properties (shear deformation, swell) during the loading and unloading of buckets and cars in loading and transportation systems are important properties of the fragmented material. The automation of loading and hauling will be strongly influenced by the ability to control the size distribution of the ore, and frequent boulders will jeopardize any attempt to automate LHD operations.

Fragment size distribution is also very important in the filling and drawing of shafts and bins. Many serious problems with hang-ups, jamming or other flow problems in ore shafts are also related to the inability to control fragmentation and especially the occurrence of boulders. These problems will have a negative influence on production and production scheduling, and will create additional shaft wear while at the same time generating unsafe or even dangerous work situations when trying to restore the ore flow.

The deformation and compaction properties of fragmented rock during blasting against confined fragmented rock mass (sublevel caving, rill mining) are not well understood. This material also influences the load-bearing capacity and deformation properties as passive elements in rock mechanics stability calculations. For caving mining methods the gravitational flow and the draw point control are strongly influenced by size distribution of the blasted rock. Serious problems and production disruptions occur if the size distribution cannot be controlled and if the quantity of boulders cannot be maintained at a minimum level. Uncontrolled fragmentation will lead to reduced ore recovery and increased waste contamination.

The capacity and efficiency of crushing and grinding devices are strongly influenced by the fragment size distributions of the feed to the machines. For efficient separation of value minerals in mineral processing, the control of size distribution and full liberation of value minerals is a key factor for achieving high recovery.

Fragmented rock has its own deformation and flow properties that are quite different from both solid materials and fine-grained soils, the latter of which is



dealt with in the science of soil mechanics. Fragmented rock is very sensitive to the stress level in the material, the degree of packing and consolidation with time. The material also needs to expand (dilate) when it is deformed, and for this reason space for expansion is important. If the fragmented mass is confined, the “strength” of the material increases dramatically. For this reason, frictional properties and the roughness of walls in contact with fragmented rock also have a major impact on behaviour and flow properties. The behaviour of broken rock is not well understood and a fundamental understanding of fragmented rock is needed. Typical properties of flowing and stagnant fractured material, and of boundaries that influence the behaviour of fragmented rock, are: fragment size distribution, particularly large sizes and boulders, internal angle of friction, dilation, degree of packing and consolidation, bulk density, confinement and humidity/cohesion. The stress situation also plays a major role.

The level and variation of stresses in moving and stagnant material during gravity flow are to a large extent unknown. The theoretical base for the design of cave mining methods is also under discussion. As an example, it is generally believed that material drawn by gravity forces emanates from draw bodies in the fragmented material (theory of ellipsoids). This contradicts observations in the field that the waste rock content of the loaded material in sublevel caving varies. It appears that accepted draw body theories do not satisfactorily describe the real flow. It may be that disturbed flow is the general behaviour of mine caving gravity flow rather than formation of body shapes. The behaviour of fragmented rock is a science that is still in its infancy, and extensive research and development efforts are needed to support visions and goals in order to improve ore recovery.

The handling of the fragmented material requires stable drifts and ore passes as well as smoothly operating equipment (LHD's, trucks, boulder breakers). Fallouts of rock and/or shotcrete, caved orepasses and/or hang-ups in the orepasses and failing equipment/machines disturb the material flow. A ground control strategy and an orepass management plan for deep mines are necessary to minimize ground-related disturbance.

Mining equipment operates in extreme environments and equipment design, maintenance and operation needs to be optimized 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 minimized.

The operating environment factors influence the failure rate and behaviour, but are rarely adequately addressed in the analysis and design of mining equip-

ment. Missing, incomplete or inaccurate data for the analysis of equipment failure leads to labour-intensive studies of a small part of a system, or to a statistically incorrect analysis of complex systems. In addition, there is a general lack of knowledge of how and why components fail and of the consequences of failures.

High equipment availability needs to be supported by effective maintenance programmes. The programme used today is often very general and not adapted to suit varying operational conditions, machine age etc. Maintenance programmes that come from the equipment suppliers do not always fulfil the needs and expectations of the users (Mean time between failure, cost, etc.).

Reliability studies have in a broad sense been carried out in connection with open pit and underground mining. Most of the studies were made 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 as the most general case of reliability analysis 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. There is a need for studies of failure rate variation, remaining useful life of components, optimal maintenance strategy, maintenance scheduling and spare parts management in a complete and general way. It may be concluded that there is a considerable potential for improving mining economy, safety and product quality through reliability studies in mining.

The increasing environmental concerns for the Swedish mining industry create a specific focus on energy reduction in the mining process. Media is one of the major energy consumers in mining, and for underground mining ventilation accounts for a major share of the total energy consumption and a significant part of the operating cost for a mine. Efficient ventilation will become 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 jeopardize 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. A prime concern for deep mines is the issues related to rock mechanics and ground support. Examples are:

- Stress magnitudes exceeding strength of the intact rock, geological structures and the rock mass, e.g., mining-induced seismic events, large deformations and squeezing at ore contacts.
- Complex geology where the underground infrastructure will be situated makes it difficult to decide the location of and to design the infrastructure around the production areas.
- Rock support issues, for example over-stressed, over-strained and non-functional ground support systems, expensive and time-consuming installation methods, high material costs especially in seismically active mining areas.

There has been a great deal of new experience acquisition and development in mining seismology related to deep mining during recent years. Seismic networks now operate in numerous mines worldwide and the seismic events are detected and localized on a routine basis in almost every seismically active mine. Therefore, there are now greater 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 as unpredictable and remains one of the greatest challenges, especially in deep mining. New advances, based on high quality data and tools, are clearly needed to improve the rockburst mitigation and new research is necessary, especially for deep mining.

The traditional deterministic methods used for underground mine design typically do not consider the inherent variability in the rock mass properties. Therefore, there is a need for stochastic methods, which incorporate the variability and uncertainties of the rock mass properties. To achieve a reasonable degree of accuracy in the results with the numerical software available today, the number of required simulations is very high. There is therefore a need for the development of probabilistic numerical methods, which are more efficient and can produce results with accuracy acceptable for the mine design.

The success of the numerical analysis is based on the accuracy of the input data and the knowledge of the level of their uncertainty and, of course, the relevance of the input data is of the highest importance. However, the output from conventional numerical analysis does only indicate where plastic flow will occur and the development of shear bands and volumetric strain concentrations. No information can be obtained regarding whether cracks or fallouts are formed.

The present design of rock support is based on the philosophy that the support should help 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, laboratory – and numerical studies. However, the laboratory testing methods available for seismic loading are mainly based on energy capacity with no consideration given to the frequency content of the seismic events and the rock mass behaviour. Furthermore, comprehensive information from real seismic events, combining the seismic characteristics and the rock mass - rock support system response is sparse. The seismic event can, if a seismic network is available, be analysed in great detail. However, the “transfer function” between the source of the event and the drift or stope affected by the seismic waves is not known today. How can the output from the seismic network be used to decide upon the size of the openings and intersections and the design of the drifts or stopes and the rock support? Thorough examinations of seismic hazards (with respect to damage to support and rock mass and the source characteristics of the seismic event) directly after the occurrence are important. Experience from large-scale tests to mimic the dynamic loading from a seismic event, has revealed that these tests have to be thoroughly designed using numerical analyses and trial tests. Numerical studies can make a contribution, but the models have to be validated against the real behaviour.

The design of rock support worldwide is generally controlled by the traditions 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. These methods have later, in many cases, attracted worldwide attention despite their limitations and flaws. The solutions obtained are therefore often not the optimum solutions. They may even be dangerous since they are not always conservative.

Several mines in Sweden will face or are already facing the challenge of transition from open pit to underground mining. The transition process from surface to underground mining is extremely important in order to maintain production rate and positive cash flow during the transition period. Technology transition must be planned far in advance to optimize equipment usage,

planning tools and other facilities that have to follow the production from surface to underground.

Continuous excavation is a possible solution for some mining operations. The use of continuous excavation would facilitate a more continuous process, which would in turn 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. These machines are part of a continuous excavation system. 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 total change of mining system needed 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 improvements in cutter head and machine system design. It is also concluded that new developments in mobile tunnel miners are ongoing and at the same time represent an interesting alternative in certain underground environments.

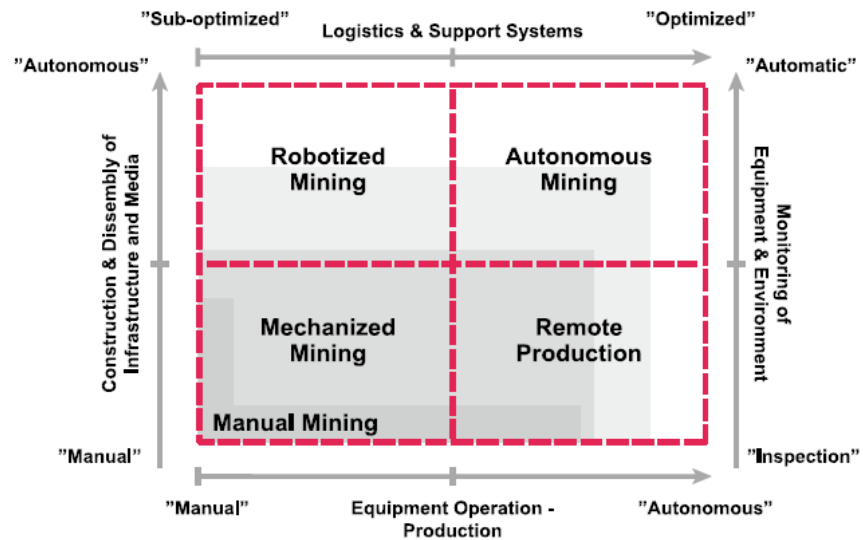
The automation of mobile equipment is also one way of minimizing human exposure to high-risk areas and unfavourable climate, and of improving efficiency to compensate for the more unfavourable production conditions. A study has been made in SMIFU II on remote control and automation in mining production areas. All unit operations at the production area were included in the study. The conclusion reached is that 9% of the tasks that were analysed today fulfil 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.

Remote control and automation are necessary, not only for production equipment but also for infrastructure, support systems and monitoring. A proposed road map to reach the vision of no human exposure through fully autonomous mines is illustrated in Figure 4-5.

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



Figure 4-5. Road map to reach the vision of fully autonomous mining operations without human presence in the production areas. The darker grey box illustrates the current status. The lighter grey 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.



the surface), all have their 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 standalone control loops, equipped with local onboard control systems, usually with an operator panel or workstation to manually execute the different tasks and fine-tune the operational parameters. For these cases, there is a requirement for 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. Characteristic examples are the utilization of the production data such as drilled metres, scaled hours, hammer hours etc., together with the downtime and utilization that have been manually collected and reported into databases, without advanced and integrated analysis, performance evaluation, or optimization activities. Experience indicates that the deviation between planned and actual production from the mine often cannot be correlated with available data. This difficulty is probably due to the fact that the data are being stored in different (non-integrated) systems and also that there is an extended lack of measured data.

The mine is a very large-scale complex system that incorporates the need for the real-time acquisition of thousands of signals, analysing them, calculating optimal control strategies and finally distributing the planned control strategy in thousands of control loops. Such a control scheme, which can also be called dynamic real-time optimization, has to be applied throughout the mine area for improving the entire processes and fine-tuning them.

