norden

NordMin

FINAL

NordMin Work Programme and

Strategic Research and Innovation Agenda

2013-2016

Content

Introduction

NordMin is as a Nordic network of expertise and research focusing on sustainable non-energy raw materials, and is initiated by the Nordic Council of Ministers with its management at Luleå University of Technology. NordMin will support research, development, innovation and education initiatives in the raw materials sector in all Nordic countries and Greenland. The strength and synergy from the complementary capacities of the Nordic countries will give NordMin a competitive edge internationally.

The network will serve as a platform for existing and future Nordic co-operation in the mining and mineral sector, and will be designed through dialogue with participating stakeholders. The aim is to improve sustainability in the Nordic mining and mineral sector in terms of resource efficiency, impact on the environment and impact on society. The problems of attracting skilled and gender balanced labour force to the sector will also be addressed.

The network will be funded by the Nordic Council of Ministers for four years (2013-2016). From 2016 onwards, NordMin should be financially self-sufficient through financing from other sources. The aim is to create long-term Nordic cooperation in the mining and mineral sector.

The NordMin Project is based on the SusMin proposal of 12 October 2011 which was submitted to the Barents Council. This proposal was developed in dialogue with researcher- and industry representatives in the Nordic region. The proposal addressed the needs identified in: Europe 2020, in the European Raw Materials Initiative, in various policies and strategies relating to minerals in the High North adopted nationally in the Nordic countries and in strategic research programs in the mining and mineral sector.

Supply of non-energy raw materials is essential to the global economy and to maintain our quality of life. They are also vital for the Nordic economy and for the development of environmentally friendly technologies that are essential to downstream Nordic industry. To fully meet future societal needs, metals and mineral products from both primary and secondary resources are required. Advanced research and innovation is essential to improve the Nordic knowledge base and to strengthen technological developments which will lead to discoveries of new deposits, and to improved efficiency along the raw materials value chain - from the knowledge base through to exploration, mining, processing, metallurgy and product development. Every step of this value chain needs to be sustainable and associated with strict environmental standards.

Research regarding the raw materials value chain needs to go beyond the present-day economic and technological constraints, and should be closely integrated with training and education, in order to enhance and ensure desired skills developments. It also has to enable the sharing of the most recent advances among Nordic research institutions and industrial sectors. This, in turn, requires inputs comprising different scientific and technical skills and competences which should all form part of NordMin, such as; earth sciences, material sciences and technology, chemistry, physics, engineering, biology, environmental sciences, economy, social and human sciences.

Vision

The vision for NordMin is to create a world leading network for RDI in the raw materials sector.

The purpose of the NordMin network is to increase the global competitiveness and sustainability of the mining and mineral industry in the Nordic region.

The goals of NordMin are to:

a) develop a collaborative platform for the Nordic mining and minerals industry, universities, research institutes and innovation instruments

b) establish a "Nordic Mining School" for coordination and cooperation of Master's and PhD programs

c) in dialogue with industry, national research and innovation financiers, regional authority and other stakeholders, develop Nordic cooperation in research, innovation and demonstrative projects that can contribute to a sustainable mining and mineral industry.

d) create a platform for exchange of experience on Nordic countries' mineral strategies as well as other policy areas that affect the mining and mineral industry, and to examine the need for a platform for exchange of national authorities' lessons learned of working with the extracting industry.

e) attract external funding to a degree that makes it possible for the network to thrive also beyond the three years of Nordic funding, and to work to attract further investment in the network through EU funds, national funds and private investors, so the network can achieve long-term volume as described below, e.g. budget of approx. 100 million. DKK per year.

f) address issues of mutual importance for the extractive industry and society for ensuring a sustainable mining and mineral industry in the Nordic region, including such issues as CSR, gender equality etc.

g) increase the global visibility of the mining and mineral industry in the Nordic region

h) initiate a broad stakeholder dialogue on the future challenges of the mining and mineral industry

Expected outcome/Deliverables

The following deliverables and results are foreseen:

- Formalized academic and industry collaboration within research and innovation projects, that will result in:
    - Competitive Nordic sustainable mining industry and academia with global impact and reputation
    - Improvement of best available technology and reduction of the environmental footprint
    - A Nordic critical mass in post graduate education, based on PhD involvement in all NordMin initiatives which will lead to a stronger sector wide recruitment base
    - Increased processing of raw materials (minerals) within the region to ensure improved regional societal benefits from mining
    - Innovations that will lead to the development of new opportunities for both women and men in the sector that relates to the development of sustainable settlements in the Nordic countries.
- An established network of Nordic stakeholders in the mining and minerals area, to be maintained and mobilized for future Nordic and European actions
    - Strengthened Nordic collaboration on sustainable mining and mining innovation in a network with global impact and reputation
    - Minimize and mitigate the risk of adverse societal and environmental impact of mining and extraction
    - Contribute to a broad stakeholder debate regarding best practices for a social sustainable, acceptable and attractive mining industry in the Nordic countries.
- An established and formalized Nordic educational collaboration within mining and minerals on masters (Nordic Mining School) and post graduate level. This will be achieved by, for example, development of unique courses on subjects such as CSR, mineral entrepreneurship, mineral economy etc.
- Joint Nordic applications and actions within the framework of Horizon 2020

