



Minerals Policy Guidance for
Europe

Innovative Processing

Deliverable 4.1

*Preliminary Report on the Policy and Legislation
Framework Conditions for Innovation in Mineral and
Metallurgical Processing – Version 1, December 2016*



This project receives funding from the European Union's Horizon
2020 research and innovation programme under grant agreement
No. 689527

Author(s):

Anders Sand, Minerals and Metallurgical Engineering, Luleå University of Technology
Jan Rosenkranz, Minerals and Metallurgical Engineering, Luleå University of Technology
Johan Frishammar, Innovation and Design, Luleå University of Technology

With contributions by:

Michael Tost (Montanuniversität Leoben), Andreas Endl and Gerald Berger (Wirtschaftsuniversität Wien)

Manuscript completed in December, 2016.

ACKNOWLEDGEMENT & DISCLAIMER

This publication is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 689527.

This publication reflects only the authors' views. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of the information contained in this publication.

Reproduction and translation for non-commercial purposes are authorized, provided the source is acknowledged and the publisher is given prior notice and sent a copy.

MIN-GUIDE Project partners



Institute for Managing Sustainability, Vienna University of Economics and Business (Coordinator)

Vienna, Austria

UNIVERSITY OF WESTMINSTER

Policy Studies Institute, University of Westminster

London, United Kingdom



Montanuniversität Leoben

Leoben, Austria



Luleå University of Technology, Department of Civil, Environmental and Natural Resources Engineering

Luleå, Sweden



National Technical University of Athens

Athens, Greece



Instituto Geológico y Minero de España

Madrid, Spain



University of Aveiro

Aveiro, Portugal



GOPA Com.

Brussels, Belgium



University of Zagreb – Faculty of Mining, Geology and Petroleum Engineering

Zagreb, Croatia



Ministry of the Employment and the Economy

Helsinki, Finland

Table of Contents

1	Background and Objectives	5
1.1	Challenges for EU supply of mineral raw materials	5
1.2	MIN-GUIDE: A brief introduction	6
1.3	Work package 4: Scope and objectives	7
1.4	Terminology and definitions	8
1.5	Mineral and metallurgical processing systems	8
1.6	The stakeholder network in mineral and metallurgical processing	10
2	Approach	11
2.1	Methods applied	11
2.2	Innovation processes in mineral and metallurgical processing	13
2.2.1	Identification of relevant innovation process models and extent of collaboration (organisational structures)	14
2.2.2	Dominant modes (types) of innovation and examples	16
3	Catalysing and inhibiting elements in innovative mineral and metallurgical processing	18
3.1	Barriers to innovation	19
3.1.1	External barriers to innovation	19
3.1.2	Organizational barriers to innovation	20
3.1.3	Group barriers to innovation	21
3.1.4	Individual barriers to innovation	22
3.2	Reflections on the mineral and metallurgical processing sector	22
4	Innovation in mineral and metallurgical processing and links to policy and legislation	22
4.1	Identification of relevant innovation cases	22
4.2	Identification of relevant policies and legislation	26
4.3	Preliminary analysis of innovation cases	29
5	Conclusions	32
6	References	33
7	Appendices	36
7.1	List of Abbreviations	36

