MIFU | SMART MINE OF THE FUTURE

CONCEPTUAL STUDY 2009-2010

FINAL REPORT

November 2010

RTC
ROCK TECH CENTRE

CONTENTS

"The difficulty lies not so much in developing new ideas as in escaping from old ones..."
- John Maynard Keynes

PREFACE

To stay competitive and to further develop safe, lean and green mining, the mining companies Boliden and LKAB in Sweden and KGHM in Poland joined forces with several major global suppliers and the academia to develop a common vision for future mining. The conceptual study "Mine of the Future" identifies the most strategic issues that need to be addressed and defines important areas for research, development and innovation that will form a basis for the Swedish Strategic Research, Development and Innovation Agenda (SRDIA) 2011 – 2020.

It is envisioned that the SRDIA will also constitute a basis for collaboration within the European Union in their framework programmes for research and technological development. The sector is innovative, interesting and sustainable, which is necessary in order to meet the grand challenge of mineral supply for a growing world and a growing economy.

The authors would like to acknowledge the invaluable input and ideas received from the partners of the Mine of the Future project. The study has been partially financed by VINNOVA (Grant 2008-03466) through the Strategic Mining Research Programme.

Luleå in November 2010

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EXECUTIVE SUMMARY

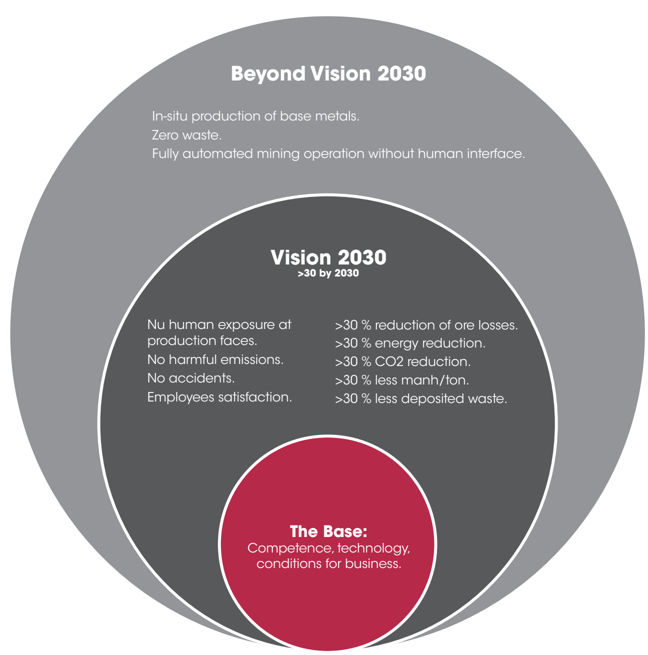
The conceptual study "Mine of the Future" brings together major Swedish and Polish mining companies, several major global suppliers and the academia to develop a common vision for future mining. The study has been executed within the framework of the agreement between VINNOVA and MITU concerning the Swedish Mining Research Programme. The work is limited to the production system for a deep (1,500 m -2,000 m) underground mine from the ore and its characterisation to the finished raw material or product, ready for transportation to the customer (for example a smelter or a pelletising plant).

The conceptual study aims to:

- create a vision of the Mine of the Future,
- identify the most strategic problems that need to be solved in present mining operations to become world class in production and on a level with world-class manufacturers in other sectors,
- determine the course of action needed to meet the vision, and
- prepare the framework for a Swedish national mining Strategic Research, Development and Innovation Agenda (SRDIA) 2011 – 2020. The framework will, for example, define the focus of the SRDIA and core mining competence needed, but also routes for cooperation with other industrial sectors to track and transfer pertinent solutions researched and developed by them.

A vision has been created for the Smart Mine of the Future by 2030. Based on this vision, a number of key performance indicators have been selected as well as target values for these indicators in comparison with the present baseline. The organisations endorsing the vision:

- strive for zero accidents through the development of technology and promotion of innovations in organisation and safety culture,
- contribute to sustainable mining by cutting energy consumption, CO_2 emissions and ore losses by more than 30% compared to the current baseline and striving to prevent harmful emissions from the operations, and
- stay competitive by means of vigorous efforts in research, development and innovation whereby the mining industry is moving in stages from full mechanisation to a fully controlled process industry.



The key features of the Smart Mine of the Future are illustrated in the figure below.

1. **One control room.** The control room receives online processed information from the rock, from the personnel and from the machinery and equipment that makes it possible to control and fine-tune the complete operation (process control and product control) from resource characterisation to the final product. Sensors and the extensive use of cameras and image techniques permit "live performances" in the control room or elsewhere as needed.

2. **No human presence in the production areas.** All work processes (including rock characterisation) are remote controlled or automated. Special robots are developed for the preventive maintenance of equipment and safe retrieval operations. The maintenance of the robots, as well as necessary equipment repair, are conducted in structurally safe underground vaults. All equipment underground is electrical and the use of diesel is banned.

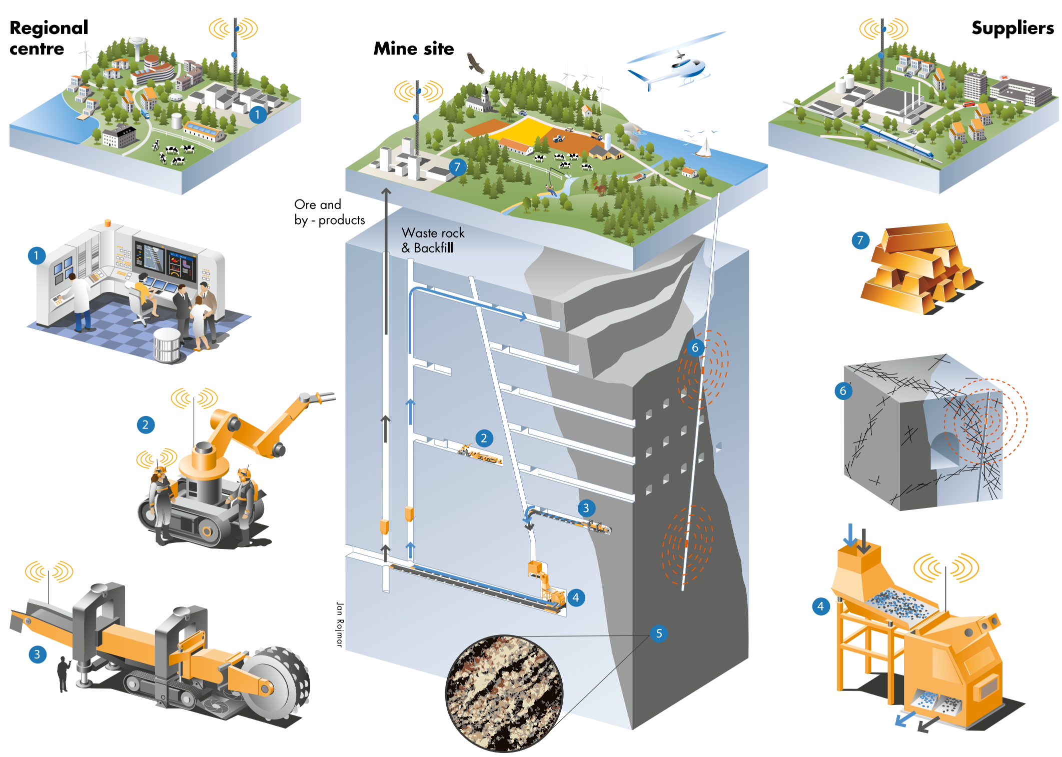
3. **Continuous mechanical excavation.** Continuous flow is a key issue for lean mining and further automation. The future mine is a continuous process, which means that continuous mechanical operation is also used in hard rock types.

4. **Pre-concentration.** Barren rock is separated underground to minimise energy for haulage and transport, as well as environmental impact on the surface.

5. **Resource characterisation – mineralogy.** Systems are used that permit product control (geometallurgy) and maximisation of the inherent values in the rock.

6. **Resource characterisation – structural control.** Systems are used that describe the rock with its structures to aid process control.

7. **Final product.** From a sustainability point of view, waste rock should be turned into products. The metal should, if possible, be manufactured at the mine site to avoid unnecessary transportation. Added value generated in situ should also contribute to a richer social life at the mine site.



The next stage of the Mine of the Future is the MIFU II Feasibility Stage, in which a number of ideas will be explored in depth before the SRDIA (MIFU III) is prepared. MIFU II will continue as an integrated study. Such studies may be open to organisations that did not participate in the conceptual stage.

It is foreseen in this context that MIFU III will be developed as large-scale integrated Research and Development projects on the national level, set up in a similar manner as the present VINNOVA/MITU Strategic Mining Research Programme. We also believe that there should be good links between the national initiatives and the European initiatives.

Consequently, the national programme should ideally also link to the European framework programmes FP7 and FP8. The latter programme commences in 2014. We also foresee that demonstration plants will be implemented through the EU flagship Innovation Union[1] where the Commission plans to create Innovation Partnerships to ensure a secure supply and achieve efficient and sustainable management and use of non-energy materials throughout the entire value chain in Europe.

The long-term commitment from industry, universities and research institutes, governments and the European Union creates the solutions necessary to meet the needs of its citizens. The metal mining sector will continue to supply the raw materials necessary for the sound functioning of society, attractive jobs for young men and women, continue to be a facilitator for the development of new technology and be a strong driver for the development of regions.

[1] Europe 2020 Flagship Initiative Innovation Union COM(2010) 546.

1 VIEWS ON CURRENT AND FUTURE MINING

A well-functioning society without metals and minerals is unthinkable. The global development of the economy and the increase in world population will continue to impose unprecedented pressure on securing the supply of minerals; the future mineral supply cannot be taken for granted.

The mining industry produces metals and minerals for the wellbeing of the individual citizen and society at large (Figure 1).

Besides the supply of metals, the sector also offers highly advanced and interesting jobs on all levels, in which man, technology and organisation endeavour to conquer the challenges posed by nature. The mining industry is capital-intensive; in the last ten years Boliden and LKAB alone have invested over EUR 5 billion in the improvement and expansion of their production systems.