Organisation and governance structure

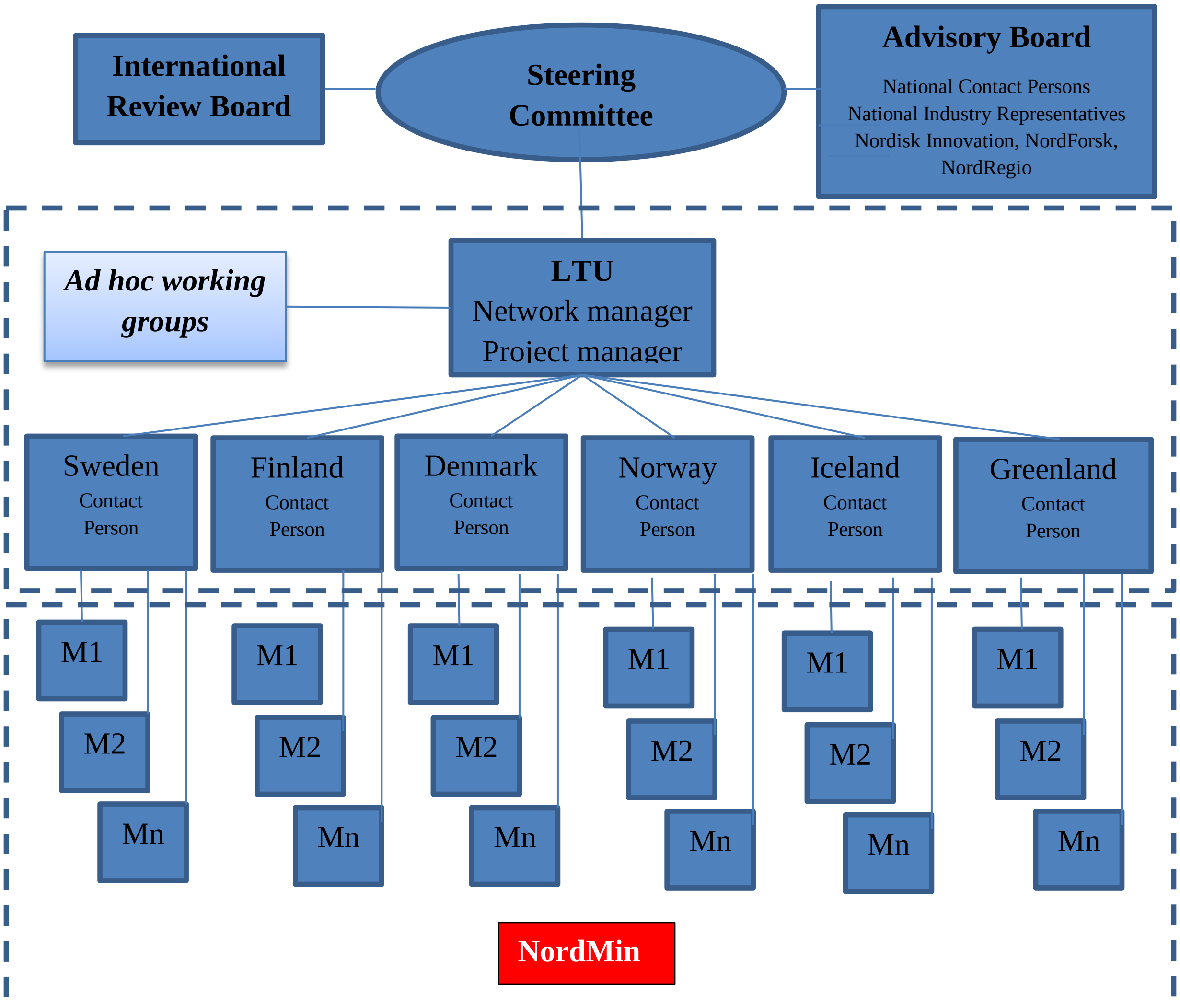
A **Steering Committee (SC)** for the NordMin network of expertise is appointed by the participating countries and comprises six members, including one member from Greenland and one member from the secretariat of the NCM (NCMS) with observer status.

Network **Management** is hosted at Luleå University of Technology and is composed of a NordMin manager who is responsible for the NordMin execution. The NordMin manager will work together with a project manager/leader as an executive body. Additional resources for a NordMin secretariat will be set up by LTU.

Ad hoc working groups can be appointed by the Management to assist is different tasks, such as organisation of workshops. An ad hoc working group, called the “Expert group**”**, assisted the NordMin management in developing the NordMin Strategic Agenda.

The **Advisory board** shall consist of two persons per country, and Greenland, representing industry and academia. The national Contact Persons could hold one of the two positions from each country. The Nordic research institutes, Nordforsk, Nordregio and Nordisk Innovation shall also have one person per institute in the Advisory board. The task of the Advisory Board is to advice the Steering Committee on the activities that are planned within the network, e.g. organisation, monitoring and evaluation of workshops, courses and preparatory projects. The Advisory Board will be convened by the Management. The project management still has the overall responsibility to inform and engage relevant actors from the Nordic Region.

An International Review board should be asked to give its view on the NordMin Strategic Agenda, assist in the evaluation of proposals that are submitted to the call for research and innovation projects and eventually evaluate the NordMin initiative after 2015. A limited number of persons (approximately 2-4) should be appointed for the international review board. The international review board will also be asked to evaluate research and innovation project proposals (see below)



Core actions

The NordMin knowledge network on sustainable non-energy raw materials will have a number of core actions:

1. Workshops as a stakeholder forum and for identifying key challenges and joint collaborative leverage projects within the defined themes
2. Research and Innovation projects
3. A Post graduate program with joint Nordic courses on relevant themes
4. Preparatory projects based on outcomes from workshops

The "**core actions**", are defined on the basis of the strategic agenda (see annex 1). The **core themes (see below)** form the basis for a joint call for research and innovation projects (item 2 above) and also form the basis for the planned workshops (item 1 above). They are aimed at addressing topics of general importance for all countries and represent the "base-load" activities for the research-oriented innovation and feasibility projects (item 4 above). Coupled to the research projects it is also the ambition of NordMin to develop a few post-graduate courses on the “non-technological” themes of common interest to all PhD-students involved (i.e. mineral entrepreneurship, sustainability of the mining sector, CSR etc., item 3 above)

The following core themes are proposed (see annex 1, strategic agenda for more info on the different core themes);

CT1: Exploration
CT2: Mining
CT3: Mineral processing
CT4: Metallurgy
CT5: Mine closure and rehabilitation
CT6: Social sustainable, acceptable and attractive mining industry and regions

Core action 1: Workshops

The working model will be two-day workshops within a predefined core theme (see above) linked to a relevant call and if possible, in connection to a conference related to the topic. Invited speakers, representing academy, research institutes, NGOs and industry, will open the workshop and collectively describe the relevant challenges we face in particular core theme and put forth directions for possible solutions. The *deliverables* from each workshop will be; (a) Knowledge exchange, and challenge Best Available Techniques (BAT) and practices (b) Information on NordMin projects, and post-graduate program (c) Launch of Preparatory Project call to fulfil leverage within the core theme, linked to an external funding possibility.