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 system are in fact collections of many sub-systems that need to be optimized and controlled to achieve the planned objective. In the field of mining, these systems can be considered as being: a) classical operation-independent processes that should still fulfil specific objectives and for reaching that goal, other types of systems should also be incorporated and be interactive, b) for reaching a general goal, e.g. ore production optimization, each involved system should be autonomously controlled but at the same time the overall process of production should also be controlled as a separate and integrated system.

#### **4.2.3 Research and innovation needs and strategies and actions**

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

##### **4.2.3.1 Resource characterization**

Short- to medium-term

- Apply use new resource characterisation techniques for measuring geological, rock mechanical and metallurgical properties by “On-line analysis” techniques.
- Facilitate the use of new monitoring methods for rock mechanics by adapting the use of existing “Sensor” techniques.
- New “Resource management” tools which enable real-time data integration, effective data visualisation production planning and scenario analysis.
- Developing a tool for “Resource efficiency assessment” and sustainability evaluation of existing and planned mining operation.

Long-term:

- Facilitating the use of new on-line analysis tools, sensing methods, and management tools, all integrated in a geometallurgical model and resource management system.
- Develop interdisciplinary tools for rock mass characterization. A common visualization platform based on an open source Virtual Reality technique could possibly be used.
- Development and implementation of novel resource characterization techniques.

- Develop MWD and AWD (analysis while drilling) technology to deliver data for on-line process design, optimization, prediction and planning for ore delineation, rock mechanics, drilling, continuous mechanical excavation, blasting, crushing and grinding or milling.

#### **4.2.3.2 Efficient unit operations for mining**

Short- to medium-term

- Develop the unit operations to facilitate automation and efficient extraction.
- Improve the efficiency of the 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 effect on fragmentation.
- 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 have to be optimized).
- Development of continuous excavation methods adapted to Swedish mining conditions.
- Minimizing the environmental effects by:
  - Reducing the amount of mine waste.
  - Developing more selective mining methods.
  - Developing a near-face processing scheme.

#### **4.2.3.3 Optimized processes and automation**

Short- to medium-term

- Automation and optimization of mine ventilation and fleet monitoring and dispatch systems.
- Manage effective transition from open pit to underground mining.
- Model-predictive control of unit operations.
- Production prediction systems, calculation and prediction of KPIs in real time.
- Integration of maintenance systems into scheduling models.
- Fleet monitoring and control.
- Ventilation monitoring and control.

Long-term:

- Improve and optimise the overall mining process:
  - Apply a systems approach using, for example, discrete event simulation combined with optimization methods, e.g. mixed integer linear programming (MILP).

- Optimize the utilization of mining equipment and automation:
  - Robotizing and automation of unit operations.

In order to optimize the mining process and integrate all control loops in the mine, the focus should be on developing the dynamic simulation models and optimisation tools as well as the acquisition and communication of real-time data (integrated process control).

#### 4.2.3.4 Improved ore recovery and fragmentation

Short- to medium-term

- Studies of problems related to increased mining depth.
- Full-scale gravity flow studies, possibly based on draw point or bucket monitoring or active markers.
- Development of numerical models and conceptual studies
- Mine verification study.
- Review of previous work and theory formulation.
- Laboratory tests of physical material properties, possibly physical model scaled tests.

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.
- Address deep mining related issues such as blast-hole stability, detonation of explosives (e.g. avoid dead pressure) and blast damage.
- Develop understanding of the behaviour of fragmented rock.
- Develop a better understanding of fundamental material properties. 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. This work will also 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.

#### 4.2.3.5 Mining seismology

Increasing the 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 and monitoring and evaluation of real seismic events and the numerical analyses are done hand-in-hand.

Short- to medium-term

- Develop an understanding of the correlation between seismic hazards and mining depth.
- Develop an understanding of the difference in characteristics of different types of seismic events (shear events, strain burst, tensile cracks, collapse etc.).

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

Long-term

- Increased control and knowledge of seismic events.

#### **4.2.3.6 Rock Support and Numerical analysis of static and seismic conditions**

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

- 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.
- Improve numerical modelling capabilities, which describe well-constrained failure and post-failure deformation mechanisms.
- 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
- Evaluation of the performance of rock support systems and the rock mass – rock support system interaction.
- Understand static conditions – By monitoring and damage mapping assess the performance of the rock mass and the rock support system.
- 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.



Long-term:

- Seismicity – By thorough investigation of seismic hazards, evaluation of the rockburst mechanisms.
- Development of interpretation methods that can assist in judging whether failure surfaces and fallouts are formed.

#### **4.2.3.7 Breakage of hard rock**

Short- to medium-term

- Determine the best cutting tools design and evaluate optimum operational parameters in relation to rock mass properties. Numerical simulation, laboratory investigations and field tests should be considered. The focus of the research should be on developing cutting tools that require low cutting forces when cutting hard rock formations.

Long-term:

- Develop a full understanding of breakage mechanisms under cutting tools and to apply this knowledge to improving continuous mechanical excavation processes.
- *Develop Measurement While Grinding (MWG)* develop Measurement While Grinding technology and full-body modelling of mills with grinding charges to be able to continuously measure and dynamically control comminution circuits (jointly with mineral processing).

#### **4.2.3.8 Energy and infrastructure**

Short- to medium-term

- Improving and developing ventilation, for instance by optimising heat exchange and flow control.
- Developing new power sources.
- Developing mining processes, mine layout and infrastructure that enable minimized transports and efficient flows.
- Innovative processes such as near-to-face processing and continuous excavation needs to be considered and developed.

Long-term

- Reducing the environmental impact (the overall energy consumption and optimising the mine infrastructure).

#### **4.2.3.9 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 optimization.
- Models and equipment prototype design.

#### 4.2.3.10 Integrated process control

In order to achieve an optimized mining process 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.
- Localization and navigation systems.
- Traffic management systems.
- Sensor networks.
- Human interaction in automated systems.
- Automated inspection and image analysis.
- Human–machine interfaces and interaction.
- Automated reporting (IPT – right information to right person at right time).
- Information gathering systems.
- 3D Image processing.
- Video processing (generating data for control or dispatchers alarms and warnings).
- Robust and reliable sensors for machine automation.
- In-situ sensors for product quality measures, for example water content in concentrates or sensors embedded in pellets capable of following the flow of raw material.
- Energy harvesting capabilities (sensors that don't relay of external power supply and are capable of completely stand-alone operation).

Long-term

- “Plug & Play” (common control and communication architecture).
- Mobile machine monitoring and remote diagnostics.
- Augmented reality.
- Autonomous patrolling robots.
- Field robotics in order to facilitate autonomous mining.

- Sensors for mine environmental characterization (identification of fall-outs, road condition, gas detection, etc.).
- Model-based integrated decision-making and monitoring support systems.

#### 4.2.4 Expected impact

Technical:

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

Economic:

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

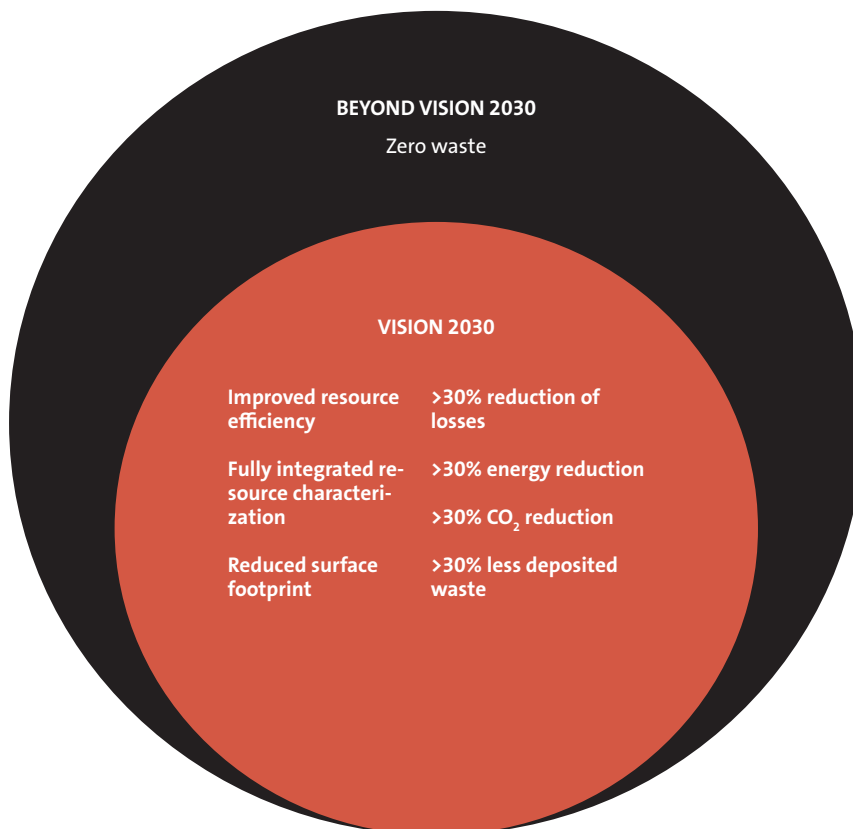


Figure 4-6. Vision 2030 and Key Performance Indicators for Mineral processing.

Environmental:

- Reduced energy consumption.
- Reduction of deposited waste on surface.
- Decrease in harmful emissions.
- Reduced CO<sub>2</sub>.

Social:

- Increased job satisfaction.

## **4.3 MINERAL PROCESSING**

### **4.3.1 Vision**

The resource efficiency within mineral processing will be significantly improved by 2030, resulting in lower energy consumption and related CO<sub>2</sub> emissions as well as reduced losses of valuable minerals during the course of processing. Innovative process design and control optimization of comminution and physical separation stages will make use of advanced analysis methods and online sensor technology (see Fig. 4-6).

### **4.3.2 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 from defined application properties. Available processes and technologies have matured during recent decades but are still some distance away from being 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 more complicated ore properties. Considering the general trends 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 of comminution devices today are often not optimal due to limited ore characterization, 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 the recent years through the adaptation, for instance, of high pressure grinding rolls and stirred media mills to ore comminution.

In comminution, models are 'laboratory rock test'-based, or in some cases assume artificial materials. In laboratory test-based models, fundamental material properties are not used, and when artificial material modelling is used, the basic material properties are assumed but the structure of such models makes it very difficult to relate them to the geological and mineralogical descriptions of rocks. Currently, many ore and waste rock properties used in the analysis and modelling of processes are determined through laboratory tests such as in mechanical excavation, blasting, crushing and milling. These tests are often time-consuming and costly. Consequently the number of samples and tests are reduced, which reduces the reliability and variability of the information about the deposit as a whole. Only in a few reports additional geological and mineralogical descriptions or images of thin sections of rocks are included. In a longer perspective, the approaches used today will not be sufficient and must be replaced by models that take into account mineralogy and texture. It is expected that present comminution devices may successively be replaced by machines such as the HPGR and stirred media mills.

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 valuable 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 intensity 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 underground mining sites. Also other approaches to improving the entire process, using for example 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.

The agglomeration (pelletizing, briquetting) 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 pelletizing of ore concentrates is mainly limited to iron ore, resulting in energy



savings and improved performance in the blast furnace. However, demand for the pelletizing processes can be expected to grow in the future and pelletization may be employed for other ores as well as for the recycling of materials.

In order to make iron ore pelletization as efficient as possible, it is crucial to minimize the recycling loads in balling circuits, caused by disturbances in the balling process. Another approach to effectivization of the iron making process is to increase the iron content in the pellets by using a binder that does not contaminate the pellets. Contamination leads to a decrease in iron making efficiency, increased consumption of flux additives, and increased slag production.