Mining companies are advanced clients for the suppliers. They push the limits of what technology can offer, thereby fostering world-class equipment suppliers. The suppliers can then offer safe, lean and green technology for the rest of the world as well.

Mining is also an important driver for the development of regions, and the importance of Boliden, KGHM and LKAB in the development of the regions in which they are located has been clearly manifested for many years. It is also recognised by the leading powers in the world: *"Raw materials produced by the extractive sector are a key factor for sustainable growth in industrialised, [but also for] the emerging and developing economies"*[2] The general context for mining will set new challenges for mankind, technology and organisation. Financial crises and swings in prices and market will come and go. The securing of finance will be more challenging. From a technological point of view, open-pit surface mining may continue to dominate in the future, but for certain commodities and companies, a focus on underground mining is a must. Future mines will be deeper, and will mine lower grades under stiffer working and environmental regulations. They will also probably be located in remote areas with harsh climatic conditions coupled with more consistent demands for societal responsibility.

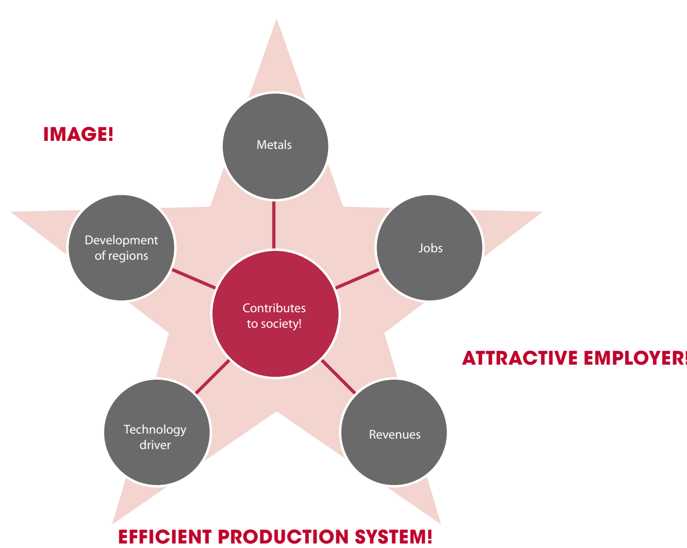


Figure 1. The mining industry contributes to society

[2] G8 Heiligendamm June 7, 2007. Growth and responsibility in the world economy. Summit declaration.

The challenges and changes are so large and numerous that comprehensive international cooperation is needed both within and outside the mining sector in order to succeed. The recent initiatives by the European Commission to support the raw materials sector are welcome[3,4]. In the latter document the Commission states. "With a view to achieve the EU 2020 objective of a smart, sustainable and inclusive growth, the Commission intends to launch innovation partnerships in key areas addressing major societal challenges, such as energy security, transport, climate change and resource efficiency, health and ageing, environmentally-friendly production methods and land management.". The Commission further identifies the "Sustainable supply of non-energy raw materials for a Modern Society" as a priority to "ensure a secure supply and achieve efficient and sustainable management and use of non-energy materials along the entire value chain in Europe."

In the conceptual study "Mine of the Future", we focus on the efficiency of the future production system. Among the issues discussed are how to make the deep (> 1,500 m below surface) mining of the future safer, leaner and greener. The short answer to this is that most of all, we need an innovative organisation that attracts talented young men and women to meet the grand challenges and opportunities of future mineral supply. And through improved production systems in harmony with society and nature, the image of the sector will continue to improve.

In our work, we project our view of mining to the year 2030 and beyond – more or less 20 years ahead. Therefore, it would also be prudent to look in the mirror and discover what the industry looked like 20 years ago – in the late 80s. What new technologies have been developed? Which technologies have become obsolete and have been abandoned? The truth is that recent decades have seen very few major breakthroughs in technology. In mineral processing, the major breakthroughs took place about 100 years ago (flotation) and 40 years ago (solvent extraction). In mining, the revolutionary developments include, for example, the invention of dynamite, the introduction of tungsten carbide drills and the adoption of underground mass mining methods.

Despite the lack of major breakthroughs, mining is now much safer, more efficient and greener than it was 20 years ago as a result of incremental changes in the production system. Major trends in the past have included continued mechanisation in the mine, where most of the current work carried out is fully mechanised, an increase in the scale of mines and mineral processing plants, and the extensive use of IT for process control, not least in connection with mineral processing.

- It is our firm belief that the mining industry should move towards becoming a process industry, making use as far as possible of continuous processes.

- It is our firm belief that the opportunities offered by an increase in scale have reached their final limits, within both mining as well as mineral processing. The mining method must suit the ore and its characteristics; we cannot use equipment that is any larger than that being used at present. In mineral processing, it is pointless to build autogenous mills that are any larger than the new Boliden mill at Aitik with its 21 MW installed capacity or flotation cells beyond 300 – 400 m3 that are now being used in some mineral processing plants elsewhere

During the last 20 years, we have seen tremendous improvements in process modelling and process control. However:

- It is our firm belief that the opportunity for using IT for managing and controlling the mine and mineral processing is still in its infancy, but we need much better methods to characterise the host rock and the ore to maximise the inherent values as well as to minimise penalty elements and non-marketable residues.

- It is our firm belief that by 2030 we will not yet have achieved "invisible mining", "zero waste" or the fully "intelligent, automated mine without any human presence". Such endeavours will have to be mastered by the future mining society, and realisation of the Mine of the Future by 2030 is merely a stepping stone to the future.

- But it is also our firm belief that we need something that will make a difference – something that goes beyond the typical gradual incremental change for meeting the demands of the future.

[3] The raw materials initiative — meeting our critical needs for growth and jobs in Europe COM(2008) 699.
[4] Europe 2020 Flagship Initiative Innovation Union COM(2010) 546.

2 OUR VISION OF THE MINE OF THE FUTURE

We base our image of the Smart Mine of the Future on a shared vision and shared commitments.

Our vision

The mining industry is an important supplier of efficient and sustainable solutions to meet the needs of modern society for metals and minerals. Safe, Lean and Green technology and an innovative organisation attract talented young men and women to meet the grand challenges and opportunities of future mineral supply.

Our commitment:

The organisations endorsing our vision:

- strive for zero accidents through the development of technology and promotion of innovations in organisation and safety culture,
- contribute to sustainable mining by cutting energy consumption, CO_2 emissions and ore losses by more than 30% compared to the current baseline and striving to prevent harmful emissions from the operations, and
- stay competitive by means of vigorous efforts in research, development and innovation whereby the mining industry is moving in stages from full mechanisation to a fully controlled process industry.

Based on the vision and commitments, we envisage the following image of the Smart Mine of the Future:

Future mining will use fewer hands for manual work but more qualified experts for product and process optimisation, maintenance planning and environmental control. These experts need to interact with each other to cover the complete value chain. "One control room" would be the best solution. It is likely that the experts will become more competent dealing with several mines. Due to the progress of communication technology, the overall control centre can theoretically be located anywhere in the world. However, this is not possible in reality, since each mine has its own unique geological characteristics, which means that we believe in regional control centres. Such centres can be situated close to existing principal mines, if such mines exist. Sensors and automated data processing systems will provide essential information on-line for product and process control. Miners equipped with on-line video cameras could for everyday and emergency situations provide their colleagues in the Mine Control Centre with information that would be difficult to communicate verbally. Virtual Reality (VR) technologies would be used to link production functions such as planning, mining, maintenance, logistics, purchasing and facilities for the coordination of external contractors, equipment suppliers, customers, etc. Everything would be connected to a production flow, a value adding chain, where everyone shares the same goal and sees the same common entity. A common visualisation of problems and opportunities in the system enables overall optimisation of the value-chain.

The role of the equipment suppliers will be more important; they should determine how the equipment is really used in order to finely tune the design of their products and to plan for preventive maintenance. On site, the main task is preventive maintenance. Will each equipment supplier have its own resources on-site or will there be specialised maintenance companies that carry out maintenance for the owners and suppliers? Would the efficiency of the operators be increased if they were to be in contact with the equipment suppliers on-line through audio-visual contact?

The environmental impact is considerably limited at the mine site due to closed process loops and the fact that noxious elements have been neutralised. When possible, barren rock is kept below surface level, and material brought to the surface is made into products. The residues are landscaped to increase the attractiveness of the environment and the risk posed by metal-bearing waste products, for example pyrite, is minimised.

There is a strong consensus among the participating mining companies that resource characterisation should be much improved. Better non-destructive sensors and methods for converting raw data into integrated and useful information for both product and process control through the complete value chain are indispensable for transforming mining into a process industry. The rapidly growing discipline geometallurgy provides a structured approach for combining geology with the metallurgical processes.

In the underground environment, we need a continuous process rather than the present batch process using drill and blast technique. Continuous flow is a key issue for lean production and would simplify automation. An immediate solution for making the process more continuous would be to significantly improve the reliability of the equipment. Lean mining is not practicable under present conditions. In the case of both Boliden, which uses the mining method known as "cut and fill", and KGHM, which uses the "room and pillar" technique, continuous mechanical excavation would be a major step forward. For LKAB, which uses the mining method referred to as "sub-level caving", drill and blast is the only viable method for ore production in the immediate future, but all development work should be based on mechanical excavation. One important feature is that there should be no human exposure in the active mine production areas. Production should be either remote-controlled or automated. Ground support in infrastructure and entry zones should be strong and ductile, and adapted to large deformations and dynamic loads. In the non-entry zones, ground support should be sufficient to protect the equipment. It could be self-propelled and reuseable, similar to the long-wall mining methods used in coal mining.

To reduce the need for energy and surface deposition, the barren rock should not be transported to the surface, but be separated in the pre-concentrator. Petroleum-based diesel fuel should not to be used to power any vehicle underground or on the surface in order to reduce CO_2 emissions and the need for ventilation/energy usage underground. All equipment underground will be powered by electricity (cable, battery or fuel cells).