The workshops will contain following:

- 1-2 workshops per year. One workshop/country. Managed by the country-coordinator on decision made by the NordMin Steering Committee after recommendation from the Advisory Board.
- Information and update on the post-graduate program, and if possible post-graduate course modules held in conjunction with workshops
- Stimulation of project ideas and discussions on forming preparatory projects to develop NordMin leverage (explained below)The Management, supported by the Advisory Board, will present a plan to the Steering Committee for when and where the workshops could be organised. The goal should be to as a large extent as possible organise the workshops in conjunction with other conferences and seminars within relevant fields.

Core action 2: Research & Innovation projects

Research and Innovation projects will be developed within core themes on basis of the NordMin Strategic agenda. These R&D projects[1] should involve cross-nation collaboration and preferably be coupled with national funding schemes in participating countries in joint collaboration or/and by other external research program (Horizon 2020, ERA-Min etc.) Environmental and for the R&D activity (see part 4 in the project proposal template attached).

The research and innovation projects should be characterized by the following:

- At least three countries should be represented
- Industrial relevance and active involvement is mandatory
- Could include post-graduate students, post-doc and senior researchers. Associated schemes for post-doc and mobility funding should be investigated as potential leverage.
- Plan that clearly states objectives, milestones and modes of dissemination of outcomes
- Include a plan for leverage and post 2016 funding

It is recommended that each R&I project started includes minimum 1 post-graduate student (funding from NordMin 500 000 Dkr/year). Funding for post-doc and senior researchers can cover salary (incl. OH). Industry involvement should be a minimum 20% of total project budget, but 50% is to be aimed for, by cash or in-kind (should be specified in a detailed project budget). NordMin contribution to total project cost can be maximum 70% and will be maximum 5MDkr/project.

Timetable:

- The Strategic Agenda is on public consultation from the 16th of July – 27th of August 2013
- Call opens on 18 October – 13 December 2013
- NordMin brokerage event 13 November, Copenhagen
- Applications are reviewed by the International Review Group until 31 January 2014
- Beginning of February 2014, final decision is made the Steering Committee based on the recommendation from the International Review board.
- End of March 2014, signing of contracts
- 1 April 2014, projects start working

[1] Example: The Norwegian Research Council will like to see other Nordic partners in projects financed through their programs (e.g. in the User-driven Research based Innovation program). Typically two calls per year.

Core action 3: Post-graduate (PhD) program

Parallel to the NordMin network, NCM has funded an initiative that is aimed at establishing a collaborative Nordic Master's program within geosciences and engineering in non-energy-related raw materials, with the ambition to launch a double degree programs involving all Nordic countries (incl. Greenland) within the next two years. This project will report on its achievements by end of 2013. This initiative will help with setting up also a joint post-graduate program funded by NordMin; involving, as a requirement, the PhD-candidates funded by NordMin, and open to all other PhD-students in the Nordic countries interested in the raw materials sector.

A NordMin post-graduate education should develop pertinent courses that could be offered to all involved PhD-candidates. The ambition is to develop course modules in the subjects under core theme 6, as described above. However, components related to innovation and entrepreneurship should also be included, along with set rules for project evaluation and funding. It is anticipated that all HEI´s involved will offer their post-graduate course program to all NordMin PhD-candidates. The course modules should also be open for involved industry partners, although a fee will be charged for the industry participation. The NordMin management will work as facilitator in setting up this program by contacting relevant course leaders, teachers etc., based on recommendations from the expert group, industry and SC. For this purpose 800 000 Dkr is allocated for course preparation, invited speakers costs, travel expenses etc. for invited speakers. Costs for participation by PhD-students involved in the NordMin projects should be covered by the projects and be identified in the project budgets.

Besides the post-graduate program NordMin will also look into the possibility to facilitate, "on demand", short courses, especially for industry. The type of courses offered will be based on recommendation from the expert group, industry and the SC. Such short courses should be fully paid for by fees from participant.

Core action 4: Preparatory projects based on outcomes from workshops

Preparatory projects based on results from workshops should address NordMin leverage within the core themes and should if possible also address research issues identified in the R&D projects. NordMin will cover costs for establishing a partnership to develop the ideas for leverage from national, Nordic or International (EU) sources. It should be clearly stated how the preparatory projects will address funding possibilities within the different funding bodies, on EU or national level. In order to ensure success it is essential to focus on professionalism in project management, complete dedication amongst the project partners, and produce outputs of highest quality. Preparatory project call opens for 4 weeks at every NordMin seminar, 1-2 times/year. The call is based on the theme chosen for each NordMin seminar and linked to a coming external call. NordMin will cover the costs for establishing a partnership to develop the ideas for leverage from national, Nordic or International (EU) sources up to max 250 000 DKR/PP. One preparatory project per seminar will be approved. There will be a simple application form to fill in to be find on the webpage of NordMin; www.nordmin-network.org. Minimum 3 Letters of

Interest from 3 Nordic countries should be attached to the application. Decision will be made by the NordMin Steering Committee latest 2 weeks after preparatory call closure.

Budget allocation

Out of the 30 MDkr for the years 2013-2016, 5.5 MDkr is allocated to the NordMin administration and management. The remaining 24.5 MDkr will be spent on core actions as defined above. 6 workshops will be executed during the NordMin initial phase. For planning the workshop, venue for two full days, plus costs for invited speakers and workshop facilitators, each workshop will cost about 350 000 Dkr;/year in total 2 100 000 MDkr. Another 400 000 Dkr/year is reserved for post workshop activities (Feasibility projects); in total 1.2 MDkr. For the research and innovation projects 18 000 000 MDkr in total is allocated in the NordMin budget.

NordMin will launch one large joint call where it is the ambition of NordMin to part-finance a few larger projects as described above (CA2). As mentioned above it is strongly recommended that the NordMin funding is seen as an integrated part in larger projects funded from national sources, for post-docs, mobility etc. or from other Nordic or EU sources.