1 Background and Objectives

1.1 Challenges for EU supply of mineral raw materials

The foremost challenge for the European Union in terms of secure and sustainable supply of mineral raw materials is the high dependence on imports. This has recently been pointed out in the Strategic Implementation Plan for the European Innovation Partnership on Raw Materials (EIP SIP Raw Materials Part I, 2013). While being mostly self-sufficient on construction minerals and industrial mineral, this concerns several ores and metals, for which the European Union is heavily reliant on imports. Of EU metal production, recycling represents 40-60% of the feedstock for the most common metals. The extraction of virgin ores containing chromium, copper, lead, silver and zinc is still an important industrial sector in some regions of the EU, for instance in the Nordic countries, Ireland, the Iberian Peninsula as well as Eastern Europe. The supply of these domestic sources, however, is still falling short of industry demands. For other metallic ores, such as PGEs (Platinum Group Elements) and REEs (Rare Earth Elements), the EU is almost completely depending on imports. In addition to the EU perspective, the limited internal market supply is also pointed out in several mineral strategies on national level, particularly in countries with limited or no metallic ore mining activities (e.g. The German Government's Raw Materials Strategy –Safeguarding a sustainable supply of non-energy mineral resources for Germany, 2010; A Review of National Resource Strategies and Research, 2012). Conversely, several Member States with active mining industries are mainly addressing the challenges of the industry itself, for instance with relation to technical challenges (e.g. R&D, resource management and efficiency, environment, innovation) and other challenges such as in training and education, expertise, public acceptance (Finland's Mineral Strategy, 2010; Sweden's Mineral Strategy, 2013; Der Österreichische Rohstoffplan, Weber et al. 2012).

The challenges for addressing this issue are spanning the full value chain of mineral and metal production, including exploration and extraction, processing and refining as well as recycling and substitution of minerals and metals. General challenges faced globally by the sector include more complex and low-grade ores, translated into more complicated and economically unfavourable processing and refining. As challenges specific to processing and refining within the EU, high investment costs, waste and tailings management, flexibility and automation, safety of operations and transport and logistics have been presented (EIP SIP Raw Materials Part I, 2013). With focus on the policy side, lack of clarity and efficiency are pointed out as the most important issues. Such examples include the wide variety of interacting policies, lack of public implementation support, and lack of coordination between different policymaking levels (EU, Member State, regional, local) as well as ambiguities and sometimes direct conflicts with other policies. Other related challenges include scattered research and development actions, lack of coordination between stakeholders and lack of skilled workforce. With emphasis on the minerals and metallurgical processing part of the value chain, direct links between policymaking and processing operations appear to be few, compare section 4. Instead, challenges in this respect are more indirectly linked to challenges and competing needs of a sustainable society, such as resource efficiency (raw material, energy, water, land use), environmental challenges (waste management, hazardous substances, emissions), and health and safety aspects. This is of course at the same time linked to the economic feasibility of operations.

As part of the mitigation scheme presented in the Strategic Implementation Plan (EIP SIP Raw Materials Part I, 2013), cross value chain innovation and boosting of innovation capacity of the EU raw materials sector are listed as a key factor for success. This also needs to be supported by modern raw material policies and improved framework conditions which can facilitate such innovation and also support entrepreneurship within the sector (National Minerals Policy Indicators – Framework conditions for the sustainable supply of raw materials in the EU, 2014).

A number of the challenges listed above are addressed within the MIN-GUIDE project. This particularly concerns issues related to policy and legislation framework and coordination between policymaking levels, as well as the facilitation of innovation in the sector, in order to overcome the various technological and other challenges for innovation faced by actors in various parts of the value chain.

1.2 MIN-GUIDE: A brief introduction

The MIN-GUIDE project is a Coordination & Support Action funded within Horizon2020 that contributes to the secure and sustainable supply of minerals in the EU (Strategic Implementation Plan for the European Innovation Partnership on Raw Materials, Part I, 2013). The challenges of raw material supply for Europe, along with challenges related to innovation in the raw materials sector, have been recognised both on EU level and in many of its Member States (A Review of National Resource Strategies and Research, 2012; Vidal et al., 2013; Jarvis et al. 2012).

The main focus of the project is on generating a database on mineral policy and legislation both on EU and national levels, and further to elucidate good practices in policymaking in terms of how innovation in the mining industry is facilitated or inhibited by these policies. For this purpose, the key objectives of the project are to:

1. Provide guidance for EU and EU Member state minerals policy
2. Facilitate minerals policy decision-making through knowledge co-production for transferability of best practice minerals policy
3. Foster community and network building for the co-management of an innovation-catalysing minerals policy framework

The project is divided into 8 work packages, see Table 1.