Recovery is improved by more efficient mining methods and by mineral processing that sorts and extracts the minerals more efficiently. For iron ore, sorting, comminution and flotation will be further developed. For base metals, extraction by, for example, bio-leaching is used for refractory minerals such as gold bearing arsenopyrite and for chalcopyrite. Other leaching routes using ferric ions will also be important for the direct production of metals from concentrates at the mine site. By these means, the transportation of noxious elements can be avoided. The traditional methods will be further developed to permit mineral liberation, selectivity, the removal of penalty elements and the recovery of fine particles (< 10μm) and credit elements. One important area is the flotation of ultra-fine and coarse particles. Almost complete liberation is achieved by on-line measurements and control of the comminution process. From a sustainability point of view, waste should be converted into products.

The processes in the mine (e.g. ventilation) and mineral processing plant (e.g. grinding) are much more energy-efficient and are often engineered in closed loops.

The improvements in the production systems allow even lower emissions to water and air. Innovative solutions will be developed to mitigate the environmental impact of the waste that will remain long after the mine is closed.

Irrespective of their position in the company, everyone understands the importance of motivation and involvement for successful business. Strategic, tactical plans and contingency plans are well-known instruments. The development of technology and the organisation and nurturing of a safety culture strongly improves the health and safety of personnel. The future miner is just as likely to be a man as a woman. Figure 2 highlights the key features of the future production process (see numbers in figure).

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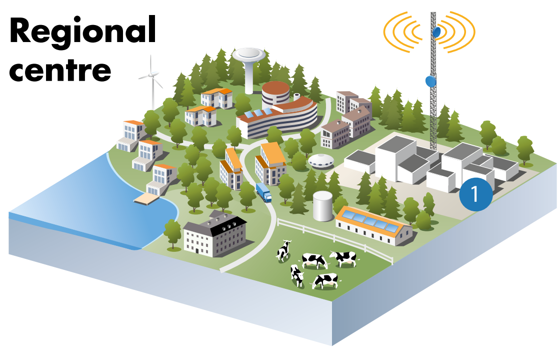
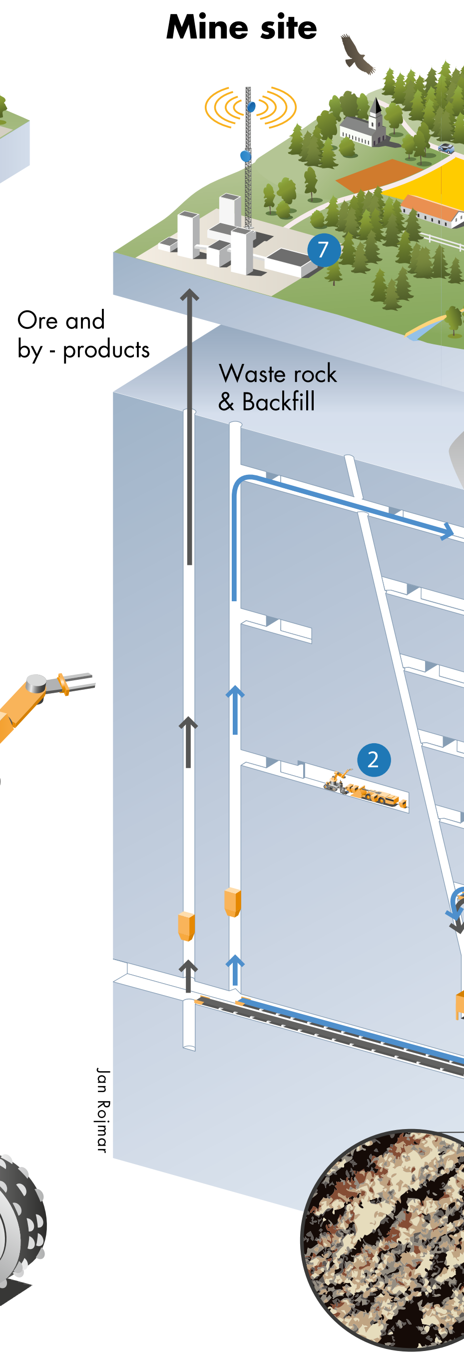
Figure 2. Important features of the underground Smart Mine of the Future. See text for explanations.





1. **One control room.** The control room receives on-line processed information from the rock, from the personnel and from the machinery and equipments that permits the control and fine-tuning of the complete operation (process control and product control) from resource characterisation to the final product. Sensors and the extensive use of cameras and image techniques permit "live performances" in the control room or elsewhere as needed.

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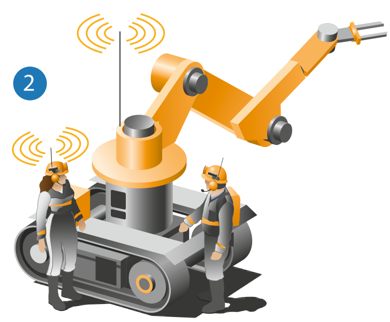
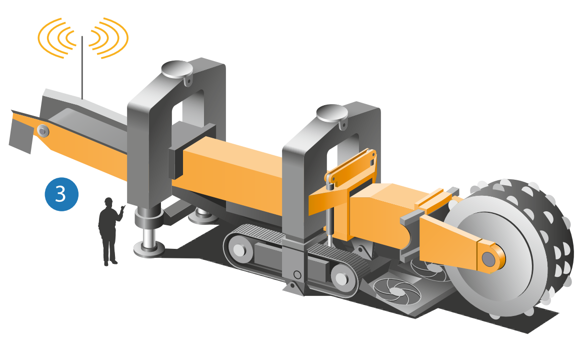
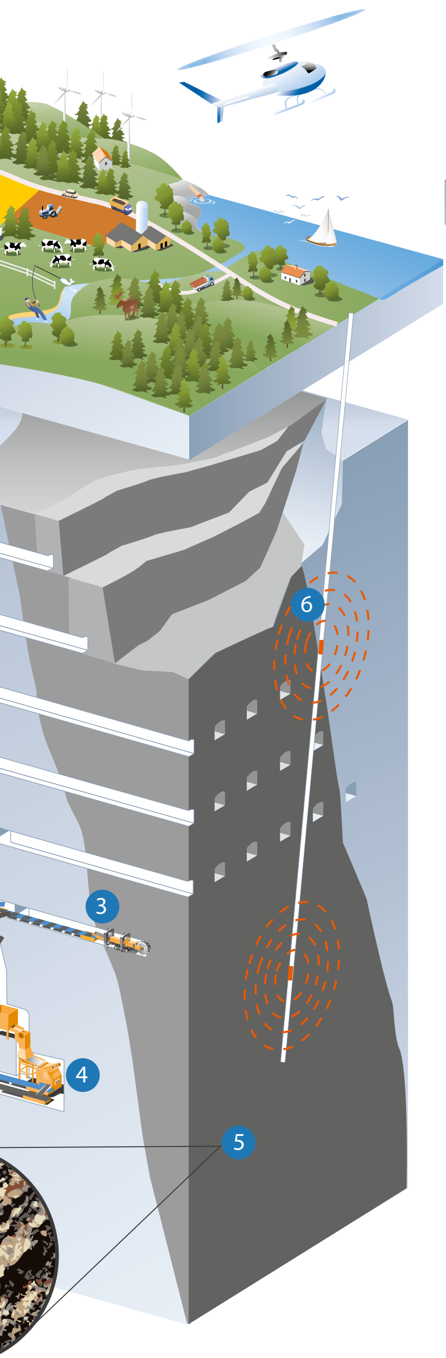
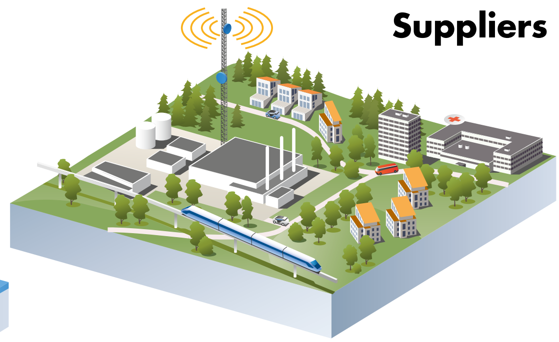


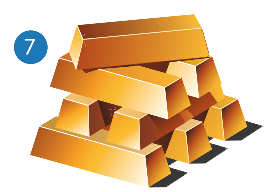


3. **Continuous mechanical excavation.** The continuous flow is a key issue for lean mining and further automation. The future mine is a continuous process, and therefore continuous mechanical operation is also used in hard rock

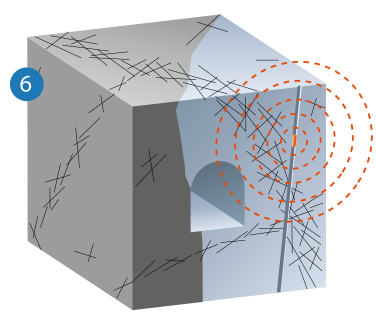


Suppliers

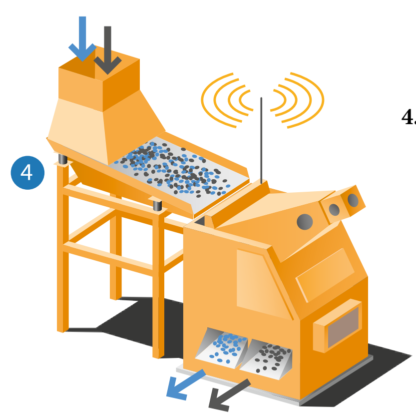




7. **Final product.** For reasons of sustainability, waste rock should be turned into products. The metal should, if possible, be manufactured at the mine site to avoid unnecessary transportation. Added value generated in situ should also contribute to a richer social life at the mine site.



6. **Resource characterisation – structural control.** Systems are used that describe the rock with its structures to aid process control.



4. **Pre-concentration.** Barren rock is separated underground to minimise energy consumption for haulage and transport as well as environmental impact on the surface.

5. **Resource characterisation – mineralogy.** Systems are used that permit product control (geometallurgy) and maximisation of the inherent values in the rock.

3 PERFORMANCE TARGETS FOR THE SMART MINE OF THE FUTURE

The Smart Mine of the Future covers the value chain from mineral economy to waste management, but excludes the pelletising of iron ore and smelting of base metals concentrates[5]. To the left of Figure 3 we define the overall system requirements and to the right we measure the output from the production system in between.