For post-graduate education NordMin will set aside 400 000 Dkr/year (year two and three) for course development, teacher salaries etc. In total 800 000 MDkr

Activity	2013	2014	2015	2016	**Total**
Administration and Management	1 425 000	1 425 000	1 425 000	1 225 000	**5 500 000**
Communications Budget	100 000	200 000	200 000	100 000	**600 000**
National coordinators	200 000	500 000	500 000	300 000	**1 500 000**
6 Workshops	100 000	700 000	700 000	**600 000**	**2 100 000**
Preparatory projects	-	500 000	500 000	500 000	**1 500 000**
Call NordMin	-	6 000 000	6 000 000	6 000 000	**18 000 000**
Post graduate education 2 courses	-	400 000	400 000	**-**	**800 000**

Terms of condition, reporting, IPR etc

Reports and financial statements on Research & Innovation projects and Preparatory projects should be performed according to Standard Terms and Condition for the Nordic Council of Ministers´ Framework Agreements (01/01/2012). Reports and financial statements must be submitted to NordMin Management at least once a year and always when project activities are completed. A contract will be signed between project owners and NordMin Management.

Project Results shall be the property of the Party generating the results if otherwise is not agreed. If a Project result has been jointly generated by several Parties and if their respective share of the results cannot be ascertained, they shall have joint ownership of such Project Results. Said Parties shall establish an agreement regarding the allocation and terms of exercising that joint ownership within 6 months from the Project Result coming into existence. If Project Results have the potential to be exploited industrially or commercially, its owner and any relevant other Parties shall agree to provide and pay for an adequate and effective protection.

An important principle for publicly financed research is that society benefits from the achieved results in a widest possible sense, both through dissemination and commercial utilisation.

Annexes:

Annex 1: NordMin Strategic agenda

Annex 1

NordMin Strategic Research and Innovation Agenda

2013-2016

Main research and innovation challenges

The strategic agenda of NordMin draws on the result from the recent road mapping of the ERA-NET on raw materials ERA-MIN[2]. The following main challenges of research and innovation for Nordic collaboration are identified:

- Improve exploration and mining technologies that are necessary to satisfy the growing worldwide demand. World class discoveries are made less often and research into exploitation of deep deposits as well as development of knowledge of unconventional resources is important.
- Improved resource and energy efficiency in any process along the value chain ("make more out of less").
- Improve the best available technology and improve reduction of the environmental footprint.
- Ensure that, in harmony with stakeholders and the society at large, the flow of minerals and metals needed by the society is ensured and that this is done within a sustainable framework.
- Ensure the highest-quality training of future generations, which will have to deal with the multi-faceted raw material issues. Training of professionals is also necessary to disseminate state-of-the-art knowledge and good practices in the fast evolving field of research on non-energy and non-agricultural raw materials.

Specific issues along the raw material value chain

Primary resources supply

In a context of growing demand, new resources have to be found on shore and off shore. However, exploration and mining activities will be possible only if eco-efficient and environmentally sound technologies are developed; a process that should also include social dialogue. It is also necessary to develop technologies adjusted to the properties of the processed raw materials to increase extraction efficiency, maximizing mineral and metal recoveries of the production processes and minimizing pollutant emissions at competitive production costs. NordMin should thus strive to:

- Compile new geological, geophysical and geochemical data, to maintain and develop a Nordic-led role in 21st Century exploration.

[2] see http://www.era-min-eu.org

- Address the social and ecological aspects of sustainable development both on land and at sea. Environmental goals like waste reduction reduced mass movement and land use should become inherent objectives of the ecological part of every future mining/quarrying related development activities.
- Find new methods and technologies for safe extraction from deep mines with high rock pressure, high temperatures and dusty and remote single working place
- Develop new methods and technologies for mineral processing at an industrial scale, from comminution to concentration and extraction. These technologies will need to be energy- and resource-efficient, whilst at the same time have a minimal environmental footprint, and they will be adapted to the treatment of primary mineral resources of increasing complexity and decreasing grade. Innovation in industrial minerals production and metallurgy is one of the key factors to unlock the development of a growing number of mineral deposits that otherwise cannot be technical and economically exploited.

Secondary resources supply
Recycling is important for improvement of resource management, energy efficiency and reducing the environmental impacts of extractive and metal producing industry. Metals in principle are infinitely recyclable without a degradation of quality. However, recycling becomes much more difficult with increasing product complexity. Improved recycling requires innovation throughout the entire life cycle, and technical solutions that offer the flexibility to cope with future and new product types. Technical innovation is however not sufficient, and recycling needs to be embedded in a broader context of non-technical, economic and social/behavioral issues.

The following challenges should be in the focus of NordMin:

- Knowledge-based as well as environmentally conscientious and social sustainable mineral resources exploration and mining
- Recycling of mining and smelting residues (including historical dumps and tailings)
- Metallurgical extraction
- Product manufacturing
- Product distribution & use
- End-of-life collection and logistics
- End-of-life pre-processing

The overarching objective is to integrate these challenges into a systemic view of the whole chain with all research activities coherently feeding into this while considering interdependencies.

Public policy support and mineral intelligence
The achievement of sustainable, secure and affordable access to mineral raw materials and the efficient, environmentally responsible use of mineral resources not only depends on scientific and technical progresses. It also depends on i) clear, enabling public policies, ii) capable and responsible partners in the primary and secondary minerals and metals industries; iii) effective, well-trained and suitably resourced administration iv) collaboration of public and private sectors in a spirit of partnership.

NordMin should thus also focus on:

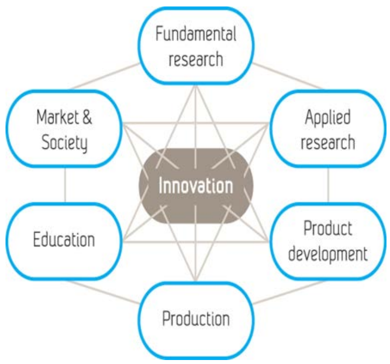
- Corporate social responsibility issues
- The social license to operate
- Relations with nearby community and indigenous people
- Innovation and entrepreneurial aspects
- A platform for exchange of experience on Nordic countries' mineral strategies as well as other policy areas that affect the mining and mineral industry.
- A platform for exchange of national authorities' lessons learned of working with the extracting industry.
- A dialogue on the future challenges of the mining and mineral industry