#### **4.3.3 Research and innovation needs and strategies and actions**

In the long-term perspective research is needed to:

- Develop and implement energy-efficient processes, particularly for ore comminution.
- Develop efficient separation processes for treating more finely dispersed, polymetallic ores.
- Improve and optimize mineral beneficiation processes towards better resource-efficiency and sustainability, i.e. reduction of waste rock and tailings, reduction of process water needed.
- Develop suitable pre-concentration processes for separation close to the mining production face.
- Develop new processes for the efficient extraction of valuable minerals from by-product and waste streams from existing mineral beneficiation plants.
- Understand the effect of different processing steps on the physicochemical properties of the ore.

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 to optimizing entire processing plants. The research needs and suggested short and medium-term actions involve both fundamental and applied research.

##### **4.3.3.1 Comminution of hard rocks**

For more efficient crushing and grinding, the currently existing processes need to be optimized or novel technologies have to be provided:

- Enhance mineral liberation by adjusting target particle size and breakage mechanism for grinding to ore texture and mineral associations.
- Develop integrated solutions for Measurement While Grinding using advanced on-line sensor technology.
- Optimize design and operating conditions of comminution devices using advanced modelling and simulation methods.

- Provide new breakage mechanisms and technologies for hard ore comminution with consideration to energy for grinding and wear characteristics.
- Develop Measurement While Grinding technology and full-body modelling of mills with grinding charges to be able to continuously measure and dynamically control comminution circuits (jointly with Breakage of Hard Rocks).

#### 4.3.3.2 Physical separation

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

- Investigate processing routes for pre-concentration 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, including fundamental studies of particle surface phenomena and bubble generation.
- Develop new separation technology for the effective separation of complex mixtures of minerals.
- Improve the understanding of the effect of flotation reagents on the processing behaviour of ore concentrates in downstream processes.

#### 4.3.3.3 Process systems engineering

In addition to the optimization 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 more complex flow sheets based on successive separation and size reduction to improve the efficiency of comminution circuits.
- Optimize the whole chain of ore comminution from in-situ rock mass to the final mill product based on the integrated modelling of blasting, mechanical cutting, crushing and grinding.
- Develop geometallurgical models together with innovative analysis methods for resource characterization for the design and control production along the entire chain from mining to mineral processing.
- Develop process designs for flexible plant operation in order to respond to ore domains of different mineralogical, textural and chemical composition.
- Develop strategies for the efficient management of process water.

#### 4.3.4 Expected impact

Technical:

- Providing designs for energy-efficient comminution.
- Providing innovative Measurement While Grinding solutions for reducing wear and enhanced mill control.

- Providing solutions for enhanced coarse and fine particle flotation.

**Economical:**

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

**Environmental:**

- Reduced CO<sub>2</sub> emissions due to decreased energy consumption.
- Less water usage due to reduced material amounts.
- Less material to be deposited.

**Social:**

- Improved social acceptance of mineral processing plant operation due to higher resource efficiency and less emissions and waste.

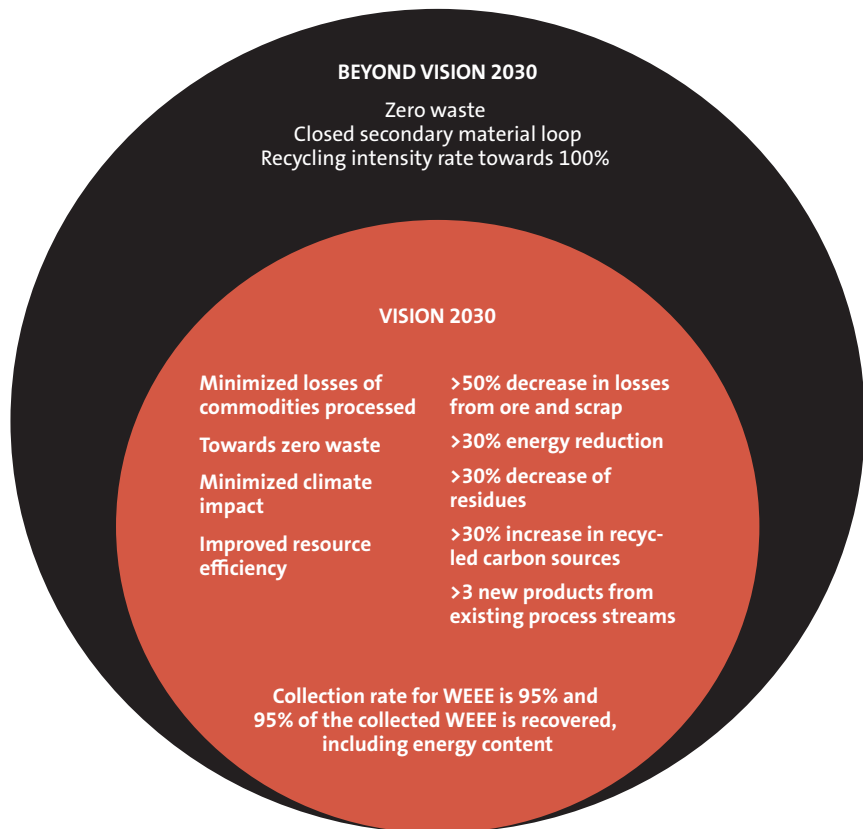


Figure 4-7. Vision 2030 and Key Performance Indicators for Metallurgy and Recycling.

## 4.4 RECYCLING AND METALLURGY

### 4.4.1 Vision

Through combined novel pre-treatment and metallurgical operations, to make full use of ore concentrates, scrap and residues in order to maximize the economic outcome and minimize the environmental impact of the entire process chain. Visions and Key Performance Indicators are displayed in Figure 4-7.

### 4.4.2 State of the Art

Sweden is one of the leading countries in Europe for the mining of iron, base metals (copper, zinc, lead) and precious metals such as silver and gold. Some of the ores are used for metals extraction within Sweden. The production figures for base and precious metals within Sweden are given in Figure 4-8.

The metal extraction is carried out by means of processes with very high demands for 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 residues, the proportions depending on the process. Some types of scrap are recovered in specially designed processes for treating scrap, such 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, fairly considerable quantities of scrap are used for cooling purposes in processes originally designed primarily to treat ores and concentrates.

Base metals are usually extracted from concentrates produced from complex sulphidic ores that contain other valuable metals and impurities such as Au, Ag, Pt, Pd, Ir, Sb, As, Bi etc. These other valuable metals and impurities may either follow the main product stream, such as gold follows copper until it is finally refined by electrolysis, or be enriched in residue streams, i.e. dust and sludge from



Figure 4-8. 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.

the gas purification operations or in the slag formed by the oxides. The content of some of the minor elements, such as i.e. As, Bi and Sb, in copper extraction, in many cases has a limiting impact on the extent of impure raw materials that can be used in the processes as these elements are detrimental for the final refining of copper in the electrolysis process. In the processes that are used for the extraction of base and precious metals from sulphidic ores and recycled materials, Boliden is in Sweden currently extracting Cu, Pb and Pb-alloys, Au, Ag, crude Se as well as Zn, Pt/Pd/Rh, part of the Ni and crude copper-telluride as intermediate products. An increased extraction of some of the minor elements into product streams as a bleed from the main product streams would increase the capacity to treat more new complex raw materials and thereby increase the raw material base, making some of the known mineralisations into ores.

Processes and business structures already exist for the collection, handling, marketing and processing of most of the larger metals (in terms of tonnage) contained in scrap. As an example, Boliden is one of the leading companies in the world for the recycling of WEEE, with over double the capacity to treat this type of scrap following the investment in another Kaldo plant which became operational in early 2012. The capacity to treat WEEE is today 120 kt annually. The share of metals produced from scrap in Sweden is illustrated in Figure 4-8. It should be pointed out that with the new Kaldo for smelting WEEE, the share of especially Au and Cu produced from recycled material will increase considerably. In Sweden there are some 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 characterized by a large number of smaller companies active within the sector.

The recycling of metals from rich material streams has been and will continue to be an attractive and economically viable business. Metals can always be extracted from scrap with a lower total energy consumption and usually also lower total environmental impact compared to production from ores. The recycling chain consists of collection, fragmentation, sorting, upgrading through physical processing steps followed by extraction of the metal contained in the various process streams using hydro- or pyrometallurgical methods. However, the separation of metals into the different material streams is not entirely comprehensive, thereby resulting in complex scrap concentrates, usually containing several metals in various concentrations, entering the extraction processes.

The process steps for extracting metals from ores, scrap and residues are for many metals highly interconnected. Residues containing metals or reductant/fuel with an economical value are recycled within the processes to the extent that is currently possible. Zinc contained in the galvanised scrap smelted in steelmaking is recovered within the base metals industry. Intermediate products from the production of one base metal are used in the production of another base metal. An increased extraction of metals, which are not fully recov-



ered today, will therefore require a thorough understanding of all parts of these interconnected production chains.

Ores, scrap and residues contain elements that are not recovered today, despite the fact that they exist in such amounts that their recovery could be economically viable. The same elements may also be impurities that are detrimental to existing metal production processes. One example of this is Sb, which can enter the smelter both from the ores and from, for example, electronic scrap. The intake of Sb has to be limited to quite low amounts as it is detrimental for the final refining of, for instance, copper. Both ores and scrap are becoming more and more complex in composition and several examples exist where an increased extraction would be favourable from the point of view of processing both ores and scrap. A holistic approach is therefore necessary in which 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, would have the potential to substantially increase the amount of recycled scrap as well as the capacity to process more impure scrap and ores. This potential would benefit from closer collaboration between smelters, mining companies and recycling companies.

Modern processes for the extraction of metals have been developed to a state where the utilisation of supplied or produced energy is very high. In a flash furnace for the production of copper, the energy produced from the combustion of sulphur into  $\text{SO}_2(\text{g})$  is fully utilised for smelting the material and the process can be carried out in such a way that no external energy is needed for the smelting, so called autogenous smelting. Heat contained in hot gases is recovered in waste heat boilers and most smelters have the capacity to supply both electricity and hot water in considerable amounts to the surrounding community if the need exists. There are, nevertheless, process streams that are not fully utilised, especially gas streams with a lower heat content and slag. There are also a number of material streams containing metals that also contain organic materials in such quantities that could be further utilised for reduction and energy recovery, thereby replacing mined fossil reductants such as coal and coke.

#### **4.4.3 Research and innovation needs and strategies and actions**

LTU has earlier been involved in several research projects on the bio-leaching and/or chemical leaching of sulphidic concentrates together with Boliden and with financing from several funding organisations as well as from Boliden. The focus has mainly been on the leaching of mineralisations that are today not ores due to a too low metal content or an impurity content that is too high for processing in the traditional way, i.e. beneficiation and smelting.

Research related to recycling within the metallurgical industry has recently been dealt with in a number of larger research programmes. The Steel-Eco cycle,

financed by MISTRA, has incorporated projects on ways to better utilize slags from the steel industry, on using waste from the recycling industry for preheating scrap, on recovery of the metal content in slags, on increasing the yield of alloying elements and on better sorting techniques for shredded scrap. Research projects have been carried out by Swerea MEFOS, LTU, KTH, Swerea KIMAB etc. The recently completed Steel Research Programme, financed by Vinnova, contained one project on products from slag for the construction industry, carried out at LTU. The Mining Research Programme, also financed by Vinnova, contained a project entitled “Wise process routes”, carried out at LTU which focused on the strategies for treating Sb-containing materials, from both the mining and the smelting point of view.