WP1 is intended to provide background information and define a common approach for WP2-6, which provide the core content contribution to the project. These work packages focus on stocktaking of mineral policies and legislation both on EU and Member State level (WP2), value chain-specific investigation of innovations in industry and their connection to policymaking (WP3-WP5), review of the mineral data base and standardisation for systematic reporting (WP6). WP7 is devoted to stakeholder management including communication and dissemination actions and WP8 towards project management.

Table 1. MIN-GUIDE structure and work packages

Type	WP #	Description
Common Approach	WP1	Minerals policy guide development and conceptual basis
	WP2	Stock-taking of EU and EU MS mineral policy and legislation
Core Content	WP3	Innovative exploration and extraction
	WP4	Innovative mineral and metallurgical processing
	WP5	Innovative waste management and mine closure
	WP6	Raw materials knowledge and information base
Cross-cutting management and engagement	WP7	Stakeholder management, communication and dissemination
	WP8	Project management

1.3 Work package 4: Scope and objectives

As part of the MIN-GUIDE project, work packages 3-5 are devoted towards studying the linkages between innovation, policy and legislative frameworks within EU Member States. A value chain approach has been taken, where WP3 focuses on mineral exploration and extraction, WP4 minerals and metallurgical processing and WP5 waste management and mine closure. The main inputs from other work packages include the conceptual basis and the ‘Minerals Policy Guide’ developed in WP1 as well as the stocktaking of policies and legislation conducted within WP2.

The specific tasks within WP4 are directed towards studying how innovation is taking place within mining companies, metal producers and suppliers to the sector (engineering service providers, manufacturers etc.) in the context of mineral processing and metal production and to study which impact policy and legislation framework has on these processes. This requires firstly a detailed definition of the relevant value chain constituents and the related stakeholder network, followed by a discussion on the most relevant innovation types for these actors and within this part of the value chain. Based on this, a number of concrete innovations are used as cases in order to exemplify the links to various policies and qualitatively evaluating their roles as barriers and facilitators for innovation.

The aims of WP4 “Innovative Processing” are to elucidate (i) how innovations in mineral and metallurgical processing are generated or taken up in different EU Member States and on EU-level and (ii) how this is either facilitated or inhibited by policies and legislation on EU Member State or EU level. In the second phase of the project, the work within WP4 will continue by dissemination of identified good practices and efforts aimed at enhancing the transferability of such practices across the EU.

The objectives of WP4 can therefore be summarised as follows:

- Identifying existing innovation facilitating and inhibiting elements in policy and legislation for processing including permitting procedures.
- Exchanging of good practices for innovation in processing and facilitating their transferability.
- Exploring future policy developments in order to foster innovation in mineral and metallurgical processing.

The deliverables D4.1 and D4.2 are provided as two parts of a coherent report on both (i) the policy and legislation framework and (ii) innovation promotion and inhibiting factors and examples of good practices, where part 1 constitutes a topic overview based on literature surveys and preliminary case studies and analysis. For part 2 the work is extended by interviews and questionnaires, along with more in-depth analysis of policy, legislation and innovation cases.

1.4 Terminology and definitions

Within the MIN-GUIDE project the below-listed innovation types or categories are considered, based on the MIN-GUIDE Common Approach D1.1 (Bicket and Watson, 2016). These are further discussed and exemplified in section 2.2.2 of this report.

- **Product** innovation: introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses, e.g. a new processing equipment.
- **Process** innovation: implementation of a new or significantly improved production process or delivery method, e.g. integration of a novel mill type into a processing flowsheet.
- **Marketing** innovation: implementation of a new marketing method involving significant changes in product design or packaging, product placement, promotion or pricing, e.g. plastic bags for cement.
- **Organisational** innovation: implementation of new organisational methods in business or policy practices, workplace organisation or external relations, e.g. integration of geomettallurgical programs into production planning and control.
- **System** innovation: E.g. innovations which result in significant improvements in more than one step of the supply chain, or in another sector, e.g. utilisation of iron ore pellets in metallurgical processing.