Education and international cooperation
It is necessary to foster ***collaboration*** in research and education between Nordic countries. By the same token we should foster the relationship between Nordic countries and the producers plus consumers of raw materials throughout the world. In the past 5 years, renewed interest in the minerals sector has led to a regeneration in mining. In parallel, research and development in mineral processing and particularly in recycling has increased. Also, issues related to the security of supply of raw materials have gradually led to a growing interest in materials science and engineering. This recent evolution is accompanied by a strong need of teachers and mentors with cutting edge knowledge in all parts of the raw materials value chain. However, in many sectors, there is a scarcity of trained specialists and a lack of infrastructure and experts. Revitalized ***research*** along the raw materials value must also be coupled with improved and expanded ***teaching and training***. Promoting education and training is necessary in order to: a) contribute to Nordic countries overall expertise in the field, b) increase the public awareness of the importance of raw materials as part of the foundation of modern society's material quality of life, and c) maintain the supply of professionals (geologists, materials scientists, engineers, designers, teachers) needed to support both traditional and high-technology industries in the Nordic countries.

The Innovation dimension

Scientific knowledge and methodology, combined with research in an industrial- and market-driven context, is at the core of a modern Research and Development Initiative. This concept fits very well with the NordMin initiative where the principal aim is to develop environmentally, socially and commercially sustainable industries on the basis of local/regional raw material resources. In this context it is imperative that the program also promotes value-generating processing on a local as well as on regional scales.

The arctic areas of the Nordic countries shows excellent distributed innovation systems and R&D supply linked to the mining industry which is unique for rural regions in Europe. However, the mining and process industry needs to develop better models, frameworks and work practices to improve their R&D. The methodology on innovation processes in the mining industry is relatively underdeveloped and yet not formalized. In an industry with exceptional long product life cycles, process, product and applications, innovation together with improved raw material management are key challenges for business survival and sustainability.



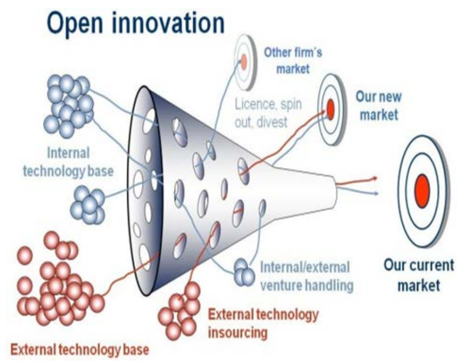


Figure: Modern innovation network and open innovation model.

Core Themes

Science & Technology Research

CT1 Exploration

Challenges
The most important issue is to integrate mineral related research to understand how small and large-scale mineralizing systems operate and how this information can be used in exploration targeting. The major goal is to understand the metallogeny and evolution of the lithosphere. Origin, distribution and exploration fingerprints of deep-sea raw materials are also key issues. Both metals and industrial mineral resources should be considered. We should understand the cause for geophysical anomalies and how ore and pathfinder elements are spread out and recorded in different substances. Another important issue is to study how different satellite data can be better utilized in exploration and integrated with ground and deep bedrock data.

New techniques and concepts for the search of deep ore deposits should be developed from the methodologies used in the oil industry. Downhole, ground and airborne geophysics as well as satellite techniques should improve their depth penetration. Drilling techniques combined with in situ chemical, mineralogical and geophysical measurement techniques, as well as high performance tools in the search of miniaturized microscopic, spectroscopic, chemical, gas content and fluid inclusion observations during logging should be developed. Advanced, laboratory and in situ, geochemical methods for different media (rock, soil, water, gas) to detect anomalies, caused by mineralizing fluids, in covered areas with no outcrops and in samples from deep drill holes away from fluid flow centres are needed. New innovative software and concepts for 3D modelling, especially in polyphase deformed crystalline bedrock, is needed to create easily upgraded models. Data management and mining of huge amounts of heterogeneous data also require new concepts, knowhow and software development. An integrated approach is called for where geological and geophysical, as well as new technology is utilized. In this respect the growing field of geometallurgy is seen as a road forward.

Innovation needs

We have to develop sustainable exploration concepts leading to social license to operate. Successful exploration along with its appropriate metallurgical process helps the Nordic countries to produce a larger share of its consumption than today, attracts new investments and creates new SME activity in exploration. The Nordic countries have to maintain its own top-level exploration industry from manufactory (drilling and measurement equipment) to services (software, concepts) to govern the whole value chain from exploration via mines and processing to high-value added products.

RDI topics

- Minerals system mapping; 2/3/4D modelling, ore deposit models, spatial data mining
- In-situ chemical, petrophysical and mineralogical analysis in drill holes
- Development of techniques integrated drilling, geological and geophysical techniques for assessment of hidden mineral resources, deep, sea floor
- Assessment of far-field geochemical characteristics of mineral deposits

CT2 Mining/Quarrying

Challenges

The Mining and quarrying area needs to work with sustainability issues and general image issues of the sector. The public perception of mining is in many parts of the Nordic countries negative while the sector in other parts works with cutting edge technology and minimal environmental impact. Investigations into new functional materials for use in mining equipment and continuous improvement of existing and development of new intelligent IT systems and sensor technologies are key actions needed. It is anticipated that many future mines will be smaller and therefore technologies for mining of small deposits should be developed together with improved extraction rates and more energy efficient mining. This could be done by further improving mechanical extraction systems, develop methods for selective mining, methods for automation of equipment and autonomous machinery and develop energy efficient transportation in the mines and quarries.

Improved waste/tailings handling (regarding land use, efficient utilisation of deposits), reduced water consumption, sustainable management of water and recovery and use of geothermal energy from deep mines are all actions that would lead to more sustainable mining and quarrying. Making mines and quarries attractive workplaces with improving health and safety conditions are also major challenges for future mining and quarrying. An integrated approach is important also within mining and quarrying and as for exploration integration of unit operations is key for competitiveness. This includes the geometallurgical concept, resource characterisation, IT and positioning systems.

Innovation needs

Demands from new technologies will also affect the demand for mineral raw materials. New technologies in almost any field of the daily life will require increasing input of crucial raw materials. There are several methods for mining minerals depending on the type of mineral and the deposit. In general, mining operations must become more eco-efficient by reducing energy and water consumption, waste production and the impact on biodiversity associated to open-pit mining. This may be achieved by developing fully automated and autonomous machinery fully integrated in the overall mining processes. This machinery should aim at selective mining with boundary layer and material detection. Local navigation systems at the face together with collision avoidance and machine guidance systems will contribute to autonomy of the machines and to eco-efficiency. Improved predictive maintenance by means of advanced on-board condition monitoring should become integral part of machinery development.