MISTRA has recently started a number of smaller projects within the programme “Closing the Loop”, in which the recycling of material streams is dealt with. As an example, LTU and Umeå University are together with SSAB Merox and Cementa, studying the possibility of increasing the use of steelmaking slag as raw material in the cement kiln.

Among research directly financed by the industry, it is worth mentioning a five-year grant from the smelting section within Boliden for research at LTU, partly connected with the recycling and process consequences of increased recycling. The Division of Industrial Metals Recycling at Chalmers, part of the Competence Centre for Recycling, CCR, at Chalmers, was started on the basis of a grant from Stena Metall AB.

The very high dependence within the EU on imported raw materials has been in focus in recent time. The question has been highlighted within the Raw Materials Initiative. A number of actions are presently in the pipeline, including the network ERAMIN, a KIC on raw materials, etc. The increasing production of metals through recycling is considered within Europe as being an important way of reducing the import dependence. For several of the metals of strategic importance for Europe, the base metals industry has the potential for playing an important role in European supplies of both ores and recycled scrap.

In addition to ongoing contract research between some companies and universities, there are very few ongoing research projects that address metallurgy and recycling within the base metals and precious metal sector with a holistic perspective in which mineral processing options, hydrometallurgy and pyrometallurgy are dealt with simultaneously in order to extract more from existing raw materials and eliminate impurities that limit the processing of scrap or minerals.

#### **4.4.3.1 Connection to other business sectors and their strategic research programmes**

The present research agenda for Metallurgy and Recycling within the mining industries’ research agenda focuses on the metallurgy and recycling conducted

within the base metals industry. The strategic agenda on “Resource efficient material utilisation” with participation from, among other bodies, Stena Recycling, IVL, Chalmers and KTH, will – in addition to questions on recycling – focus on new business models and collection of the scrap. The connection to the present agenda is within metallurgical process solutions for recycling. The strategic agenda for the steel industry will cover all aspects of hot processing into steel, both from ores and scrap. Some of the residue materials from the steel industry are or could be raw materials for the base metals industry, e.g. the zinc-containing dust produced in steelmaking. The scrap used in the production of steel originates partly from the scrapping of products that also yield scrap fractions containing base metal. For both the steel industry and the base metals industry, it is increasingly important to be able to guarantee the quality, from both the product property and the leaching point of view, of slags used in applications outside the plant, e.g. for road construction. Therefore, although the processing of base metals and steel differs considerably, common interests exist within several areas. In addition to the areas specified above, mention should be made of improved process modelling and measurement techniques for increasing the yield in the processes.

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 iron-making. Another product is the pellet used in the production of direct reduced iron, DRI, for example in processes that use natural gas for reduction. As very pure steel scrap is becoming less and less available, it is important 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 is an alternative that is becoming more interesting and which would contribute to lower emissions of greenhouse gases, and is thus another area of common interest between the mining and the steel industries.

#### **4.4.3.2 Actions**

The recycling of metals contained in material streams where the recycling can be carried out in an economically viable way has already been introduced. However, many of the material streams are very complex in composition and one of the challenges for the future is to increase the yield of the metals already recovered. It is even more important to recover more of the elements contained in the material streams, i.e. ore, scrap and residues that are not extracted today but are instead lost in by-product or waste streams. The composition of ores and scrap is gradually changing as lower grade ores and scrap from new consumer products are being used as raw materials. There are large mineral deposits which, although they have been known for a long time, cannot be converted into ores with conventional mineral processing methods owing to their complexity and fine-grained structure.

Future processes will have to be adapted to varying raw material composition. The access to new measurement techniques, such as the on-line XRF measurement technique, would then be an asset. There is also considerable flexibility in the existing processes, which is not fully utilised today. Due to increased recycling, some elements will be enriched in, for example, slag. Al and Cr concentrations in slag have already increased and are expected to increase still further resulting in changed properties for the slag and thereby possibly increased metal losses from the slag which would also jeopardize the properties of the slag as a product. Another challenge would be to increase the amount of materials collected by finding the appropriate collection methods and suitable ways of motivating the consumers to sort and hand in used consumer products. Many studies performed on the recycling of mobile telephones, for example, indicate a very low collection rate.

A further increase in the energy efficiency of the processes through energy recovery from hot gases and slag that is not used today is partially dependent on having a market for the energy recovered. With a market at hand, there are possibilities for increased energy recovery. In addition, a thorough comparison should be made between the energy efficiency levels of different processing alternatives, e.g. between different pyro- and hydrometallurgical processing alternatives. The possibility to replace mined fossil reductants by waste streams that contain metal and carbon should be studied in depth.

In order to increase the metal recovery from ores and increase the recycling of metals it is necessary to have a holistic perspective in which consideration is given to the entire recycling chain as well as the interaction with ore-based metal production and the advantages of a combination of ore- and scrap-based production. Suitable pre-treatment methods, such as bio- or hydrometallurgical processing, should be considered as a supplement to existing processes. Also, the recycling of carbon-containing waste and residue streams, with or without a metal content, should be considered as reduction agents in metallurgical processes.

In conventional base metals beneficiation, the objective is to produce separate concentrates containing a high grade of, for example, copper, zinc or lead. High grades are often achieved at the expense of recovery. An alternative is to produce a bulk concentrate which is then subjected to hydrometallurgical treatment through leaching, either chemical leaching or biooxidation and bioleaching. Furthermore, certain impurities cannot be completely removed in an easy way during the physical beneficiation of the ores, and therefore follow the metal concentrates to the smelter. Some of these fractions are valuable by-products and some of them are considered as impurities. At the smelter, these minor metals may influence the refining of the metal. A pre-treatment of bulk concentrate using hydrometallurgical methods could thus be used either to remove, before entering the smelter, some of the elements that are not necessary for the proces-

sor to produce metals directly at the mine site. The total recovery rate may in this way also increase.

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

- New innovative pyro- or hydro- or biohydrometallurgical processes to extract the metals contained.
- New knowledge of the distribution of elements between different process streams and their capacity to accept different elements.
- New innovative techniques to utilize 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. 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 suitable for use as raw materials within the base and precious metals 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 the extraction of elements contained in existing material streams but as yet not extracted, as well as securing the quality of products and by-products produced, through

- Technology development.
- Measures to increase the quality of material streams.
- Development of the necessary methods and knowledge needed to increase the type of material streams used.



- Education.
- Knowledge dissemination.

To fully utilize the energy content in raw materials, including sources with low energy content, and to increase the utilization of metal-containing organic sources.

Technology:

- Develop new methods for sorting and pre-treatment of scrap and ore concentrates through physical separation or hydrometallurgical process steps.
- Develop new processes or adapt existing processes to accept lower grade and higher variability in the raw materials.
- Perform a thorough evaluation of the extent that metals on EU's critical list are present in different material streams available within the recycling system.
- Develop the technology needed to increase the use of metal-containing combustion ashes, especially from municipal waste combustion, for the recovery of metal content. Some of these materials are already used for metal recovery (Boliden used about 5,000 tonnes in 2012), but a more efficient separation and diversion of some of the material streams would increase the possibility of recycling this type of material.
- Develop knowledge and technology to increase the yield in existing processes, with consideration given to the entire value chain for raw materials.
- Develop the technology needed to extract more elements from material streams already processed. Elements given the highest priority are Sb, Ni and Sn.
- Compile and model the energy efficiency, the environmental performance and the recyclability for processing base metals concentrates, recyclates and residues containing base metals, precious metals and the minor elements usually ending up with ores or recyclates in these processes.
- New improved methods for recovery of energy from low heat value sources.

Enhanced quality of material streams:

- Optimize the existing process chains for the simultaneous extraction of metals from ore concentrates and scrap, including the entire system from exploration, concentration of ores and scrap, and processes for extraction of the metals, in other words through improved process modelling.
- Develop methods to enhance the metal content of by-product streams and at the same time secure the quality of all by-product streams to increase the possibility of extracting more metals from these material streams.
- To introduce new drivers for sorting of consumer products with greater care at the consumer end.
- Disseminate knowledge about recycling potential and limitations to the designers of consumer products (Design for recycling).

- Introduce new methods in order to control the processes more efficiently through new measurement techniques. An example of a suitable measurement technique could be the use of on-line XRF technique to monitor the composition of dust generated in a process.
- Develop models and encourage the greater use of process and thermodynamic modelling to understand the process consequences of different actions.
- Develop the knowledge necessary to secure the product quality of the slag produced on the same time as processing consequences, e.g. foaming, of varying slag composition can be controlled.

New material streams:

- W2R, Waste to raw material – develop methods for utilising waste materials from own processes or across business sectors to enhance effectiveness and the recovery of metals, e.g. the use of waste materials containing organic substances as reductants or fuels in the extraction of metals.

Education:

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

Knowledge dissemination:

- Dissemination of knowledge to increase the understanding of both benefits and limitations for recycling to plant personnel, designers, researchers and society.
- Exchange of personnel between academy and industry.
- Collaboration and exchange with universities, research organisations and industries in other parts of the world.

#### **4.4.4 Expected impact**

Research within the following areas has the potential for creating greater efficiency in the extraction of metals from ore concentrates, scrap, residues and waste:

Technical

- Optimized use of upgrading, pre-treatment and smelting operations.
- Advice on the design of products to enhance recycling potential.
- New processing routes for complex ore and scrap materials.

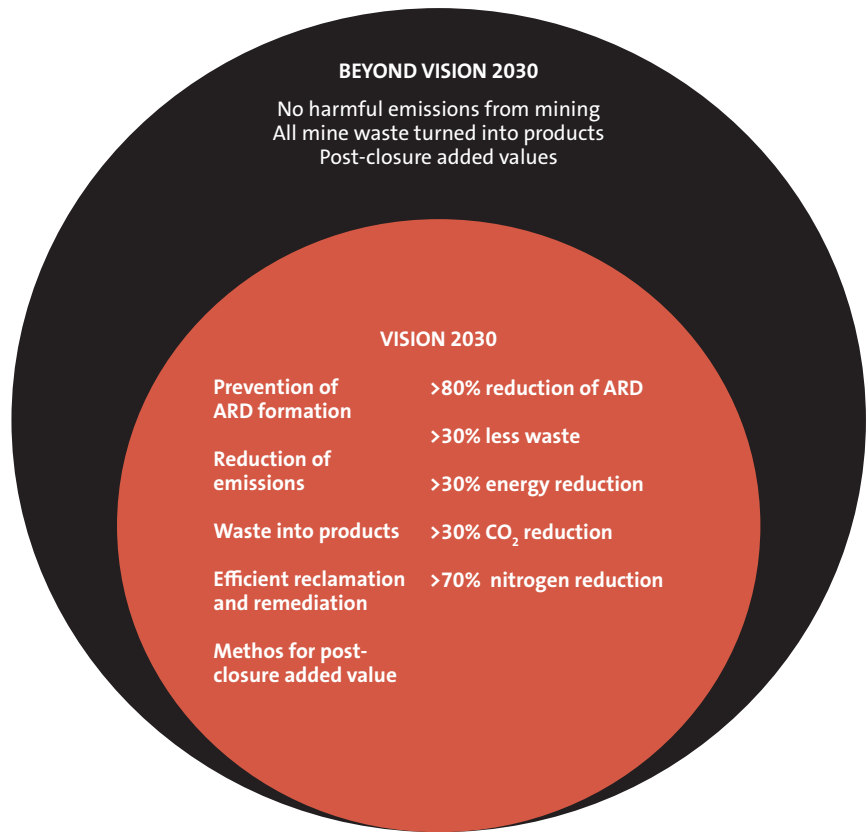


Figure 4-9. Vision 2030 and Key Performance Indicators for Reclamation and Environmental performance.