We decided to characterise the system by a number of performance parameters, but chose not to use operating cost (essentially cost for personnel, energy and consumables) as one of them (Figure 4). The rationales for the parameters were either to improve safety or efficiency, or to decrease the environmental footprint. Secondly, the equipment suppliers participating in the Mine of the Future project strongly advised us to determine the performance targets for the selected parameters in compari son with the present-day baseline. Hence, these target values have been negotiated on the basis of what we thought would be necessary and what would be reasonably achievable.

We are of the opinion that ore losses, energy consumption and CO_2 emissions, as well as labour (manh/ton) and residues deposited on the surface, should be reduced by > 30% by 2030 (Figure 5). We also consider it viable to avoid harmful emissions, human exposure at the production faces and accidents. We are also aware of those factors that contribute to employee satisfaction, thereby ensuring that the mining industry offers attractive jobs on all levels.

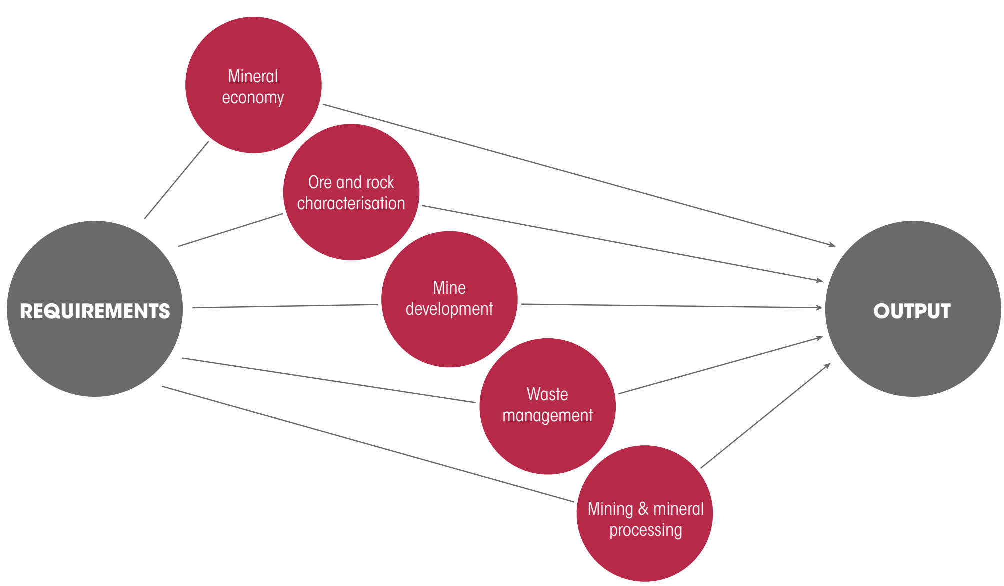
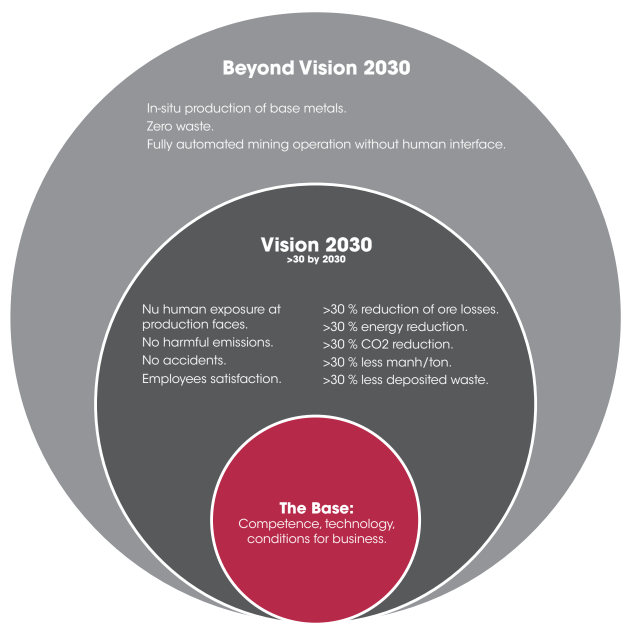


Figure 3. The value chain

[5] During the course of the project, the Steering Committee requested that mine site metal production should be considered as well.

Figure 4. Key performance indicators. The definitions of the units used are described elsewhere.

Figure 5. Vision 2030. The figure also shows what cannot be achieved. We believe, for example, that the "zero waste mine" will not be achieved until after 2030.



Data has been collected from LKAB's Kiruna mine and its concentrator, from the Boliden Kristineberg mine and its share of the concentrator situated in Boliden and from the KGHM Lubin, Polkowice and Rudna mines including their concentrators. An example follows, using the energy consumption (Figure 6). The mind-map figure shows the energy consumption, the percentage for mining and mineral processing as well as the major energy consumers at Boliden, KGHM and LKAB respectively. To cut energy consumption by > 30% compared to the current baseline, the focus should be on the major consumers of energy. These are fairly similar for the three mining companies, i.e. grinding in the concentrator plant, the energy used for transport and haulage, and the energy used for ventilation. If a decision is taken to cut energy consumption for grinding, Figure 7 shows alternative ways of doing it. An evident conclusion from this figure is the need to possess a sound overall understanding of systems in order to be able to determine the most promising way of reducing energy consumption. Similar activities have also been conducted aimed at discovering basic ways of improving on the other performance factors, for example ore recovery.

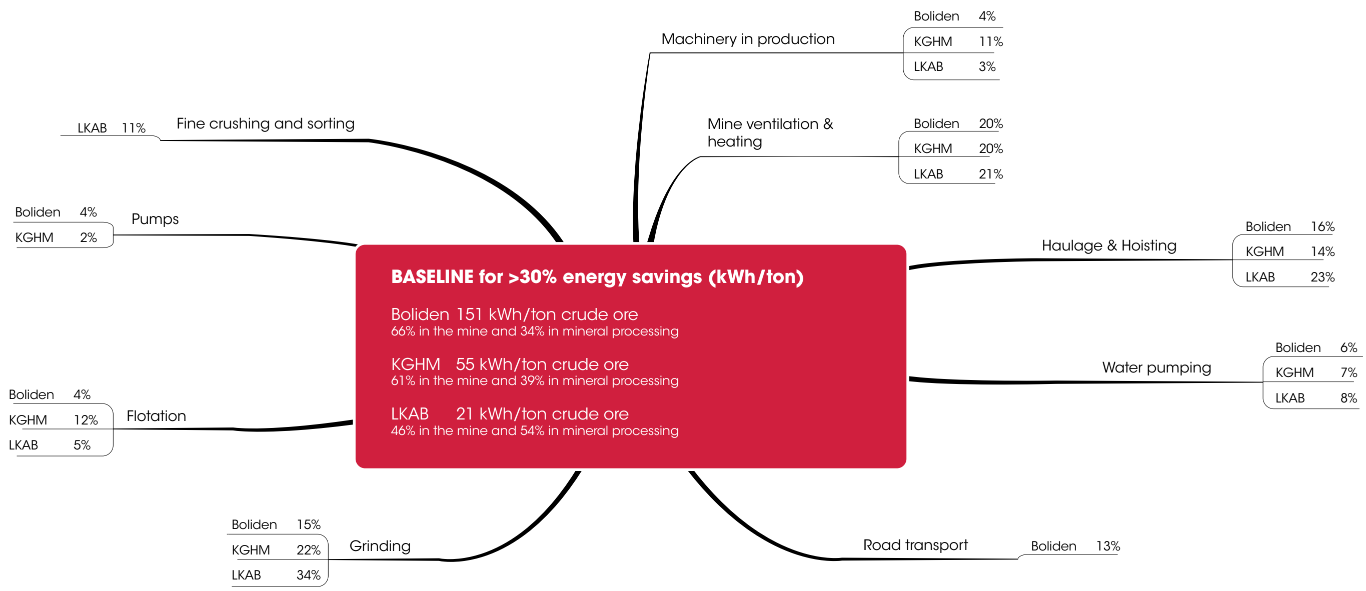


Figure 6. Baseline on the energy consumption for the Boliden, KGHM and LKAB operations

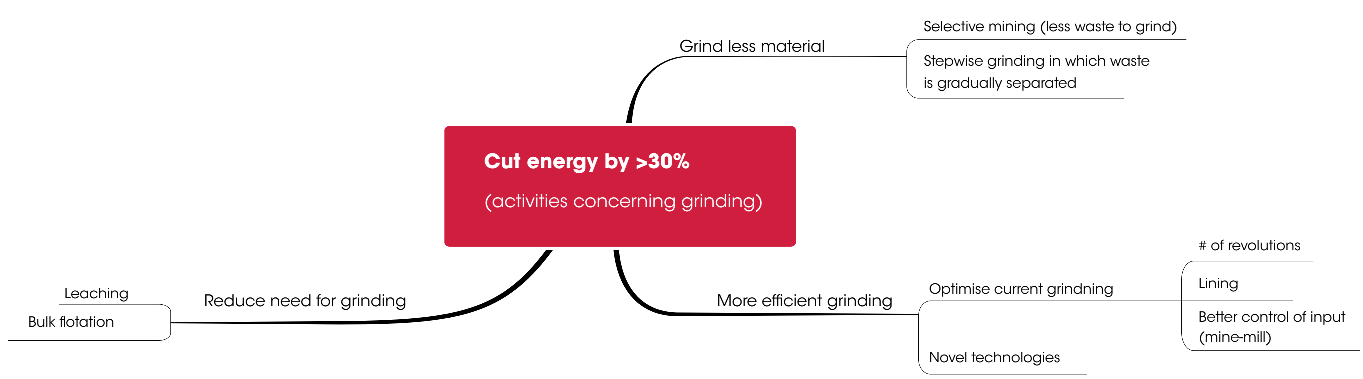


Figure 7. Potential alternatives for cutting energy consumption in grinding

"We are of the opinion that ore losses, energy consumption and CO_2 emissions, as well as labour and residues deposited on the surface, should be reduced by >30% by 2030"

4 PRIORITISED NEEDS FOR RESEARCH, DEVELOPMENT AND INNOVATION

4.1 Definitions

In this context we first define the meaning of research, development, innovation etc.

Research:

Research can be either "basic" (use of scientific methods to freely search for new knowledge) or "applied". In our use of the term research in this report we mean "applied research" to search for new knowledge with a particular application in mind, primarily for use in subsequent development.