The development of a new mine will become a real challenge especially in deep mining when operations need to access mineral raw materials in increasingly greater depths. The tools and methods for mine development need to be adapted to the conditions in greater depths, e.g. ability of cutting very hard rock or coping with challenging conditions as to rock stability. A lot of work will be necessary in this field. The (underground) mine of tomorrow will need a transition from static control model control to the dynamic control one to be able to process large amount of varying kind of data. The solution resides in novel mass flow and logistics system reference model based on centralised plant design, economic control parameters principles and an intelligent technological logistics system design. Further to that, the mass flow management and logistics has to be renewed.

New eco-efficient technologies will be applied in order to make the entire mining process more efficient and environmentally sound supporting a socio- economic community. The mine of tomorrow will run an integrated concept, meaning that all operations necessary for the eco-efficient provision of the minerals will be carried out within the boundaries of the mining operation and mainly the final product will be shipped to the customer. The emissions and waste streams shall be managed in a way that the environmental (including biodiversity) impact is minimised with the vision of zero impact. For underground mines this means minimising the installations required above ground and hence the environmental impact. The necessary level of automation in mining operations regarding also health and safety and logistics issues can only be achieved by reaching a higher level of integration in all parts of a mine. Fully integrated underground technologies and processes for diagnosis, maintenance and extraction as well as communication, health and safety issues are the key for the success. Also, improved near-to-face (pre-) concentration and processing methods including backfill procedures need to be developed. We need to improve the mining process-chain of mineral extraction at all stages ranging from the face production, transport, hoisting and processing to the final product (mine-to-mill integration). Such future improvements will have to come from fully integrated underground technologies and processes which should be developed with the vision of the next step i.e. eco-efficient and effective mine- mill-smelter integration.

No matter what kind of final solutions will be adapted in the chain of integrated processes, there will be a need for running an innovative and eco-efficient waste management (EEWM). The prerequisite of the new management concept is accepting only such solutions which lead to “zero waste” target and keep waste close to places where they are generated. It means avoiding as much as possible waste generation and recovering the fundamental part of waste volume. So, EEWM requires application of a specially refined process, which is able to fulfill such requirements. For example, in the case of underground mine, the process should selectively mines the minerals and therefore reduces waste production closer to the mineralisation. Also, another prerequisite is organising an integrated production process to treat wastes as valuable useful mineral or mixture of minerals or product, not as a waste and still looking for new possibilities of their usage. Integrated mining processes strictly connected to the processing and EEWM need solutions as e.g. backfilling but there are also other eco-efficient possibilities which should be selected, validated and tested, depending on specific limitations and waste characteristics.

To recruit employees in the future the mining industry must treat the interfaces between man-technology-organisation, and specifically study how to create sustainable attractive work places that engage and motivates even youngsters that are not particularly interested to work within the mining industry. A challenge for the future is to attract more women to the mining sector.

RDI topics

- Eco-efficient onshore and offshore mining technologies
- Eco-efficient technology for mine development
- Logistics concepts adapted to upcoming new mining environments (e.g. going deeper)
- Integrated processes, system approach
- Innovative waste management
- Safe and attractive workplaces

CT3 Mineral Processing

Challenges

Development of new and further improvement of existing technologies used to reject gangue material at coarse particle sizes, thus reducing energy consumption by rejecting unwanted material before crushing and grinding will be important. Preconcentration technologies developed to allow early concentration and separation of ore particles at the coarsest possible particle size will also be a key issue. Near-to-face comminution and pre-concentration technology solutions and comminution and pre-concentration near the place of extraction will reduce transport (energy) costs. Development of alternative comminution techniques and flow sheet solutions, including the use of HPGR (high pressure grinding rolls), electrostatic pulse and microwave-based comminution technology are called for. In general terms processing of fines should be improved.

Considerable improvements in separation technology, in particular when dealing with coarse and very fine particle sizes should be developed. Especially needed are improvements in flotation of particle sizes of < 10 µm. New technologies are needed for the effective separation of complex mixtures, including the separation of phosphates and silicates (e.g. REE minerals). This will, in particular, require the development of environmentally benign and more efficient chemicals for flotation (i.e. collectors, modifiers, activators and frothers). Production of complex concentrates with higher added value and lower environmental impact should be part of this. A quantitative understanding of processes taking place in flotation cells is also need. Development of suitable numerical models and visualization tools are important.

Optimizing the usage of water and minimizing water loss in industrial water circuits and advancing the efficiency of industrial water purification and re- circulation will increase in importance. Expanding the use of (desalinated) seawater in minerals processing and use of saline waters in the process will become important. Development of innovative dry mineral separation processes is a further challenge. Use of water in arctic conditions is also an important challenge for Nordic countries.

Bioleaching of polymetallic sulphide ores, including not only Cu, but also other base and high technology metals is seen as a challenge. Bioleaching of polymetallic Mn-Fe crusts and nodules recovered from the deep sea floor. Bioleaching of sulphide ores closely associated with organic carbon and carbonate carbon. The development of biosorption processes to effectively separate and remove metals from solutions. Increase the availability of bio- chemicals, e.g. bio-tensides for mineral processing applications.

Great improvement of the link between 3D geological knowledge and processing strategies for entire ore deposits is of importance. Effective utilization requires good knowledge of an ore body. Variability in compositions needs to be identified and production planning must accurately take the actual characteristics of the ore delivered to the processing plant into account. This geometallurgical model of the ore body will yield all characteristics tangible for minerals processing (see also “resource characterization” below). Development of suitable on-line sensors and off-line analytical methods, which will record characteristics such as grade, mineralogy, texture and metallurgical response (grinding energy required, plant throughput, expected recovery, product quality and tailings properties) should be developed. Enhanced data architecture and automation for entire processing plants.