#### Economic

- Improved competitiveness of the industry through more efficient use of existing process streams.
- Known as well as hitherto unexplored mineralisations turned into ores.
- Process streams, so far not used, become economically viable to extract.

#### Environmental

- Lower quantities of materials deposited.
- Less influence on raw material scarcity.
- More environment-friendly residue streams.

#### Social

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

## 4.5 RECLAMATION AND ENVIRONMENTAL PERFORMANCE

### 4.5.1 Vision

The environmental footprint of mining is so small that it is accepted by society. There are no harmful emissions and all mine waste is turned into products. Post-closure added values at closed mines have resulted in increased biodiversity and improved possibilities for cultural heritage and other industries as reindeer keeping, tourism, outdoor recreation etc. Visions and key performance indicators are presented in Figure 4-9.

Medium- to short-term:

- A sound understanding of which new methods are promising and worth scaling up to full-scale applications.
- New and innovative methods that have also 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.

Long-term:

- The environmental footprint of mining has been significantly reduced.
- Energy consumption and CO<sub>2</sub> emissions have decreased by over 30%. Mine waste, including the Fe sulphides, is to a large extent used as products. Efficient methods for remediation of unavoidable waste deposits are available, and after mine closure, remediated 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.
- A metal extractive and production industry that operates together with other businesses for sustainable development.

### 4.5.2 State of the art

There has been a tremendous development in reducing the environmental footprint of mining over 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 uses. The mining industry is also a major energy consumer. In addition, 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. Dust and noise problems are common at mine sites. However, these effects only occur for 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, which can remain present for hundreds or even thousands of years in different deposits. Volcanogenic massive base met-

al deposits contain a low percentage of the valuable metals, and 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 ton. The majority of all ores thus will be treated as waste. The global production of mine wastes is estimated at more than 15,000–20,000 million tonnes of solid waste per year.

ARD may be formed in waste deposits containing Fe-sulphides such as pyrite and pyrrhotite when exposed to oxygen. This ARD is often rich in heavy metals and metalloids. Conventional mining generates two main types of wastes, both of which may contain sulphide minerals. These waste categories are 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 minimize the supply of the primary reactants for sulphide oxidation, and/or to maximize the amount and availability of acid-neutralizing reactants. These methods involve minimizing oxygen supply through decreasing oxygen diffusion or advection /convection, minimizing water infiltration and leaching (water acts as both a reactant and a transport mechanism), minimizing, removing, or isolating sulphide minerals and maximizing the availability of acid-neutralizing 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 therefore usually contain a sealing layer with low hydraulic conductivity, which results in a high degree of water saturation, and above that a protective layer, protecting against root penetration, frost effects etc. 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 prevention option is to remove the source, i.e. Fe sulphides, from the mining wastes with the aim of reducing the total amount of ARD-producing waste and remediation efforts needed.

Methods that ensure safe disposal over very long periods of time are particularly important. Neutralizing ARD by liming is common practice, but is a short-term solution that results in increased amounts of waste, although of another type. Also other ways of treating drainage waters from waste piles must be considered as short-term solutions although they are sometimes necessary.

#### **4.5.3 Research and innovation needs and strategies and actions**

Research should focus on preventing the formation of ARD in mine waste, which is the major problem. However, immediate short-term problems such as dust prevention and reducing the release of nitrogen should also be included. Fundamental research on surface reactions on Fe sulphides in different physicochemical environments is needed, but otherwise most research is of an applied nature. Research in the short- to medium-term should focus on:

- Waste management
  - Desulphidisation of mine tailings – a new paradigm for waste management.
  - Water flow management processes to reduce contact with ores (including draining systems, the coating of exposed mineral surfaces, etc.).
  - Products from mine waste.
  - Dust prevention.
  - Paste disposal of mine tailings.
- Drainage water treatment
  - New technologies for the reduction of nitrogen and sulphur emissions into the environment.
- Mine closure and remediation
  - Innovative methods for the remediation of mine waste, including an increased use of waste from other industries.
  - Post-closure added values.
  - Methods for safe disposal of the waste formed when bioleaching is used.
- Energy efficiency
  - Improved energy control systems. Utilization of thermal heat.

#### **4.5.4 Expected impact**

Technical:

- New and improved methods for the remediation of mine waste will be developed.
- By-products and waste from other industries will be used for the remediation of mine waste. Two problems will be solved at the same time.
- Methods to decrease the nitrogen emissions from mine sites to an acceptable level will be developed.
- Methods to decrease the dust problems at mines will be developed.



**Economic:**

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 minimized.

**Environmental:**

An obvious result of this research is that the environmental impact of mining will decrease.

**Social:**

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. Otherwise, there will be a strong

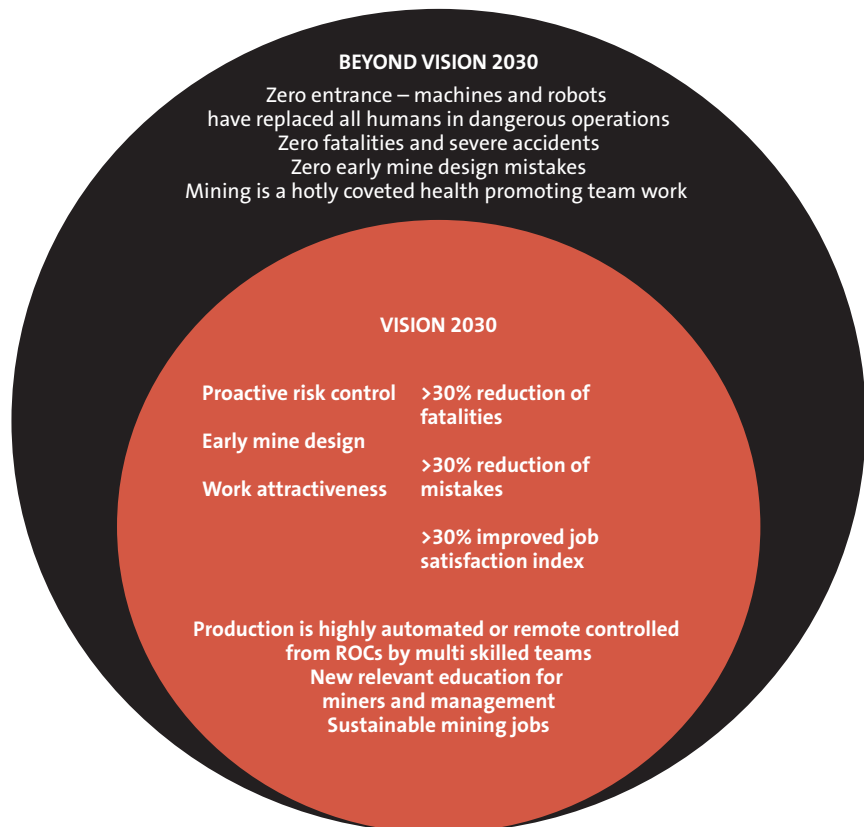


Figure 4-10. Vision 2030 and Key Performance Indicators for Attractive workplaces.

public opinion against mining. Improved environmental performance is a prerequisite for future mining within EU.

There are many possibilities for developing new added values after mine closure. Remediated waste rock deposits and tailings impoundments at abandoned mine sites may be utilised for outdoor life and recreation. Abandoned mines may be important tourist attractions. With careful planning during reclamation, old mine sites may lead to increased biodiversity.

## **4.6 ATTRACTIVE WORKPLACES**

### **4.6.1 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 organized by the new concept Lean mining, meaning a more holistic approach based 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. 4-10).

### **4.6.2 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 characterized 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. 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 impor-

tant to develop new methods for monitoring and control of the work environment, which comprises noise, dust, poor illumination, 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.

But an attractive workplace is so much more than health and safety. There is also a need for an improved learning work organization 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 systems. A sound base for such an organization 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. It is also difficult to standardize a production that is as close to a commodity that has its own logic. 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 offers. A question that will require special attention is the use and integration of contractors in the work organization, 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 on-line 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 competence. 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.

#### **4.6.3 Research and innovation needs and strategies and actions**

Research on attractive workplaces includes the relationship between man-technology-organisation, and specifically studies of how to create sustainable attractive work places, and further develop an innovative, efficient and competitive mining culture based on Lean mining by focusing on work environment, 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.

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 education programs for management and workers.
- Develop efficient programmes for development of attractive societies.

#### **4.6.4 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.

Economic:

- Reduced costs for a high turnover of miners and staff.
- Greater efficiency at work.
- The reduction of different types of waste.

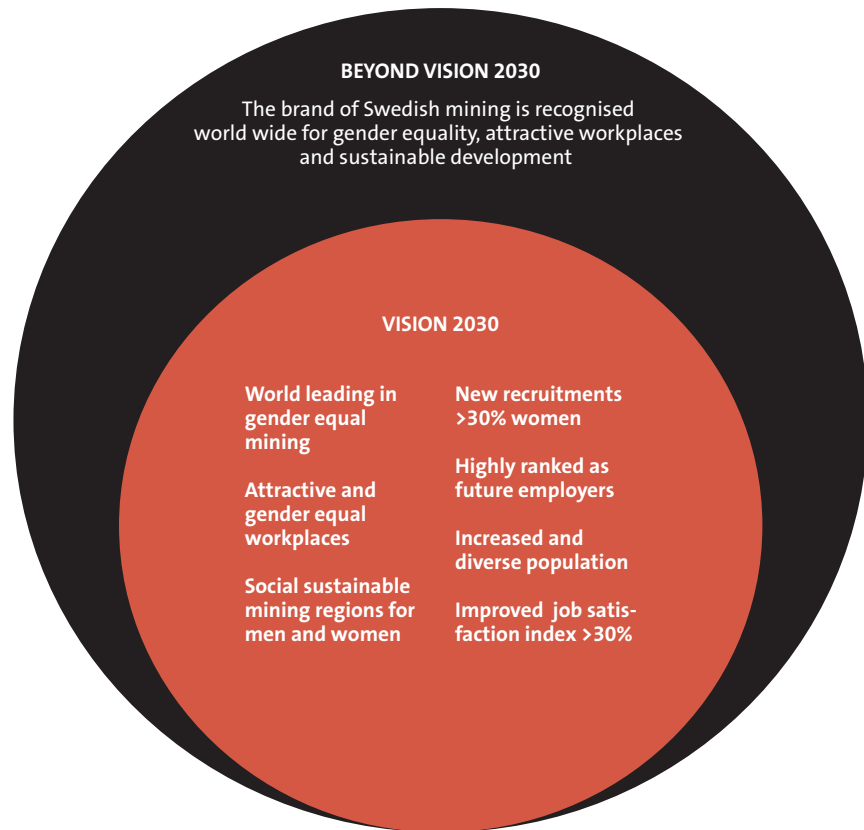


Figure 4-11. Vision 2030 and Key Performance Indicators for Gender equal mining.

Social:

- Creating sustainable jobs (also for contractors) and a socially sustainable society.