1.5 Mineral and metallurgical processing systems

Within MIN-GUIDE a value chain oriented approach is pursued. Mineral and metallurgical processing describes that part of the chain that follows the mining extraction of mineral raw materials. With regard to the latter, a distinction can be made between (i) metallic ore processing that involves the concentration of the metal bearing minerals followed by metallurgical processing and (ii) industrial mineral and rock production where minerals themselves become a product after enrichment and beneficiation. Metallurgical processing of ores is in several cases combined with the processing of secondary raw materials, as for instance waste from electronic or electrical equipment (WEEE).

Mineral processing involves the liberation of valuable minerals by usually mechanical size reduction (crushing and grinding) followed by the separation into valuable minerals and gangue. Separation is making use of differences in physical or physico-chemical properties depending on the mineral system (e.g. in gravity separation, magnetic or electrical separation, flotation). Wet processing entails dewatering as a final process step. While enrichment of metal bearing minerals is of major relevance within metallic ore concentration, the processing of industrial minerals and rocks focusses on the removal of impurities and the adjustment of particle properties, as for instance particle size or shape, in order to meet the product specifications.

Metallurgical processing of primary raw materials is aiming at extracting and refining metals from mineral concentrates, i.e. the output streams from mineral beneficiation. Depending on the mineral system, metallurgical processing can be based on pyrometallurgical and/or hydrometallurgical routes. In pyrometallurgical processing thermal heat is applied in order to smelt and refine metals from minerals. Hydrometallurgical processing extracts metals by leaching metals using chemicals or the metabolism of microorganisms (bio-hydrometallurgy). Besides metal production from ores, the processing or co-processing of secondary raw materials is an essential part of today's smelter operations. Figure 1 depicts the possible processing routes for metal production within mineral and metallurgical processing.