Innovation needs

Exploration activities in the Nordic countries will discover new mineral resources, and it will be necessary to obtain and retain the required social license to extract and process these resources. In addition, resources of the future will be of lower grade and higher complexity compared to those currently exploited. For this purpose, minerals processing technologies will need to be developed that are environmentally benign as well as more energy- and resource-efficient than technologies currently available. Another important aim is to turn current waste materials into products.

RDI topics

- Energy efficiency in mineral processing
- Recovery of fine particles
- Resource efficiency in mineral processing
- Sustainable water usage in mineral processing
- Biotechnological processing
- Geometallurgy, should be a horizontal issue, should cover the value chain

CT4 Metallurgy

Challenges

Improving the medium and long-term raw material supply in Europe and increasing the competitiveness of the European mining and metal sector will require the implementation of new sustainable and economical extractive metallurgy processes adapted to the nature of the resource containing the valuable metals. Extractive metallurgy is a complex field for which up-scaling is the critical step prior to industrial implementation and job creation. Europe needs to strengthen its existing up-scaling facilities in pre-processing and pyrometallurgy as well as complete its offer with the missing hydrometallurgy pilot scale institute. This will allow networks of competencies in the field and provide a fertile ground for innovative junior SMEs. Also new business opportunities will be developed for SMEs focusing on science-based and engineering services.

In base metals metallurgy it is becoming more and more difficult to distinguish between primary and secondary resources since at modern smelters today the amount of recycled materials is increasing and the different raw materials are entering the smelters at various stages in the metal production chain. On the other hand new installations for separate treatment of scrap materials are constructed. In addition the grades of primary ores are becoming lower with more complex mineralogy and elemental composition. The knowledge on how to economically treat complex and impurity rich mineralizations will strengthen the competitiveness of the industry and at the same time the ore reserves will increase since large tonnages of currently known but unexploited complex mineralizations can be turned into valuable material. To reach those objectives technological improvements need to be implemented in all the steps of the value chain i.e. by development of new processes (or modification of existing processes) to extract currently unused metals (e.g. In, Ge etc.) from base-metal deposits.

Fundamental research and applied research need to be intimately linked thanks to a strong Research and Industry European network, and oriented towards understanding thermodynamic and kinetic processes associated to metal separation. At the same time, metallurgical processes need to be up- scaled to assure that the developed process can be implemented in the real industrial conditions and to measure and thus minimize environmental impact (water recirculation loops, residues and dust production for downstream tests). This will allow for new processes to be developed for a sustainable use of natural and secondary resources

Many of the by-products produced in one metal production line become raw material for the production of another metal. An efficient use of by-products, such as, for example, slags, dusts (EAF), Waelz oxides, leaching residues, etc., both from the metallurgical sector itself as well as from other industrial sectors will provide for a sustainable use of mineral and metal resources by reducing the amount of waste produced and increasing the metal reserve.

To have a sustainable use of natural resources new processes have to be developed where minor and strategic elements like antimony, beryllium, gallium, germanium, indium, cobalt, magnesium, REE, niobium, PGMs, tantalum and tungsten and deficit elements like Sn, Mn, Mo, Ni, Li, Re, Te are recovered. Further development of *solvent extraction and the use of ionic liquids* to separate REE´s are important.

Optimal control of the products and processes during their entire lifecycle calls for more information on their usage and condition. For this, we need novel concepts to collect data and further to identify the relevant information. This is achieved by embedding intelligence to systems and products. Data analysis tools are researched to bring information in easily understood forms to operators and for provision of services thus enabling outstanding human-system joint intelligence. Also the geometallurgical concept as an integrated approach should be introduced.

Innovation needs

- Studies into metallurgical processes and reactions in the area of thermodynamics and kinetics of processes should be an overarching aim. Studies into new types of slags and molten salts together with new technological processes for treatment of polymetallic materials, ores, concentrates, by-products, dusts with recovery of metals are challenges that needs to be addressed.
- Promote and develop sustainable and economical extractive metallurgy.

RDI topics

- Processing of low grade and complex materials in the most efficient and sustainable way
- Treatment of metallurgical by-products and waste with a maximum recovery of bulk and accompanying minor metals
- New technologies for recovery of accompanying and critical metals for better utilisation of natural resources
- Design of large integrated multi-technology products and processes by flexible and concurrent design methodologies and tools as well as modelling and simulation
- Tackle the recurrent existing metallurgical challenges focusing on sustainable and technological overlaps in the field which include recovery energy from slags, neutralization of iron in hydrometallurgy, liquid solid separation, elimination of metals in effluents.

CT 5 Mine closure and rehabilitation

Challenges

As within the mining and quarrying subarea, also the mine closure sub area needs to work with sustainability issues and general image issues of the sector. The public perception of mining is in many parts of the Nordic countries negative while the sector in other parts works with cutting edge technology and minimal environmental impact. In this respect environmentally safe mine closure and remediation is a key factor for public acceptance of mining. The demand of metals and minerals in society will increase. It is an important challenge to increase the mining in the Nordic countries in a sustainable way without negative impact on the environment. After mine closure, it should be possible to leave remediated waste deposits without continued maintenance. It should also be possible to make products of what is now considered as waste to a much higher degree than today.

Volcanogenic massive base metal deposits contain a few percent of the valuable metals, and thus more than 90% of the ore will be 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 tons. The major parts of ores thus will be waste. The global production of mine wastes is estimated at more than 15 000 - 20 000 million ton of solid waste each year.

The primary approach to the prevention and mitigation of ARD is to minimize the supply of the primary reactants for sulphide oxidation, and/or 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 availability of acid neutralizing minerals and pore water alkalinity. Another prevention option is to remove the source, i.e., Fe sulphides, from the mining wastes with the aim to reduce the total amount of ARD-producing waste and remediation efforts needed. ARD may be formed in waste deposits containing Fe-sulphides such as pyrite and pyrrhotite when exposed for oxygen. This ARD is often rich in heavy metals and metalloids. Conventional mining generate two main types of wastes, which both may contain sulphide minerals. These waste types are waste rock (dominated by coarse material) that is removed to reach the ore, and finely ground tailings generated during the ore processing. Waste from Cu, Zn, Pb, and Au mining usually contain Fe-sulfides, in contrast to waste from Fe-oxide mining. Mine closure should be an integral part already in the mine planning stage. An issue in Europe today is reopening of closed mines and therefore also re-design of old remediated areas. One challenge with reopening of old mines is the lack of documentation of un-mined parts of old mines (problematic for historic mines). This calls for recommendation for mining companies to provide detailed information after mine closure

More work on i.e. backfill of pastes and different types of water treating methods and optimization of use of chemicals are other challenges that need attention. In relation to health and safety issues dust, noise and vibrations reduction could be treated also under this heading.