#### 4.7 GENDER EQUALITY IN MINING

The agenda area Gender equality in mining is based on gender and organisational research to meet the future challenges of capacity building and productivity for an internationally competitive and socially sustainable metal extraction and production industry. Through this, the STRIM Agenda also establishes critical, integrated and applied gender research in the Swedish mining industry as a field of excellence.

##### 4.7.1 Vision

By 2030, Swedish mining will be well-known for being world-class at breaking gender patterns, competing with gender equality organisations, attractive workplaces and gender equality workplace cultures for efficiency, productivity and innovation. The mining industry is generating prosperous and attractive min-

ing regions for men and women, as well as sustainable societal development in collaboration with local players in society (Fig. 4-11).

The long-term goal of the Swedish mining industry is to be a world leader in efficient and innovative gender equality in mining. This will be achieved by building an interactive centre for gender initiatives and research, knowledge exchange and collaboration between researcher, industry and players in society. The mining industry is an essential player for development of diversified industry in attractive societies. This will also include societies that can attract future labour force. Cross sectorial cooperation with other branches is therefore needed to broaden the labour market to increase the popularity of the local and regional society.

The short-term goal (2013–2016) is to institute new knowledge and research on gender, gender equality and masculinity in the mining sector that will facilitate fulfilment of the long-term vision and goals. It involves theoretical deepening, need-driven development of methodologies and the evaluation of best practices.

#### **4.7.2 State of the art**

Positive market trends, global competitiveness, new technology and the implementation of lean and safe mine production mean that the mining industry has a need for skilled labour and expertise. A challenge for the future is to engage youngsters and more women in education and employment in the male-dominated mining sector. For future capacity building, gender equality initiatives offer a huge potential for additional global competitiveness but also for achieving a mining sector that is both viable and sustainable for Sweden. Socially sustainable development is all about building technology, communities, organisations and clusters where humans are at the centre of development and innovation – and where no groups are disadvantaged by formal and informal structures. Here, a gender perspective on mining is of central importance. Today, the overall gender pattern of the mining sector is characterised, more or less, by stable male stereotypes – in all parts of the business clusters, within society and mining communities, as well as in education, research and innovation. Cross sectorial cooperation with other branches is needed to broaden the labour market to increase the popularity of the local and regional society. An example of cooperation is LKAB which is active in local governmental companies such as Progressum in Kiruna. The objective of this company is to develop the industry in Kiruna. Increased contributions of this type and concerted actions for development of SMEs is needed to achieve the expected result.

##### **4.7.2.1 Industry and companies**

The mining industry is a typical and “classic” male-dominated sector. Although we have seen improvements over the last decade, in the large mining companies



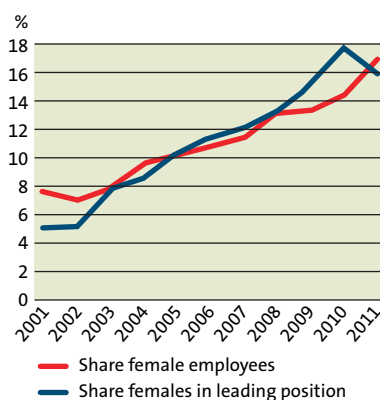


Figure 4-12. The development of gender mix of employees in LKAB during the last decade shows a steady increase in female employees.

80–90% of all employees are men and 90–95% of the workers are men (Fig. 4-12). There are also many small businesses within the mining sector, sub-contractors and entrepreneurs, where all employees are male. Here we find construction contractors, equipment manufacturers and transport companies, which are also traditionally male sectors of working life. External and temporary staff are also more common on mining sites. This group is often invisible in corporate gender statistics, but is made up almost entirely of men. In trade unions, women are more common than before but men still occupy high positions as leaders and chairmen. Mining trade unions have had a central place in the Swedish labour movement, but have also a gendered history of inequality and a focus on men and masculinity. To sum up, gender issues are encountered both within and outside mining companies. These relationships are complex and require a holistic approach and collaboration.

The mining companies struggle to attract women and young people to the industry, but few women are looking for production and maintenance jobs in mining. The Swedish mining companies have to be and want to be modern and attractive employers for both men and women. During the last years, LKAB and Boliden have implemented several ambitious gender equality initiatives, both within the companies and in collaboration with the local community. They have many years of experience in gender equality measures (e.g. wage mapping systems, women’s network, gender-aware trainee and recruitment efforts for executives and technology experts, supporting a high school program for mining with 50% girls) and they are strategically communicating that women are an important part of the new modern mining industry. The new mining company Northland Resources has also high aspirations for gender equality, using similar strategies, for example by being the main sponsor for a team in Women’s National Basketball League. Moreover, a few years back LKAB (as a pioneer) financed a research project (“Attitudes, masculinity and safety in mining”) to transform the masculine workplace-culture among miners for gender equality and safe work practices. Today all the mining companies are stressing the need for extended research and new strategies for cultural changes in the work organisations. Despite the mining companies’ consensus on the value of gender equality and several ambitious measures, it seems to be very difficult to break the mining industry’s gender patterns without further knowledge and new approaches.

Although the mining industry has evolved in many ways, old beliefs about a close relationship between mining and masculinity are still evident. Both corporate cultures as workplace cultures are very much about men and masculinity, but also about idealisation of a certain type of miner masculinity with roots 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 develop-

ment – e.g. informal opposition to new technologies and safety procedures. In addition, in gender unequal male work contexts, a resistant attitude and “femini- sation” of new technologies as automation, computerisation and robotisation and also a direct resistance to women and gender equality are often seen. Taken together this gives the mining companies problems with organisational devel- opment 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.

#### **4.7.2.2 Society and mining communities**

Breaking gender patterns is also important in communities in the region of the Swedish mining industries. In Kiruna, Gällivare, Pajala and other mining com- munities the situation is paradoxical. These rural districts have for many years suffered from emigration, stagnation and hefty cuts in the public sector. Now with a thriving mining industry the shortage of public service, housing, factory buildings and labour is a problem and the mining companies have difficulties in recruiting locally. This is a complex demographic challenge – how to attract people, especially young women, who are willing to live and work in these com- munities. A contributing factor may be that mining communities, more than other, have a history, a culture and a working life which – in somewhat simpli- fied terms – can be described as traditional, unequal, gender-segregated and male-centred. A gender-divided economy with low degree of differentiation is vulnerable in many ways. If women continue to move out to the same extent as today, some communities could 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. The booming mining sector, which has long been – and still is – male-domi- nated, is creating more businesses and industries. There is a risk that the future holds “more of the same” and the same social problems, unless we can break these patterns. A key challenge is to break up the gender-based structure of the industry and the local labour market as well as to support an entrepreneurial culture for men and women and an open business climate.

#### **4.7.2.3 Research and education**

Luleå University of Technology is a leading player in mining research in Sweden. However, LTU has for many years struggled with problems in connection with recruiting people for mining programmes and courses. Both men and women tend to 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 is working to increase the proportion of women with initiatives at all levels, among both students and researchers and

teachers. One problem is the horizontal segregation of gender where all too few women hold a professorship. In the technical faculty where most of the mining research is performed, only about 11% of the professors are women. In addition to this, we also see a horizontal segregation within technological research. In interdisciplinary technical areas (e.g. human work science), there is a reasonable gender balance, while more “hard tech” areas, such as most mining research, are 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 for 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 is of significance for the careers of doctoral students and teacher. It appears to be easier for men to obtain time and money to research and gain access to sponsors, networks and innovation. A further explanation may be found in the values of what factors are considered as being 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 such as Smart Mine of the Future (SMIFU), CAMM, I<sup>2</sup>Mine and similars are male-dominated and based on cooperation with players in the industry and mining communities, which are also unequal in terms of gender and male-dominated.

#### **4.7.3 Research and innovation needs and strategies and actions**

The industry faces challenges not only regarding breaking ore but also in breaking gender patterns. The Swedish mining industry has for many years been centred on men and associated with male-dominated activities. If nothing is done, future innovation, research and development will most likely conform to the same pattern. It is extremely important to break this pattern. In order to secure safe, lean and innovative mining and attractive workplaces, there is a need for more research and a solid understanding of what the gender structure looks like, how gender inequality operates, and at what costs and, most importantly, how problematic gender positions and patterns can be challenged and changed – and how gender equality can be constructed. Concerted actions towards SME will diversify the industry.

Medium- to short-terms:

- Form visions, policies and financing that enable research that can contribute to greater gender equality and a socially sustainable development of the mining industry and society.
- Develop systematic gender-divided statistics in industry, clusters, education and academia etc.

- Evaluate the mining companies' gender equality-related activities to support best practice.
- Promote gender-aware and strategic recruitment, promotion and retention practices in the mining industry.

Some suggested themes for research are:

- Gender patterns 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.
- Methods for support for growth of SMEs in mining societies.

The actions and tentative areas above are a result of interactive collaboration between researchers at LTU and players from LKAB, Boliden AB, Northland Resources as well as the County Council of Norrbotten, the municipality of Kiruna etc.

The research should, together with theories on gender, work and organisation, draw on theories on “undoing gender” and “degendering” and “gender toning down” or similar. One main area of research should be to explore the relations between the global mining industry, work organisations (mining companies, contracting companies), mining labour unions, local entrepreneurship, neighbouring local communities and the regional context etc. when it comes to gender and gender equality. Another main area is to find ways of challenging the existing attitudes and culture, including social constructions of gender (e.g. working class masculinities) and gender patterns in the mining sector – and how to use gender equality as a tool for competitiveness. It is important to conduct this research in close collaboration with the mining companies as well as with other players. Another area of research is the interactive design of the gender-equal mining workplaces of the future, by for example “design teams” comprising both male and female mining professionals.

Long-term:

- Collaboration between industry and society for attractive and gender-equal mining communities and sustainable societal development.
- An interactive Centre of Excellence with a node at LTU, for gender initiatives, research, knowledge exchange and collaboration between researcher, industry and players in society.

#### **4.7.4 Expected impact**

Research and actions within the described areas has a potential for having 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 gender patterns in working life and how to change them. Concepts and perspectives from gender research also have the potential to address and challenge other grounds of discrimination (age, ethnicity, disability etc.) in the mining industry.

#### Technical

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

#### Economic

- 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.