Development:

Building on the knowledge (from research), or existing knowledge (intelligence) to achieve new products and services or substantial improvements in existing products and services, as well as for the associated equipment, systems and processes.

Innovation:

Innovation is not invention; it is rather "new products, business processes and organic changes that create wealth or social welfare" (OECD) or "fresh thinking that creates value" (Goldman Sachs)6. Another simple explanation is "making money out of knowledge".

Demonstration:

The activity of showing development results in practice for the first time, on one or several special occasions, to show and verify its function. This activity is often very important in preparation for the implementation of various development outcomes.

Implementation:

Appropriate instruments of all kinds to ensure that R&D&I results will come into general use, not only during the demonstration phase.

We also arbitrarily split research and development work into two lines, one being **revolutionary** (where new thinking or new (generic) technology will allow radical staged changes) as opposed to **evolutionary** (where the changes are incremental and build on to the extension of current know-how). As discussed previously in the introductory chapter, radical staged changes in mining technology are rare.

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[6] See the special report on innovation in The Economist, Oct 13th 2007.

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As shown in Figure 8, scientific research can be classified according to whether it advances human knowledge by seeking for a fundamental understanding of nature, or whether it is primarily motivated by the need to solve immediate problems.

Three distinct classes of research are shown:

1. **Pure basic research (exemplified by the work of Niels Bohr, an early 20th Century atomic physicist).**
2. **Pure applied research (exemplified by the work of Thomas Edison, an inventor).**
3. **Use-inspired basic research (described here as "Pasteur's Quadrant").**

The split into Edison and Pasteur-type research is of course somewhat artificial.

For the Mine of the Future, we need the results from all quadrants, but the mining industry itself will probably position themselves mainly in the red Edison quadrant (incremental improvement by development and innovation). In order to find new principles for cutting energy consumption in grinding, for example, use-inspired basic research (Bohr's or Pasteur's Quadrant) would probably be needed.

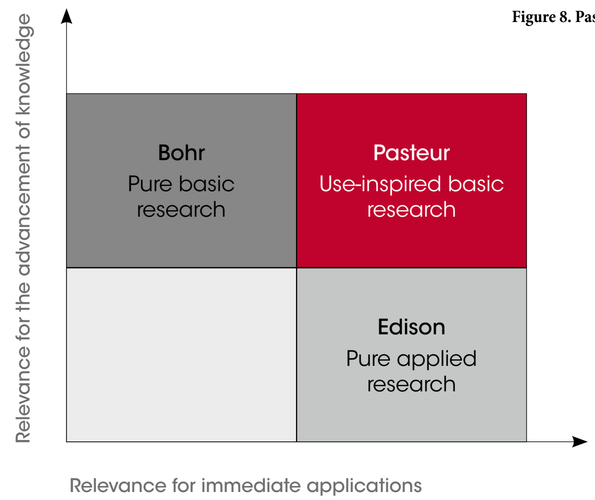


Figure 8. Pasteur's Quadrant[7]

4.2 General viewpoints

For the mining industry and the development of its production system, we have Human, Technological and Organisational challenges to overcome, see the MTO diagram[8], Figure 9, which is used as basic input for the project. We anticipate that Technology will also be a strong driver for change in the future, from development within the sector, but mostly from the transfer of technology from other sectors such as IT, biotechnology and advanced materials. The changes in Technology will offer new opportunities that will affect the Organisation as well as the knowledge and skills that are required by individuals. Therefore, the Strategic Research, Development and Innovation Agenda (SRDIA) 2011 – 2020 is focussed on the need for a change in Technology. In the following sections we discuss issues that will make mining safer, leaner and greener.

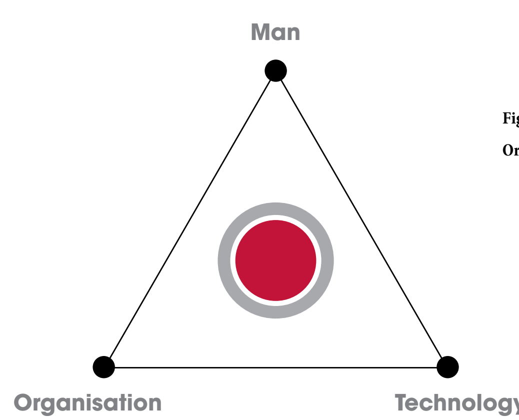


Figure 9. Man-Technology-Organisation

[7] Donald E. Stokes, Pasteur's Quadrant - Basic Science and Technological Innovation, Brookings Institution Press, 1997.
[8] MTO was created as a result of the nuclear Three Mile Island accident. MTO has been widely used by Swedish utilities and regulators to describe knowledge and analytical techniques that focus on human and organisational factors and their relationship with nuclear safety. It was the intention that the explicit mention of the three interrelated elements in the concept – Man, Technology and Organisation – would stimulate a comprehensive "system view" on safety. This view should go beyond a strict technological perspective to recognise and highlight human and organisational factors as being important moderators of risk. In retrospect, the MTO concept has been successful in stimulating a socio-technological view of nuclear safety in Sweden – a general trend supported by international developments.

4.3 Safer mining

Mining has over the years become much safer (Figure 10), but the situation still needs to be improved so that the trend towards improved safety does not level out.

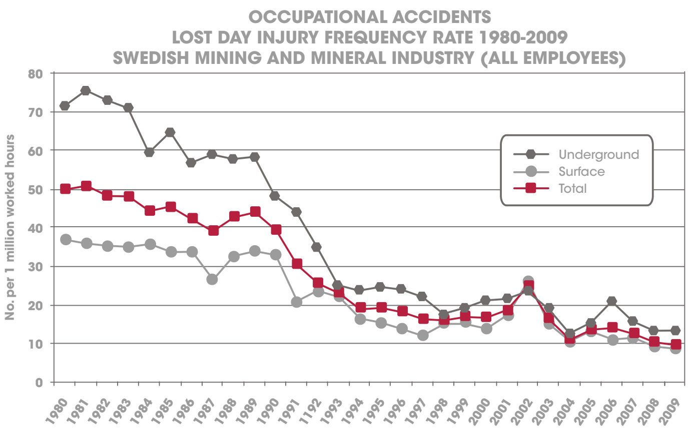


Figure 10. Occupational Accidents Lost Day Injury Frequency Rate 1980-2009. Swedish Mining and Mineral Industry (all employees). Source: SveMin

The vision for safety is for there to be zero accidents. Individual companies can then set operational targets for the extent to which safety should be improved on an annual basis.

The following are prioritised areas:

- Safety management. Safe mining is about technology, but also to a large extent about safety management, including safety culture and management tools and methods for all aspects of safety. Extra attention should be paid to proactive approaches rather than traditional reactive procedures. This is especially important with regard to risks with severe or lethal consequences, and for new risks associated with new technology. Methods for nurturing and managing a safety- and health-promoting culture in a mining context are a topic for both research and innovation.

- No human exposure in the active mining area. This target entails the development of remote-controlled or automated equipment for rock characterisation and all mining unit operations, as well as the development of rescue equipment and contingency plans. These issues are mostly a matter of development. If the mining method has to be changed for some reason, fundamental applied research may be necessary.

- Ground control. Deep mining will create dynamic effects (mining-induced seismic events, rock-burst). Research is necessary to determine design loads and the rock-ground support interaction. Development is necessary for the reliable monitoring of rock and ground support

- Resource characterisation. Cheap but reliable methods for data collection and improved models of the rock for static and dynamic conditions are vital for safer deep mining. Several aspects are research, but for many aspects we need development and true innovations.

- Safer equipment/plants. Many of the accidents are due to poor housekeeping (safety culture), but there is much room to develop or innovate new solutions that would decrease the number of slips, falls, etc.

4.4 Leaner mining

The mining industry is in “mass production” with a constantly increasing scale to “produce more in order to cut cost”. Lean production is about “eliminating waste (e.g. time) in the process in order to cut costs”. An example of this production philosophy has been developed by Toyota. On a scale to 1-10, Toyota is likely to be in the range of around 9 according to this philosphy. The leanest production companies in Sweden (such as Scania) might reach 7, whereas the mining industry is probably on a level of 3-4, and higher in mineral processing plants than in mines.

There is consideralble room for improvement in connection with streamlining production, or as Honda phrases it “Move material the shortest distance using the least amount of space in the shortest amount of time” or as expressed by Mr. Taiicho Ohno, the father of the Toyota Production System: “Times do not exist to be studied. Times exist to be reduced” and "All we are doing is looking at the time line, from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value-added wastes."

In the MIFU, a thorough review was made of lean production principles. The potential transfer of the 14 Toyota Production System principles into lean mining was assessed, together with the experience gained from introducing lean mining into one of the Boliden undergrond mines. Here, two priortity tasks are described for making mining leaner. These tasks focus on the elimination of obstacles preventing the successful implementation of the lean principles, for example creating a continuous production process and removing the main sources of disturbance in the mining operations. The production process in the mill is in most cases already suitable for the creation of a “lean mill”. The uncertainty related to ore grades and rock quality descriptions should be addressed as a next step.

- Improving the reliability of the mining equipment. The reliability of the mobile mining equipment must be improved significantly, through the redesign of mining equipment and improved operating and maintenance procedures. This would constitute the single most important step towards a lean mining operation. The equipment manufacturers should play a major role in solving this problem, looking for the sources and root-causes of machine failures within the customers’ operations and designing the next generation of mining equipment to eliminate these problems. Mobile mining equipment must be made just as reliable as the car, with built-in “Poka –yoke[9]” mechanisms to assist operators and maintenance crews. If a machine has a recommended service interval of 250 hours, it must be able to operate for 250 hours without failure. Mining companies must make sure that more reliable machinery is “the voice of the customer” the equipment manufacturers hear – not “as cheap as possible”.