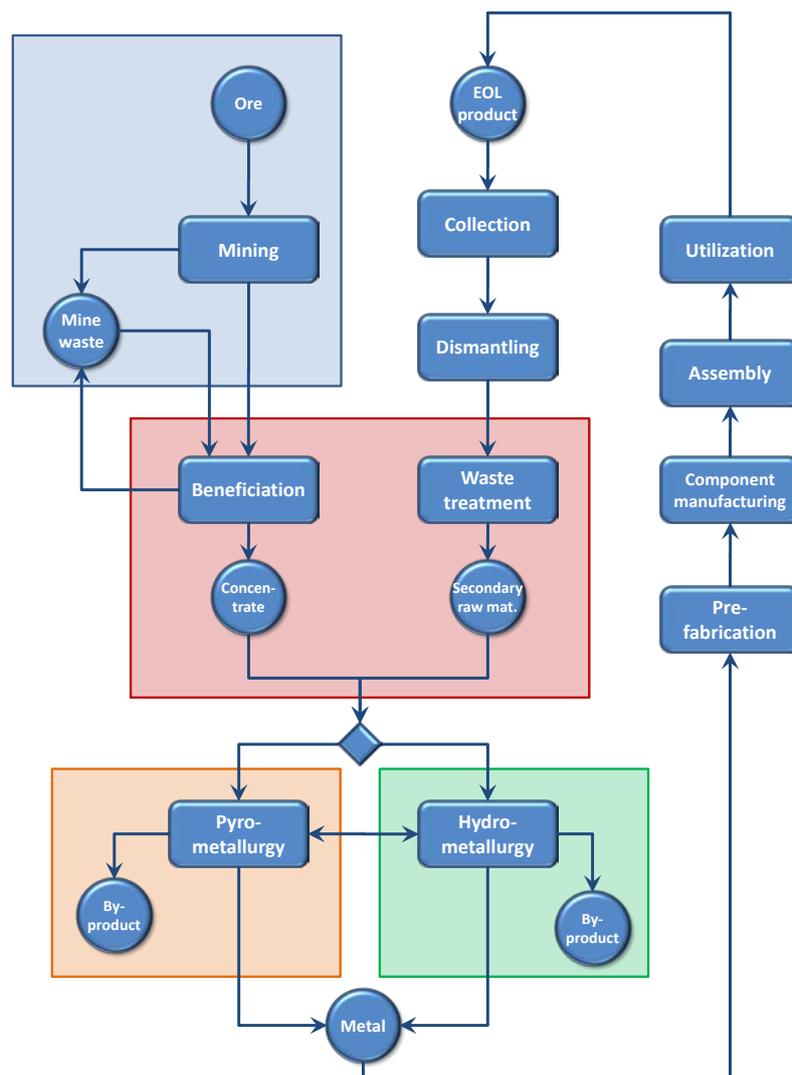


Figure 1. Mineral and metallurgical processing routes for metal production

Mineral and metallurgical production processes are, in both cases, characterized by large plant capacities and continuous or semi-continuous processing. Exceptions may exist in the case of industrial mineral production, e.g. pigments of high value and low market volume. The large scale of production processes entails large investments in plant capacity, which in turn involves long plant life cycles. Further, the large scale requires costly and time-consuming up-scaling procedures for proving new process technology and equipment during process design and development. Both aspects usually result in slow innovation processes and spreading of new technology.

Innovation is depending on a stable and future-oriented investment framework, whereas the mineral and metallurgical processing sector is characterized by many unknowns in future supply and demand, which results in uncertainty of prices. Supply is controlled by mineral exploration and reserves evaluation, while the demand is affected by the uses for minerals and metals, the level of population that consumes, and their standard of living. This is strongly linked e.g. to the technological development of modern societies in which minerals and metals are a vital for the provision of goods and services, continuing global population growth, as well as urbanisation and industrialisation particularly in emerging economies. The industries that use minerals and metals will affect return on investment from mineral and metallurgical production by their economic cycles, as well as government will do by legislation and policies, e.g. regulatory or tax policies. This all affects the mineral and metallurgical industries' investments made in research and innovation, and further the suppliers to the sector. Finally, the mineral and metallurgical processing industry, as the mining industry in general, is traditionally a conservative sector where adaption of new technology has been slow (Anderson et al., 2014; Ericsson, 2014).

Permanent optimization of production costs is another important driver for innovation. This refers to costs for energy and related greenhouse emissions (in particular related to comminution and smelt processes). In addition to that, environmental issues as emissions and processing rejects as well as the general (social) licence to operate are important drivers.

1.6 The stakeholder network in mineral and metallurgical processing

Before the task of identifying innovations and their relation to policy and legislation framework can be undertaken, a comprehensive definition of the considered stakeholder network is needed. Any actor within the stakeholder system is a potential contributor or source for innovation which can have direct or indirect impacts on other stakeholders. It is, therefore, of vital importance to specify this system before a more in-depth analysis can be undertaken (Hutcheson et al., 1995).

The core of the stakeholder system considered is the mining companies and metal producers. For the case of mining companies, the processes of exploration and mining are included separately in WP3 of the project and are therefore not of specific interest within the context of WP4. Waste management and mine closure (WP5) are indeed integral parts of mine and metallurgical plant operations, but will not be under consideration within this WP4 report.

Consequently, the focus of this study is confined to materials handling and beneficiation processes, which include mechanical processing and mineral processing. Metallurgical processing involves material handling as well as pyro and hydrometallurgical processing. Further downstream processing, e.g. casting and metal forming are considered as customer industries. Both mining companies and metal producers have a number of suppliers, of which suppliers of auxiliaries (e.g. process chemicals, fuels, explosives, fluxes), process equipment, as well as service providers and consultants (either

technical or non-technical) can be mentioned. On the customer side both manufacturing (assembled products) and process industries (non-assembled products) are relevant customers. Depending on the product, mining and metallurgical companies may also sell directly to distributors or retailers. In the case of aggregates and industrial minerals, mining companies sell products directly to customers without the need for metallurgical processing as an intermediate. Metallurgical processing plants are also important actors in the recycling of secondary raw materials of both industrial and other origin. Research institutions are involved in all parts of the stakeholder network.