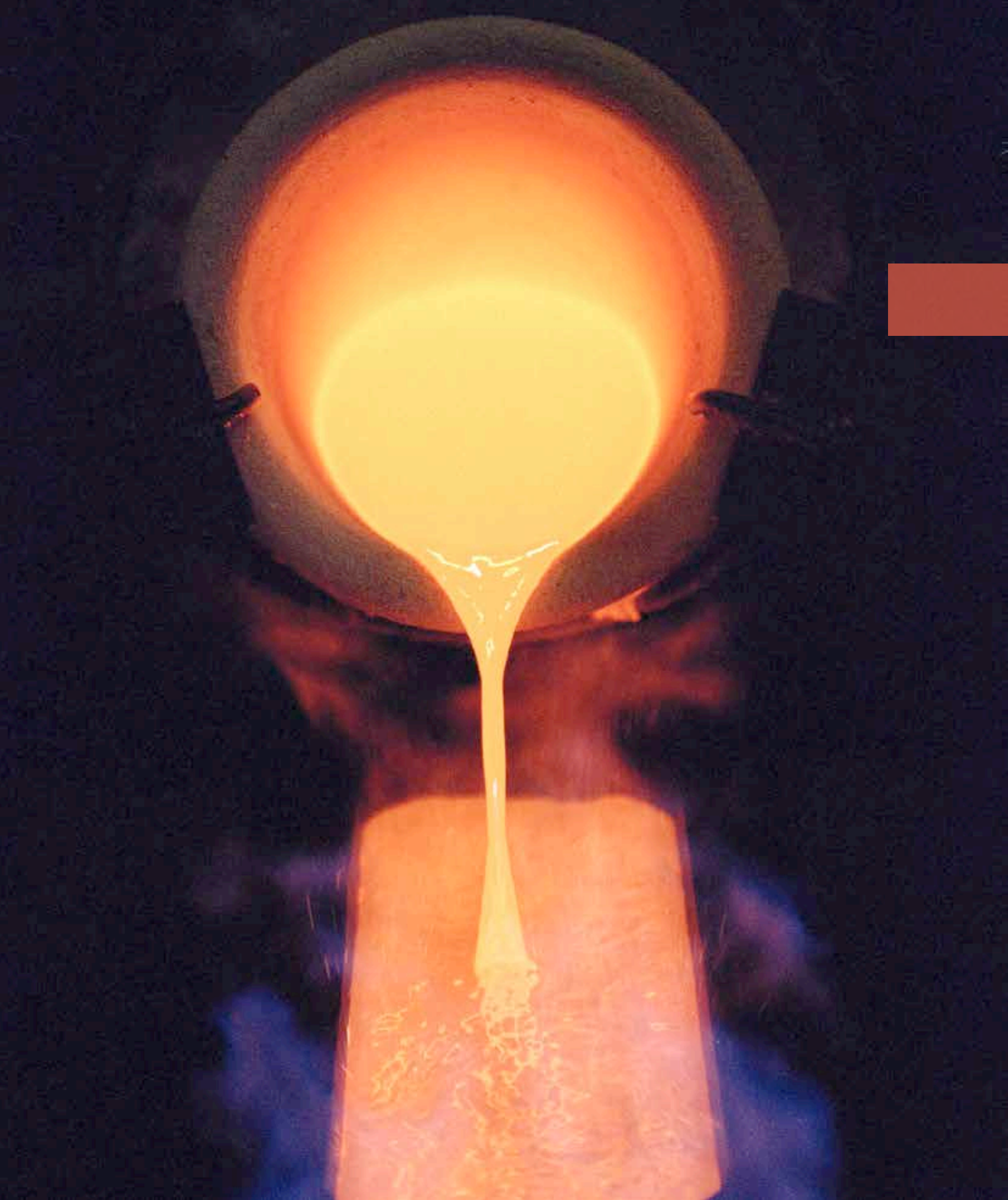
#### Social

- Improved competence recruitment for the mining industry – thanks to possibilities to attract skilled people from the entire population.
- Safe, healthy and attractive leadership and workplaces in the mining industry for both women and men.
- Enable more women to stay in the region.
- Additional employment opportunities for men and women.
- Prevent fly-in-fly-out societies.
- Attractive, sustainable and creative mining communities for both women and men.
- Entrepreneurial cultures in the mining communities.

For a comprehensive outlook on gender strategies in Swedish mining see also *Breaking ore and gender patterns – a strategic and sustainable R&I-agenda for the Swedish mining industry* (2012-01826).







## 5 Expected impact

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

Agenda area	Technical Impacts	Economic impacts	Environmental Impacts	Social Impacts
<b>Deep Innovative Exploration</b>	<ul style="list-style-type: none"> <li>• Providing Sweden with innovative, world-class technology for minerals exploration of deep ore bodies.</li> <li>• Providing Sweden with a first Pan-European 3D-model of the crust down to several kilometres, to be used for decision making on land planning issues.</li> </ul>	<ul style="list-style-type: none"> <li>• Deeply located deposits can be defined and economically evaluated.</li> <li>• Improved self-sufficiency and a stable supply of base, critical and other metals for the Swedish and European economy.</li> <li>• Forster development of Swedish-based downstream industries on domestic mineral resources.</li> <li>• Create wealth in many less densely populated areas of Sweden.</li> </ul>	<ul style="list-style-type: none"> <li>• Definition of deeply buried resources to minimize the effect of mining.</li> <li>• Define where the mining potential is in Sweden for the coming century to be used also as a tool for decision making on land use, protection etc.</li> </ul>	<ul style="list-style-type: none"> <li>• Less problems with access to space in densely populated areas.</li> <li>• Lead to increased employment opportunities in less populated and rural regions of Sweden with a good potential for the extraction of metals and minerals.</li> <li>• Training of decision makers on resource geography, potential and predictive models will lead to improved governance of Swedish resources.</li> </ul>
<b>Mining</b>	<ul style="list-style-type: none"> <li>• Reduction of ore losses</li> <li>• Optimized mining processes</li> <li>• More continuous processes</li> <li>• Integrated process control and one control room</li> <li>• Minimized human exposure at the production face</li> <li>• Increased conversion of waste into products</li> <li>• Increased degree of automation</li> <li>• Safer mining with decreased number of accidents</li> </ul>	<ul style="list-style-type: none"> <li>• Reduction of man-hours per tonne</li> <li>• More cost-effective rock support</li> </ul>	<ul style="list-style-type: none"> <li>• Reduced energy consumption</li> <li>• Reduction of deposited waste on surface</li> <li>• Decrease in harmful emissions</li> <li>• Reduced CO<sub>2</sub></li> </ul>	<ul style="list-style-type: none"> <li>• Increased job satisfaction</li> </ul>
<b>Mineral Processing</b>	<ul style="list-style-type: none"> <li>• Providing designs for energy-efficient comminution</li> <li>• Providing innovative Measurement While Grinding solutions for reducing wear and enhanced mill control</li> <li>• Providing solutions for enhanced coarse and fine particle flotation</li> </ul>	<ul style="list-style-type: none"> <li>• Reduced costs from less energy consumption in ore comminution.</li> <li>• Higher revenue from increased recovery of valuable minerals.</li> <li>• Increased production due to reduced material amounts after pre-concentration.</li> </ul>	<ul style="list-style-type: none"> <li>• Reduced CO<sub>2</sub> emissions due to decreased energy consumption.</li> <li>• Less water usage due to reduced material amounts</li> <li>• Less material to be deposited.</li> </ul>	<ul style="list-style-type: none"> <li>• Improved social acceptance of mineral processing plant operation due to higher resource efficiency and less emissions/waste.</li> </ul>

Agenda area	Technical Impacts	Economic impacts	Environmental Impacts	Social Impacts
<b>Recycling and Metallurgy</b>	<ul style="list-style-type: none"> <li>Optimized use of upgrading, pre-treatment and smelting operations.</li> <li>Advice on design of products to enhance recycling possibilities.</li> <li>New processing routes for complex ore and scrap materials.</li> </ul>	<ul style="list-style-type: none"> <li>Improved competitiveness of the industry through more efficient use of existing process streams.</li> <li>Known as well as hitherto unexplored mineralisations turned into ores.</li> <li>Process streams, so far not used, become economically viable to extract.</li> </ul>	<ul style="list-style-type: none"> <li>Less amount of materials deposited.</li> <li>Less influence on raw material scarcity.</li> <li>More environment-friendly residue streams.</li> </ul>	<ul style="list-style-type: none"> <li>Increased employment opportunities</li> <li>Higher awareness of sustainability issues connected to metallurgy and recycling among plant people, designers, recycling industry and society as a whole</li> </ul>
<b>Reclamation/Environmental Performance</b>	<ul style="list-style-type: none"> <li>New and improved methods for remediation of mine waste will be developed.</li> <li>By-products and waste from other industries will be used for remediation of mine waste. Two problems will be solved at the same time.</li> <li>Methods to decrease the nitrogen emissions from mine sites to an acceptable level will be developed.</li> <li>Methods to decrease the dust problems at mines will be developed.</li> </ul>	<ul style="list-style-type: none"> <li>The costs for remediation and environmental control will decrease if efficient methods are developed. The needs for maintenance and monitoring a long time after mine closure will decrease and thus the costs for that will decrease. It will be faster and easier to gain permission to start new mines and expand existing mines if the environmental impact of mining is minimized.</li> </ul>	<ul style="list-style-type: none"> <li>An obvious result of this research is that the environmental impact of mining will decrease.</li> </ul>	<ul style="list-style-type: none"> <li>The demand for metals and minerals in society will increase. Within the European Union much larger quantities of metals are used than what are mined. It is important to increase the mining in the Union in a sustainable way without negative impact on the environment. Otherwise there will be a strong public opinion against mining. Improved environmental performance is a prerequisite for future mining within the Union.</li> <li>There are many possibilities to develop new added values after closure of mines. Remediated waste rock deposits and tailing impoundments at abandoned mine sites may be utilised for outdoor life and recreation. Abandoned mines may be important tourist attractions. With careful planning during reclamation, old mine sites may lead to increased biodiversity.</li> </ul>
<b>Attractive Workplaces</b>	<ul style="list-style-type: none"> <li>Improved health and safety conditions in mining</li> <li>Significant reduction in the number of severe and fatal accidents</li> <li>Significant reduction in the number of occupational diseases</li> </ul>	<ul style="list-style-type: none"> <li>Reduced costs for high turnover of miners and staff</li> <li>Increased efficiency at work</li> <li>Reduction of different types of waste</li> </ul>		<ul style="list-style-type: none"> <li>Creating sustainable jobs (also for contractors) and a socially sustainable society</li> </ul>

Agenda area	Technical Impacts	Economic impacts	Environmental Impacts	Social Impacts
<b>Gender Equality in Mining</b>	<ul style="list-style-type: none"> <li>• Improved implementation of new technology</li> <li>• Improved implementation of lean and safe production</li> <li>• Creativity and innovativeness in organisational processes and technological development</li> </ul>	<ul style="list-style-type: none"> <li>• Improved competitiveness through diverse capacity building</li> <li>• Flexibility to change and development within the industry</li> <li>• Flexibility to societal progression, locally and globally</li> <li>• Reduced vulnerability due to a gender-segregated economy and labour market</li> <li>• Sustainable economic growth in rural regions in Sweden</li> </ul>		<ul style="list-style-type: none"> <li>• Improved competence recruitment for the mining industry – thanks to possibilities to attract skilled people from the entire population</li> <li>• Safe, healthy and attractive leadership and workplaces in the mining industry for both women and men</li> <li>• Enable more women to stay in the region</li> <li>• Additional employment opportunities for men and women</li> <li>• Prevent fly-in-fly-out societies</li> <li>• Attractive, sustainable and creative mining communities for both women and men</li> <li>• Entrepreneurial cultures in the mining communities</li> </ul>







## 6 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 2013–2020 and will form the basis for any strategic implementation on a national or international level. The actions are listed below for each STRIM area.