- Creating a continuous mining process. Creating a continuous mining process for hard rock mining would probably involve substituting fragmentation by drill and blast for mechanical excavation. Machinery would have to be developed that breaks the rock at the face and conveys it to a conveyor system or to a waiting truck, and at the same time installs the required rock support behind and above itself. To be of use in cut-and fill operations, this machine must remain flexible enough to follow the boundaries of the ore and negotiate sharp curves. The same requirements with respect to reliability as described above will also apply to this type of equipment. Again, suppliers of mining equipment will have to be heavily involved in developing the technology. The mining companies must be prepared to deal with the problems that are expected to surface as a continuous process is introduced and there is suddenly no slack between operations or buffers for work in progress. It should be noted that a continuous mining process will influence the subsequent mineral processing since large, competent pebble stones for autogenous grinding will be lacking.

[9] Poka-yoke (ポカヨケ) is any mechanism in a lean manufacturing process that helps an equipment operator avoid (yokeru) mistakes (poka). Its purpose is to eliminate product defects by preventing, correcting, or drawing attention to human errors as they occur.

4.5 Greener mining

The mining industry has successfully produced more tonnes of metals with a considerable decrease in environmental impact, thereby proving that de-coupling growth from environmental impact is possible, Figure 11. The improvements are a result of better processes, recirculation, and clean and green technology. For the future, it is vital to continue work on limiting the environmental impact, and in this context we also need to incorporate issues to limit climate change with higher energy efficiency and lower emissions of greenhouse gases.

4.5.1 Energy efficiency and CO_2-reduction

The mining industry is a major energy consumer both in Sweden and Poland. For instance, in 2009 LKAB used 1.6TWh of electricity, the Boliden group in total 3.3TWh, which is expected to increase to 3.9 TWh for 2010 due to increases in production, and KGHM is forecast to use 2.4 TWh of electricity for 2010. In addition, large quantities of oil and diesel are used.

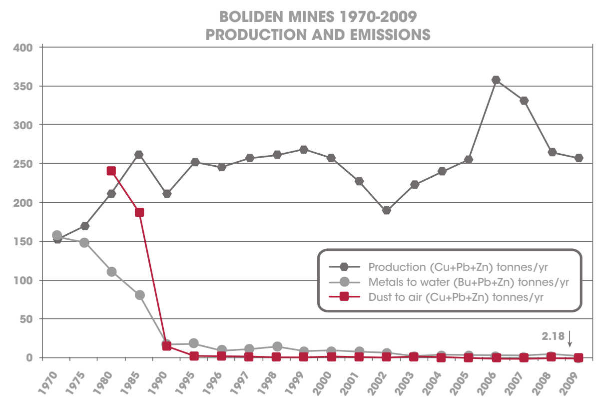


Figure 11. Production and metal emissions to water and air from the Boliden mining operations. Note that the left-hand axis shows ktonnes/yr for the production rate, but tonnes/yr for the emissions.

The baseline studies performed for Boliden, KGHM and LKAB show similar patterns, even if the companies are using completely different mining methods. In this study we do not evaluate how power is generated (mainly hydropower and nuclear energy in Sweden and in principle by domestic hard coal in Poland).

In mines, the main consumption of energy is for haulage, hoisting and ventilation. In mineral processing plants, the unit operations that consume the largest proportion of energy are flotation and grinding.

The principal activities for higher energy efficiency and lower greenhouse emissions are the following:

1. CO_2-reduction: For reasons of CO_2 generation, energy and health, diesel petroleum fuel is to be completely avoided. Biofuel, with considerably lower CO_2 emissions, could be an interesting option. New power trains for vehicles are to be researched and developed. Fuel cells or battery operation could be an option. Energy consumption for heating/cooling of ventilation air can be decreased by better optimisation and by an increased use of heat exchangers.

2. Energy efficiency: By avoiding the use of diesel underground and introducing increased remote control and automation, the need for ventilation should decrease, see the above bulleted point. Hoisting is already very energy-efficient, so the only way of lowering the energy demand is to decrease the hoisting of non-value-adding material. This calls for selective mining and the sorting/pre-concentration of ore/waste underground. It could be possible to reduce the energy used for comminution by searching for beneficiation methods that require less grinding or grind less material as a result of selective mining, by better optimisation of current technology or by completely novel techniques for grinding.

4.5.2 Increased ore recovery

Increased ore recovery is important from both a sustainability and an economic point of view.

The main activities are:

- Improved knowledge of the rock: with fewer people underground in the future and greater importance attached to data for process and product control, reliable models of the rock and its properties will be a major challenge. This includes the development of suitable sensors as well as the development of methods for turning data flows into useful information and reliable models.

- Selective mining: Improved mining methods and an increased use of mechanical excavation and suitable equipment should increase ore recovery.

- Improved mineral processing: Methods to increase the liberation of ore minerals by controlling the comminution process, improved recovery of fine particles (especially in flotation), the development of flotation equipment for the recovery of coarse particles and direct metal production from base metal concentrates.

4.5.3 Reduction of emissions

One specific concern is the reduction of concentrations of nitrogen species in mine effluents. An important source of nitrogen is, for example, the ammonium nitrate-based explosives used in mining operations. In underground mines, a large proportion of the nitric gases formed during explosions are dissolved in mine waters, which are pumped up from the mines. Also, undetonated explosives sorb to particle surfaces, and follow ore and waste rock to the processing plants or waste rock dumps. During processing, the undetonated explosives are washed out and nitrogen is dissolved in the process water. Waters discharged from mining areas often have considerably higher nitrogen concentrations than the 5 mg/l suggested as the upper limit by the Swedish Environmental Protection Agency.

Research is to be focussed on:

- Lowering the amount of undetonated explosives and spill.

- Treating high nitrogen concentrations in drainage waters by using low-cost biological methods. One suggestion could be to use common duckweed in tailing ponds, which takes up nitrogen. Another idea would be to distribute the nitrogen-rich waters in forest areas, thereby increasing the forest growth since nitrogen is the limiting nutrient in such areas.

The first step would be a thorough literature/feasibility study to search for and evaluate innovative and realistic ideas.

4.5.4 Reduced impacts of the waste generated - waste into products

Waste as a concept is clearly linked to something unwanted or an unsuitable type of material. Hence – from a philosophical point – what is waste for one person may be something useful for someone else, or similarly what is waste today could be a potential asset tomorrow.

"Mining waste" today is mainly the "clean" barren rock that is derived from drifting and the tailings that remain after mineral beneficiation. Coarse barren rock can find its applications in civil engineering. However, the use of fine-grained tailings from flotation with a particle size of below 150 µm would be more problematic, but by stabilisation such material could be used for example as a backfill material. Depending on the mining method used, etc. the ratios between the barren rock and the tailings are different. Owing to the magnetic characteristics of the ore it mines, LKAB can easily separate the ore from the barren rock. The process in itself is clean and will generate emissions apart from the effects of stray materials due to mining (explosives, etc.). On the other hand, base metals are often associated with pyrites that are liberated during beneficiation, and clearly constitute a long-term hazard for the environment unless managed properly.

The main ideas for reduced environmental impacts are:

- No harmful emissions: For the base metal mines, the pyrites should be removed by roasting/bio-leaching. The process will create energy and useful by-products such as sulphuric acid. The residues from roasting (cinders) consist primarily of ferrous and ferric oxides which can be used as a raw material for iron making and as an iron-bearing component in the production of Portland cement. The use of tailings for backfill should be maximised under anaerobic conditions. The credit elements found in the pyrite, such as cobalt, nickel and gold, should be extracted. Another important issue is to reduce nitrogen effluents generated through the use of explosives by biological treatment.

- 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.

- Natural background concentrations in mineralised areas: Release of heavy metals to the environment is a natural process in mineralised areas. From a sustainability point of view, the impact of man-made metal release from mining operations should be assessed in relation to the natural weathering and release of metals from different rock/soil types.

- Market and product development: Continue with research and development and innovation activities aimed at turning waste into products. Barren rock could be used for aggregates in road construction concrete. Waste and tailings could be used for construction purposes after stabilisation. The waste volumes could potentially be used to increase the attractiveness of the landscape or community.

- Mine site metal production: Solvent EXtraction-ElectroWinning (SX-EW) is an increasingly common technology for producing copper from oxide minerals, but is not yet used for sulphide ores. Mine site metal production would decrease the need for transportation in general as well as the need for smelters.

4.6 Resource characterisation

A strong message from the participating mining companies is that a better understanding of the geology is needed, so that important indicator parameters may be developed to control the product quality and ensure a smooth production process. Depending on the issue, the investigations are on scales from 10 billion m^3 down to a billionth of a billionth m^3, and even less. We need to parametrise the geology with respect to thermal, mechanical, hydrogeological, chemical and (micro-) biological properties and deduce the key parameters that essentially govern product and process quality, see Figure 12.

Resource characterisation is a huge field of research, development and innovation. The main research aspects are connected to model development and the selection of suitable performance indicators or substitute parameters that can easily be used to unveil the important features of the rock. Improvements are necessary with respect to non-destructive testing, drilling and logging technology, as well as data processing and visualisation of information. Promising technology for on-line analysis of drill cutting is already commercially availble using X-ray fluorescence (XRF) or laser-induced fluorescence (LIF).

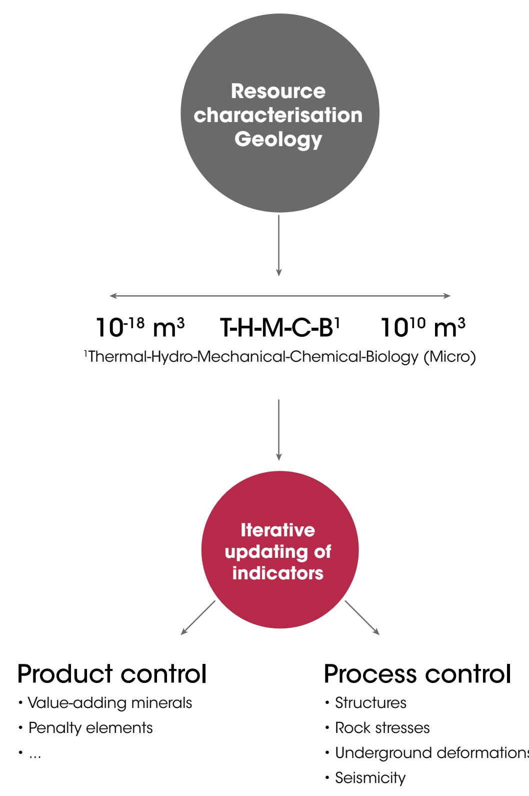


Figure 12. Need for improved methods for resource characterisation

4.7 The attractive workplace

The Mine of the Future project deals with the interfaces between Man-Technology-Organisation, and has specifically studied how to create the attractive workplace that engages and motivates young people who are in general not particularly interested in working in the industrial sector. We searched for ways of further developing an innovative, efficient and competitive mining culture.