Innovation needs

While decreased energy consumption and decreased waste production are important parts here we should focus on the prevention of formation of ARD in mine waste, the major problem. However, also immediate short-term problems such as metal recovery from drainage waters and dust prevention should be included. In general, the research will be of applied character. In some cases fundamental research will be needed to elucidate processes or properties of particular importance, e.g. surface reactions on Fe sulphides in different physiochemical environments.

Desulphidisation of mine tailings should be a new paradigm for waste management. Water flow management processes to reduce contact with ores (including draining systems, coating of exposed mineral surfaces, etc.) is a key sustainability indicator. Making products from mine waste and dust prevention are important issues where innovation is needed. Dry technologies development to avoid/reduce the water and energy related consumption and LCA/LCC studies to optimize the processes as much as possible are other environmental performance indicators that should be addressed.

Active biological processing of ARD and polluted soils needs further attention. Hybrid technologies for treatment of wastewater and eluates generated in industrial processes combined with metal recovery. New technologies for removal of toxic elements from material cycles in non-ferrous metals production are called for as well as new technologies for reduction of emission of sulphur and its compounds to the environment.

More innovative and efficient methods for remediation of mine waste, including increased use of waste from other industries (two problems solved at the same time) are needed. Post-closure added values for the society and the biosphere should be addressed. Methods for safe disposal of the waste formed when bioleaching is used are called for.

RDI topics

- Waste management
- Drainage and mine water treatment
- New technologies for rehabilitation of mines and tailings
- Long term monitoring system

CT 6 Social sustainable, acceptable and attractive Mining industry and regions

Challenges

Ensuring the stable supply of raw materials from sources in the Nordic countries requires improved awareness and understanding of the impacts and responsibilities associated with the consumption of natural resources. In a Nordic context most mining industry are in artic areas, in turn characterized by extremely sparsely populated regions with demographic challenges and a less diversified regional economy. Mining activities often exist side-by-side with indigenous people in a sensitive environment where there are multiple pressures on land-use, for example reindeer herding, recreation, tourism activities and/or mining. Consequently, good examples are required which show how sustainable mining can exist next to and/or together with other land users in a fruitful and mutually beneficial way. When competition for natural resources and land intensifies, conflicts may arise between landowners, and other stakeholders. Research is needed to investigate whether there are forms of regulation and partnerships that can more easily resolve such conflicts and thereby contribute to a long-term more sustainable use of land and resources.

The limited size of the regional economy in the Nordic mining regions requires that innovative approaches to developing new added-value activities may be pursued next to mining. Another challenge for the Nordic mining regions and the industry is to change existing gender patterns and make the industry more attractive for women. Where women work the families tend to stay, which is why the concern of women in the mining industry is not only a concern for the competitiveness and attractiveness of the companies but more broadly for the sustainability of local communities and regions. The mining industry has for many years been centered on men and associated with male-dominated activities, and without concerted efforts to change this, future innovation, research and development will probably continue to be restricted in a similar manner. In order to secure, safe, innovative and attractive workplaces in the mining sector, there is a need to first obtain a good understanding of present gender structures, how gender inequality operates and, most importantly, how problematic gender positions and patterns can be challenged and changed and thereby how gender equality can be achieved.

In the Nordic mining industry, as elsewhere, sustainable development may be achieved only through addressing all three of its dimensions:

- economic development – careful re-investment of the revenues generated by mining is needed to ensure the future development and livelihood of local communities as well as the wider society,
- environmental protection – the environmental impact of natural resources exploitation should be minimized and land should to be better rehabilitated to allow former mining areas to be used for other purposes post mining,
- social cohesion – minimization of social and cultural disruption to the impacted communities may be achieved through initiatives such as improved stakeholder dialogue, and by ensuring that public institutions and processes are efficient, fair and transparent.

There are several areas of the mineral development process that from an institutional point of view remain poorly understood. To better understand the interactions between existing national policies, local institutional settings and the various stakeholders within any one mining development project, and the out-put that these interactions generate, requires research. This research requires the actions and underlying drivers of both formal and informal institutions and stakeholders be studied and understood. Of vital importance is the character and role of different forms of administrative systems and government culture. Whereas the mining industry, and many of its practices, is becoming increasingly global and streamlined, there may still be a "Nordic" approach to mineral development that differs from what is regarded as "international best practise". Given that an increasing number of exploration and mining companies that are active in the Nordic region have their origins elsewhere (e.g. Austria, UK, Canada), differences between the mining development processes in the Nordic countries, and that which may be expected by the investors from elsewhere and the results of this juxtaposition of expectations and experiences warrants further study.

Maintaining 'a social license to operate' is a constant challenge for most mining companies. Resistance to mining can lead to a company's plans for exploration and/or mining to be delayed, made more costly or in the most severe case, to be suspended. How can the mineral sector be more recognized by society and among people outside the industry as safe, sustainable, acceptable and attractive? In recent years, concerns about the sustainability and social responsibility of industry have become an increasingly high profile issue also within the Nordic countries.

There are unfortunately some recent examples of poor environmental and/or social performance by few mining companies in the Nordic countries. The adoption of the concepts entailed within "Corporate social responsibility" (CSR) is increasingly a way in which mining companies attempt to improve their relationship with their different stakeholders. More knowledge regarding CSR initiatives in the Nordic countries is needed.

Innovation Needs

Innovation is needed to develop methods, procedures and best practice on issues related to how to achieve socially sustainable, acceptable and attractive mining industry.

RDI Topics

- Indigenous people and mining
- Multiple and successive land use and rural economic development in an attractive mining environment
- Land use conflict
- Changing gender patterns
- Secure, safe, innovative and attractive workplaces in the mining sector
- Formal and informal institutions and government culture
- Social license to operate and initiatives related to Corporate Social Responsibility (CSR)