### DEEP INNOVATIVE EXPLORATION

Area	Action	Time frame
<b>Modelling</b>	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
<b>Technology</b>	Start technical specifications for new exploration technologies	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 deep geophysical techniques	Long-term
<b>Infrastructure</b>	Start to utilise results in training across Europe	Medium-term
	Building visualization centres.	Short-term



## MINING

Area	Action	Time frame
<b>Resource Characterization</b>	Use use new resource characterisation techniques for measuring geological, rock mechanical and metallurgical properties by “On-line analysis” techniques	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
	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 operation.	Short- to medium-term
	Facilitate the use new on-line analysis tools, sensing methods, and management tools, all integrated in a geometallurgical model and resource management system.	Long-term
	Develop interdisciplinary tools for rock mass characterization. A common visualization platform based on an open source Virtual Reality technique could possibly be used.	Long-term
	Develop and implement novel resource characterization techniques.	Long-term
	Develop MWD and AWD (analysis while drilling) technology to deliver data for on-line process design, optimization, prediction and planning for ore delineation, rock mechanics, drilling, continuous mechanical excavation, blasting, crushing and grinding/ milling.	Long-term
<b>Efficient unit operations of mining</b>	Develop some of the unit operations to facilitate automation.	Short- to medium-term
	Improve the efficiency of materials handling.	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 effect on fragmentation	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 optimized).	Long-term
	Develop continuous excavation methods adapted to Swedish mining conditions.	Long-term
Minimize the environmental effects.	Long-term	
<b>Optimized processes and automation</b>	Automation and optimization of mine ventilation and fleet monitoring and dispatch systems.	Short- to medium-term
	Manage effective transition from open pit to underground mining.	Short- to medium-term
	Model predictive control of unit operations	Short- to medium-term
	Production prediction systems, calculation and prediction of KPIs in real time	Short- to medium-term
	Integration of maintenance systems into scheduling models	Short- to medium-term
	Fleet monitoring and control	Short- to medium-term
	Ventilation monitoring and control	Short- to medium-term
	Improve and optimise the overall mining process (dynamic real time optimisation)	Long-term
	Optimise the utilisation of mining equipment and automation	Long-term

Area	Action	Time frame
<b>Improved ore recovery and fragmentation</b>	Studies of problems related to increased mining depth	Short- to medium-term
	Full-scale gravity flow studies, possibly based on draw point/ bucket monitoring and/ or active markers.	Short- to medium-term
	Develop 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
	Address deep mining related issues such as blast-hole stability, detonation of explosives (e.g., avoid dead pressure) and blast damage.	Long-term
	Develop an understanding of the behaviour of fragmented rock.	Long-term
<b>Mining seismology</b>	Develop an understanding of the correlation of seismic hazards and mining depth.	Short- to medium-term
	Develop an understanding of the difference in characteristics between seismic events of different type (e.g. shear events, strain burst, tensile cracks, collapse, etc.).	Short- to medium-term
	Increased control and knowledge of seismic events.	Long-term
<b>Rock support and numerical analysis of static and seismic conditions</b>	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
	Improve numerical modelling capabilities, which describe well-constrained failure and post-failure deformation mechanisms.	Short- to medium-term
	Develop monitoring technology both at mine scale and to observe the states of failure and post-failure at and in proximity to an excavation. Both scaled physical models and full-scale underground tests are 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
	Understand Static conditions – By monitoring and damage mapping assess the performance of the rock mass and the rock support system	Short- to medium-term
	To improve the understanding of the effectiveness of the rock support systems by detailed numerical analyses.	Short- to medium-term

Area	Action	Time frame
	Develop knowledge about the factors governing the interaction and performance by Large-scale field tests and development of novel laboratory testing methods	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
<b>Breakage of hard rock</b>	Determine the best cutting tools design and evaluate optimum operational parameters in relation to rock mass properties. Numerical simulation, laboratory investigations and field tests should be considered. The focus of the research should be on developing cutting tools that require low cutting forces when cutting hard rock formations.	Short- to medium-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) develop Measurement While Grinding technology and full-body modelling of mills with grinding charges to be able to continuously measure and dynamically control comminution circuits (together with mineral processing).	Long-term
<b>Energy and infrastructure</b>	Improv and develop 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 enables minimized 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
	Reduce the environmental impact (the overall energy consumption and optimising the mine infrastructure).	Long-term
<b>Mining equipment reliability and machine design</b>	Failure and maintenance data collection and analysis.	Short- to medium-term
	System reliability analysis considering 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 optimization.	Long-term
<b>Integrated process control</b>	Models and equipment prototype design.	Long-term
	Improved communication networks.	Short- to medium-term
	Localization and navigation systems.	Short- to medium-term
	Traffic management systems.	Short- to medium-term
	Sensor networks.	Short- to medium-term
	Human interaction in automated systems.	Short- to medium-term
	Automated inspection and image analysis.	Short- to medium-term
	Human Machine Interfaces and interaction.	Short- to medium-term
	Automated reporting (IPT - Right Information to Right Person at right Time).	Short- to medium-term
Information-gathering systems	Short- to medium-term	

Area	Action	Time frame
	3D Image processing.	Short- to medium-term
	Video processing (generating data for control or dispatchers alarms and warnings).	Short- to medium-term
	Robust and reliable sensors for machine automation.	Short- to medium-term
	In-situ Sensors for product quality measures, for example water content in concentrates or sensors embedded in pellets capable of following the flow of raw material.	Short- to medium-term
	Energy harvesting capabilities (sensors that do not rely on external power supply and are capable of completely stand-alone operation).	Short- to medium-term
	“Plug & Play” (common control and communication architecture).	Long-term
	Mobile machine monitoring and remote diagnostics.	Long-term
	Augmented reality.	Long-term
	Autonomous patrolling robots.	Long-term
	Field Robotics in order to facilitate autonomous mining.	Long-term
	Sensors for Mine Environmental Characterization (identification of fall-outs, road condition, gas detection, etc.).	Long-term
	Model-based integrated decision-making and monitoring support systems.	Long-term

## MINERAL PROCESSING

Area	Action	Time frame
<b>Comminution of hard rocks</b>	Enhance mineral liberation by adjusting target particle size and breakage mechanism for grinding to ore texture and mineral associations	Short- to medium-term
	Develop integrated solutions for Measurement While Grinding using advanced on-line sensor technology	Short- to medium-term
	Optimize design and operating conditions of comminution devices using advanced modelling and simulation methods	Short- to medium-term
	Provide new breakage mechanisms and technologies for hard ore comminution considering energy for grinding and wear characteristics	Short- to medium-term
	Develop Measurement While Grinding (MWG) develop Measurement While Grinding technology and full-body modelling of mills with grinding charges to be able to continuously measure and dynamically control comminution circuits (together with mining).	Long-term
	Develop efficient separation processes for treating more finely disperse, polymetallic ores	Long-term
<b>Physical separation</b>	Investigate processing routes for pre-concentration 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, including fundamental studies of particle surface phenomena and bubble generation.	Short- to medium-term
	Develop new separation technology for the effective separation of complex mixtures of minerals.	Short- to medium-term
	Improve the understanding of the effect of flotation reagents on the processing behaviour of ore concentrate in downstream processes.	Short- to medium-term
	Improve and optimize mineral beneficiation processes towards better resource-efficiency and sustainability, i.e. reduction of waste rock and tailings, reduction of process water needed	Long-term
	Develop efficient separation processes for treating more fine-disperse, polymetallic ores	Long-term
	Develop suitable pre-concentration processes for separation close to the mining production face	Long-term

Area	Action	Time frame
<b>Agglomeration</b>	Fundamental understanding of physicochemical interaction between particles should be acquired to ensure efficient agglomeration.	Short- to medium-term
	Agglomeration processes utilizing combustible organic binders for existing and emerging applications should be developed to increase sustainability of metal production.	Short- to medium-term
<b>Process systems engineering</b>	Develop more complex flow sheets based on successive separation and size reduction to improve the efficiency of comminution circuits.	Short- to medium-term
	Optimize the whole chain of ore comminution from in-situ rock mass to the final mill product based on integrated modelling of blasting, mechanical cutting, crushing and grinding.	Short- to medium-term
	Develop geometallurgical models together with innovative analysis methods for resource characterization for the design and control production along the entire chain from mining to mineral processing.	Short- to medium-term
	Develop process designs for flexible plant operation in order to respond to ore domains of different mineralogical, textural and chemical composition.	Short- to medium-term
	Develop strategies for the efficient management of process water.	Short- to medium-term
	Develop new processes for the efficient extraction of valuable minerals from by-product and waste streams from existing mineral beneficiation plants.	Long-term
	Improve and optimize mineral beneficiation processes towards better resource-efficiency and sustainability, i.e. reduction of waste rock and tailings, reduction of process water needed	Long-term

## METALLURGY AND RECYCLING

Area	Action	Time frame
<b>Technology</b>	Thorough evaluation of the extent to which metals on EU's critical list are present in different material streams available within the recycling system.	Short-term
	Develop the technology needed to increase the use of metal-containing combustion ashes, especially from municipal waste combustion, for recovery of metal content.	Short-term
	Compile and model the energy efficiency, the environmental performance and recyclability for processing base metals concentrates, recyclates and residues	Short-term
	Develop new methods for the sorting and pre-treatment of scrap and ore concentrates through physical separation or hydrometallurgical process steps.	Medium-term
	New improved methods for the recovery of energy from low heat value sources.	Medium-term
	Develop new processes or adapt existing processes to accept lower grade and higher variability in the raw materials.	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 knowledge and technology to increase the yield in existing processes.	Long-term

Area	Action	Time frame
<b>Enhanced quality of material streams</b>	Develop the knowledge necessary to secure the product quality of the slag produced and control foaming.	Short-term
	Optimize the existing process chains for simultaneous extraction of metals from ore concentrates and scrap.	Short- to medium-term
	Dissipate knowledge about recycling possibilities and limitations (Design for recycling).	Short- to medium-term
	Develop methods to enhance the metal content in by-product streams.	Medium-term
	Develop models and encourage more use of process and thermodynamic modelling.	Medium-term
	To introduce new drivers for a more careful sorting of consumer products at the consumer end.	Medium- to long-term
	Introduce new methods to control more efficiently the processes through new measurement techniques.	Long-term
<b>New material streams:</b>	W2R, 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

## RECLAMATION AND ENVIRONMENTAL PERFORMANCE

<b>Waste management</b>	<b>Desulphidisation of mine tailings – a new paradigm for waste management.</b>	<b>Short- to medium-term</b>
	Water flow management processes to reduce contact with ores (including draining systems, coating of exposed mineral surfaces, etc.).	Short- to medium-term
	Products from mine waste.	Short- to medium-term
	Dust prevention.	Short- to medium-term
	Paste disposal of mine tailings.	Short- to medium-term
<b>Drainage water treatment</b>	New technologies for reducing emissions of nitrogen and sulphur into the environment.	Short- to medium-term
<b>Mine closure and remediation</b>	Innovative methods for remediation of mine waste, including increased use of waste from other industries.	Short- to medium-term
	Post-closure added values	Short- to medium-term
	Methods for safe disposal of the waste formed when bioleaching is used.	Short- to medium-term
<b>Energy efficiency</b>	Improved energy control systems. Utilization of thermal heat.	Short- to medium-term

## ATTRACTIVE WORKPLACES

Action	Time frame
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 of health and safety effects of automation.	Short- to medium-term
Review of health and safety conditions for contractors in the mining business.	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 education programs for management and workers.	Long-term



## GENDER EQUALITY IN MINING

Action	Time frame
Form visions, policies and financing that enable research that can contribute to a more gender equality 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' gender equality-related activities to support best practice.	Short- to medium-term
Gender aware and strategic recruitment, promotion and retention practices in the mining industry.	Short- to medium-term
Collaboration between industry and society for attractive and gender equal mining communities and sustainable societal development.	Long-term
An interactive Centre of Excellence with a node at LTU, for gender initiatives, re-search, knowledge exchange and collaboration between researcher, industry and players in the society.	Long-term