Future mining will continue to be shaped in a context in which it is necessary to produce at an internationally viable cost. Further rationalisation requires both new technologies and new organisational solutions. The companies may no longer have clear boundaries but instead create enhanced informal and formal co-operation with customers and suppliers. Based on these developments, we see the need for an improved learning-oriented work organisation based on lean production that is adapted to human physiological, psychological, social and cultural conditions. An attractive workplace is also a safe workplace.

The lessons learned in the project are summarised in the following 26 statements for an attractive workplace in the Smart Mine of the Future, grouped under four themes: safety, physical work environment, psycho-social work environment and social responsibility.

Safety

- Safety is maximised through zero access to the development and production areas, based on automation and remote control technology
- Risks (especially serious risks) are minimised through systematic work environment management with actions based on systematic and thorough risk assessments

Physical work environment

- Appropriate variation in musculoskeletal workload promotes physical health
- Noise exposure is minimised (no harmful exposure, minimised disturbing noise)
- Vibration exposure is minimised (no harmful exposure, minimised disturbing vibrations)
- Chemical exposure is minimised (no harmful exposure, no vehicle exhaust fumes)
- Physical climate is comfortable (comfortable heat load)
- Proper lighting is installed (comfortable and task-supporting lighting)
- Radiation exposure is minimised (radioactive, electromagnetic)
- Premises, machines and vehicles are fit for different human needs and limits, and for efficient performance of tasks

Psycho-social work environment

- Management is supportive of and appreciated by personnel
- Co-operation between management and personnel is extensive and efficient
- Work organisation is based on autonomous production groups
- There is a good balance between demands and self-control (for groups and individuals)
- Learning includes generic theoretical knowledge to create flexibility in the production systems
- The understanding of mining production in a holistic perspective is general and good
- The work continually offers new challenges and meetings with new professions
- Under-represented groups are affirmed and the workplace culture is based on gender equality
- The wage systems promote both safety and work motivation
- Working hours and schedules are flexible and based on social requirements
- Job security is good and based on efficient production

Social responsibility

- The employees feel proud to work in the company
- The mine site has a living society with broad cultural activities
- Fly-In - Fly-out of personnel and contractors is avoided as far as possible
- Contractors have the same basic rights and obligations as the companies' own personnel
- The environmental impact is minimised

The above statements have to be given operational form before they can be practically utilised. In the detailed studies, 36 areas were identified for further research, development and innovation. All these areas were further screened and joined as one prioritised research area.

Development of design criteria and guidelines for good and safe mining work and workplaces.

Future efficient mining operations will be dependent on a highly competent and well-motivated work force, on all levels. The mining companies will have to recruit their personnel from a limited group of talented individuals with high demands and expectations on future work. In order to be successful with this, the companies must offer a safe, sound, interesting and challenging work environment. This is also extremely important for maintaining and further developing an already competent work force. The work environment in a future mine will no doubt be very special, which means that old guidelines and guidelines from other industries cannot be directly applied for the design and organisation of the Smart Mine of the Future. Our proposed research project aims at establishing new and relevant guidelines, especially for the early stages of physical and organisational design.

We also need to identify future skill requirements and shape future education programmes for mine management and workers, develop a strategy for recruiting more women, develop a mentor system for miners so that professional knowledge is transferred between generations and develop Virtual Reality for training and simulation, particularly for the operations in hazardous environments. Relevant competence development is an absolute requisite for a successful development of the future safe, attractive and efficient mine.

4.8 Prioritisations

Several important needs have been presented in Sections 4.2- 4.7 and these have been prioritised in consultation with the MIFU Steering Committee.

Figure 5 specifies the performance targets, and these should be obvious drivers for the research, development and innovation necessary. Following due analysis of the baseline conditions at Boliden, KGHM and LKAB, and potential ways of achieving the target, Table 1 was prepared. The table describes for each performance target the most promising options for success, and how each action would contribute towards achievement of the targets. The effects listed are at the present stage estimated and cursory.

+ : Target is met by 0 to 1/3
++ : Target is met by 1/3 to 2/3
+++ : Target is met by 2/3 to 1
- : Negative influence on target by 0 to -1/3
- - : Negative influence on target by -1/3 to -2/3
- - - : Negative influence on target by -2/3 to -1
0 : no effect at all.

Table 1. Effect of RDI areas on commitment targets.

Proposed RDI	Energy	CO_2	Recovery	Waste	Production	Safety	Human
Electrical operation with battery	+	++					[5]
Fuel cells	++	+++					
Mechanical excavation	-		++	+	+++[3]	+	
New technologies for fragmentation	++						
Biodiesel	+	+++					
Heating and cooling	+	+					
Vertical mills for abrasive materials and wet grinding	++						
Optimisation of the use and application of HPGR	+						
Use of stirred mills for coarser particles	++						
Optimisation of the parameters for rotary grinding	+						
Long-range R&D on new mechanisms for breakage	+++						
fundamental study into the hydrodynamics of flotation cells and bubble generation	+						
Geological knowledge and resource characterisations			+	+		+[6]	
Methods for measuring caving flow1			+	+			
Dry processing for fine particles			++				
Flotation methods for fine particles, hydrophobic interaction and other agglomeration methods			+				
Hydrodynamic studies of flotation with the objective of enhancing the recovery of coarse particles			+				
Deposition of waste underground	+			+++[2]			
Availability and machine utilisation					+		++[4]
Process control and management					+	+	
Remote control and automation					+	++	+++
Rock mechanics						++	
Robotising							[5]
Detonator development							[5]
Electrical operation without cable							[5]
Direct production of metals at the mine site			±				

1. Only LKAB
2. No effect for Boliden
3. + for LKAB
4. Referred to as conditioning system in this performance target.
5. Prerequisite for complete remote control and automation, and should therefore be included in the remote control and automation RDI area.
6. Prerequisite for Rock mechanics and should therefore be included in this RDI area

"Future efficient mining operations will be dependent on a highly competent and well-motivated work force, on all levels."

5 WAY FORWARD

The mining companies with their associated suppliers need to be competitive in order to stay in business. With the anticipated global and national challenges ahead, there is no other successful way forward than to continue to improve safety and productivity while making operations greener with higher recoveries, increased energy efficiency and decreased emissions to air and water.

Guaranteeing that the mining sector continues to be attractive to young men and women in the future requires a wide range of measures, including improvements in mine-site safety, health promotion and personal development. A further factor is continued improvements in living conditions at the mine sites and associated regional centres for mine control.

The work conducted so far in the Mine of the Future project has outlined prioritised issues for research, development and innovation. The general steps towards implementation are shown in Figure 13 and Figure 14. Each step, i.e. MIFU I, MIFU II and MIFU III, will be used to screen and cull out the most promising options before implementation. The first step - MIFU I – the conceptual stage – is reported here. Based on the results of this stage, a number of feasibility studies have been identified (Figure 15).

MIFU II will continue as an integrated study. Such studies may be open to organisations that did not participate in the conceptual stage. The feasibility stage could also – issue by issue – identify suitable partnerships between one or several mining companies and a preferred supplier. The feasibility studies in MIFU II should result in clear proposals containing detailed descriptions of the current state-of-the-art, objectives, the scope of work to be done, deliverables, schedules and costs, etc. Consequently, the MIFU II stage defines precisely the development work to be conducted in MIFU III before implementation.

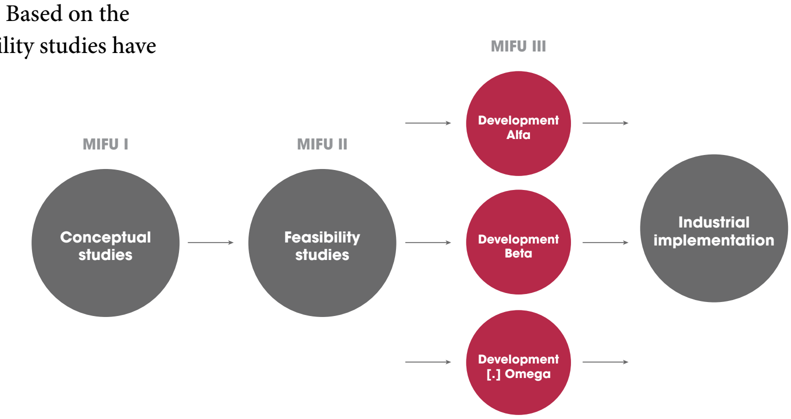


Figure 13. The process from the conceptual stage to implementation

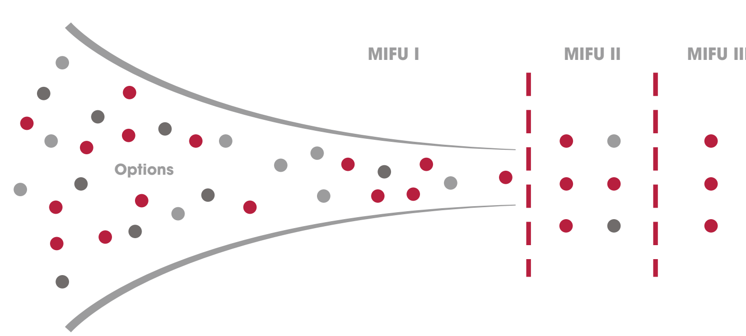


Figure 14. Priority setting during the stages

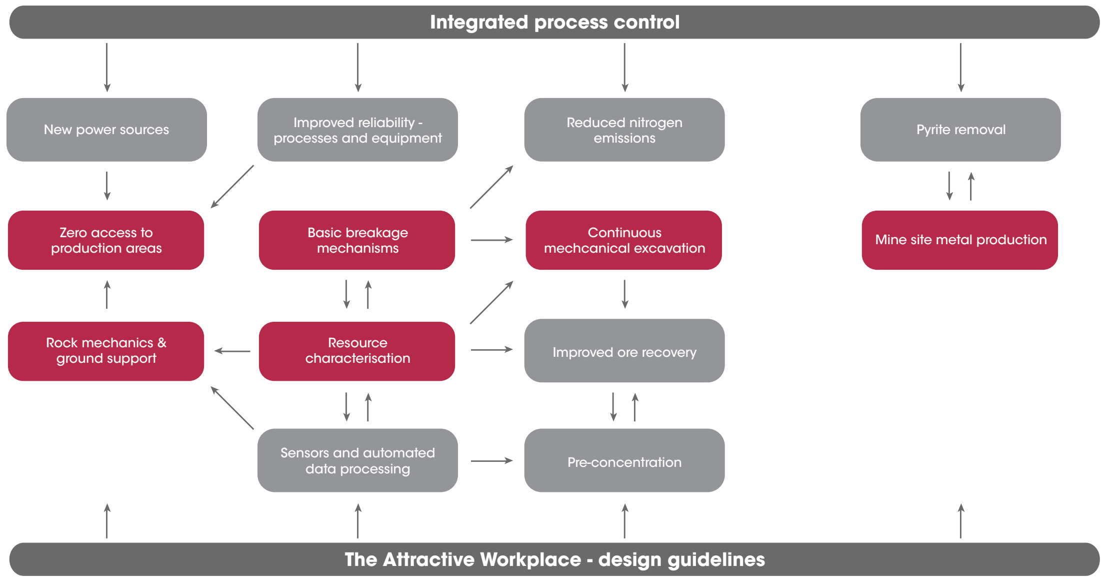


Figure 15. Preliminary suite of feasibility studies

We have good experience from working in triple helix between the industry, the academy and public agencies. The triple helix may be arranged as long-term commitments through Public Private Partnerships (PPP).

It is here foreseen that MIFU III will be developed as large scale integrated Research and Development projects on a national level, set up in a similar manner as the present VINNOVA/MITU Strategic Mining Research Programme. We also believe that there should be good links between the national initiatives and the European initiatives (Figure 16).

Figure 16. The good links between national and European programmes are essential

Consequently, the national programme should ideally also link to the European framework programmes FP7 and FP8. The latter programme commences in 2014. We also foresee that demonstration plants will be implemented through the EU flagship Innovation Union[10]. As stated in the introduction to this report, the Commission plans to create Innovation Partnerships to ensure a secure supply and achieve efficient and sustainable management and use of non-energy materials throughout the entire value chain in Europe. The Commission states that: Demonstrating ten innovative pilot plants for raw materials extraction, processing and recycling, and finding substitutes for at least three key applications of critical raw materials underpin this Partnership".

Raw materials are essential for the sustainable functioning of modern societies. To meet the grand challenge of raw material supply, vigorous efforts are needed in primary extraction, in recycling and in substitution. For the European arena, metallic minerals and "high-tech" minerals are of particular interest, due to the large import dependency.

The Nordic countries have an extremely good position to respond to the challenges of future mineral supply. The region is rich in minerals. Improved tools and methods for deep exploration will probably lead to the discovery of hitherto unknown mineral wealth. The close interaction with the very competitive mining companies and the Nordic supplier industry has fostered world-class technology that provides attractive jobs at home and competitive technology that contributes towards making mining safe, lean and green both in Europe as well as world-wide.

To maintain and further strengthen the competitive advantages, sustainable vigorous efforts in research, development and innovation are vital. The long-term commitment from industry, universities and research institutes, governments and the European Union creates the solutions necessary to meet the needs of its citizens. The metal mining sector will continue to supply the raw materials necessary for the sound functioning of society, attractive jobs for young men and women, continue to be a facilitator for the development of new technology and be a strong driver for the development of regions.

[10] Europe 2020 Flagship Initiative Innovation Union COM(2010) 546.

ANNEXES

ANNEX A

Organisations that endorse the Vision, Commitments and the Way Forward.

ABB AB
Atlas Copco AB
Boliden AB
Georange Ideella förening
KGHM Polska Miedź
Luossavaara-Kiirunavaara AB
Luleå University of Technology
Metso Minerals AB
Nordic Rock Tech Centre AB
NCC Construction Sverige AB
Sandvik Mining and Construction AB
ÅF AB

ANNEX B

The conceptual study “Mine of the Future” brings together major Swedish and Polish mining companies and several major global suppliers and the academia to develop a common vision for future mining.

Objectives

The objectives are as follows:

- to create a vision of the Mine of the Future
- to identify the most strategic problems that need to be solved in present mining operations in order to become world class in production and on a level with world-class manufacturers in other sectors
- to determine the course of action needed to meet the vision, namely:
  - improved image,
  - greater cost efficiency,
  - higher ore and metals recovery and better dilution control,
  - higher energy efficiency and lower greenhouse gas emissions,
  - reduction of human exposure, and
  - a more attractive workplace.
- to prepare the framework for a Swedish national mining Strategic Research, Development and Innovation Agenda 2011 – 2020. The framework will, for example, define the focus of the SRDIA and core mining competence needed, but also routes for co-operation with other industrial sectors to track and transfer pertinent solutions researched and developed by them.

Premises

The project is focussed on the overall production system from the ore and its characterisation to the finished raw material or product, ready for transportation to the customer (for example a smelter or a pelletising plant). The Steering Committee at the #3 meeting also decided to include base metal production by, for example, leaching.

The following assumptions are made:

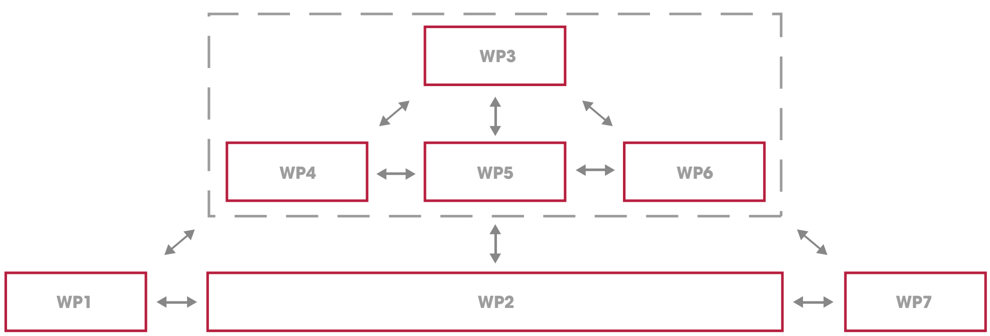
- a mine at a depth of 1,500 – 2,000 m with a sub-vertical ore (or sub-horizontal in the case of KGHM),
- for the mining method two types of mineralisation will be considered, one mass mining type and one vein type,
- “Best available technology” (albeit not on the market or adapted for the mining sector) will be the minimum standard and technology likely to be employed in 20 years’ time will be projected. It is important that the work on technology should visionary and not be limited by ongoing product development based on present technology.

Scope of Works

A number of Work Packages are included. Below are the titles of the WPs and the WP leaders:

1. Work Package 1 (Göran Bäckblom, RTC): Setting the scene
2. Work Package 2 (Göran Bäckblom, RTC): Conceptualise the Mine of the Future
3. Work Package 3 (Jan Johansson, LTU): The attractive workplace
4. Work Package 4 (Sunniva Haugen, Boliden): Lean mining
5. Work Package 5 (Torbjörn Naarttijärvi, LKAB, Eric Forssberg, LTU): New production processes and technologies
6. Work Package 6 (Björn Öhlander, LTU): Green mining and mineral processing – reducing the environmental footprint
7. Work Package 7 (Göran Bäckblom, RTC): Integration of results, the way forward and final deliverable

The overall principles for flow between the WPs are shown in the figure below



Participants and organisation

The participating organisations that signed a joint agreement on April 6, 2009 are shown below. KGHM became a member in July 2009. MIFU and VINNOVA are responsible for the Strategic Mining Research Programe agreement.

NEW BOLIDEN KGHM POLSKA MIEDŹ S.A. LKAB NCC

GEORANGE LULEÅ UNIVERSITY OF TECHNOLOGY RTC ROCK TECH CENTRE

ABB Atlas Copco metso SANDVIK

MiFU Swedish Mining Research VINNOVA

Below are the members of the Steering Committee, chaired by Ulf Marklund, Boliden.

Party	Member	Deputy
ABB	Mikael Grage	Kjell Carlsten
Atlas Copco	Mikael Ramström	Markku Teräsvasara
Boliden Mineral AB	Ulf Marklund	Sunniva Haugen
Georange	Lennart Gustavsson	Lars Lövgren
KGHM	Henryk Karas	Andrzej Niechwiej, Krzysztof Barrek
LKAB	Monica Quinteiro	Göran Adolfsson
LTU	Pär Weihed	Jan Johansson
Metso	Lars Grönvall	Jari Riihilahti, Staffan Tapper
NCC	Jan-Olof Lampinen	
RTC	Stefan Romedahl	Göran Bäckblom
Sandvik	Åke Roos	Rauno Pitkänen
ÅF	Kennert Röshoff	Ann Bäckström

The Steering Committee met regularly at workshops and formal Steering Committee meetings. In total, the Steering Committee met on six occasions. In addition, a "Summit meeting" was arranged with the top management from the participating organisations present.

The Project Group consisted of the Work Package leaders with Göran Bäckblom as overall Project Manager. The PG met at 20 PG meetings. In addition, a major workshop was arranged with the students at LTU to discuss the present and future image of the mining industry.

Deliverables and dissemination

Internal progress reports for each Work Package have been reviewed and approved by the Steering Committee. The project has prepared press releases that received good coverage in the international mining press. The project has been presented on several occasions in Sweden (Bergforsk 2010, Euromine Expo 2010) and Europe in connection with events arranged by the European Technology Platform for Sustainable Mineral Resources. A dissemination plan has been prepared and adopted by the Steering Committee.

Miscellaneous

The conceptual study was conducted over the period March 2009 – December 2010. The total cost of the project is SEK 5.5 million (approximately EUR 550,000). VINNOVA made a grant of SEK 3.1 million. The consortium was managed by Nordic Rock Tech Centre AB (RTC).

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