Policy makers are a special case as they both may and may not be considered as part of the stakeholder network, which make their role in the system more complex and non-straightforward (Laranja et al., 2008; Flanagan and Uyarra, 2016). They however constitute important actors in the system, as they are both influenced by and influencing various other actors within the stakeholder network. Policy makers in this context form a rather heterogeneous group of stakeholders comprising public administrators and decision makers at various levels (e.g. ministerial and regional public authorities), together with stakeholders that influence public policy, as lobbyists, NGOs, geographical surveys etc. An illustration summarising the system is presented in Figure 2. Arrows indicate flow of goods and/or technological or other know-how.

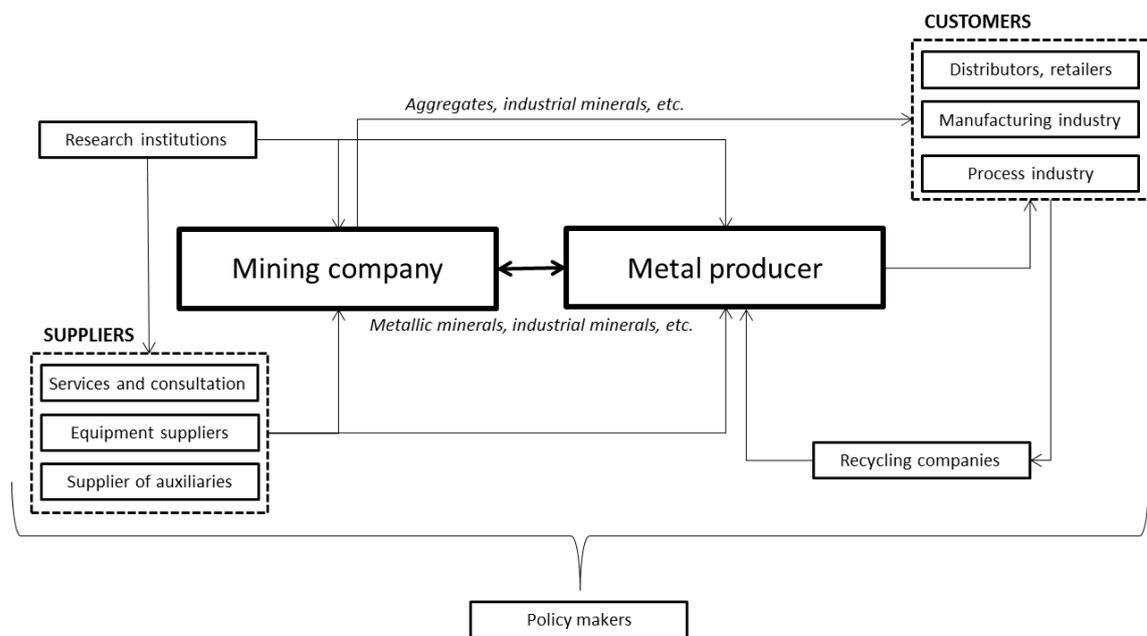


Figure 2. Stakeholder network in mineral and metallurgical processing.

2 Approach

2.1 Methods applied

A couple of prior related research projects has been used as input for deliverable D4.1, from which aggregated analysis of empirical materials helped to better understand the various facets of innovation in mineral and metallurgical processing. This refers particularly to data collected within the frames of the projects (see below), in which members from Luleå University of Technology have participated. Most data (e.g. interviews) were collected in Sweden, but the empirical materials also extend to other countries in the European Union, such as Denmark, Finland, France, Germany and

The Netherlands. These research projects also resulted in multiple research articles in technology- and innovation management journals that were used for deliverable D4.1. In addition, other related scientific literature was evaluated together with the MIN-GUIDE deliverable D1.1 (Bicket and Watson, 2016), which provides the innovation framework for D4.1. A brief description of these earlier research projects underpinning D4.1 is presented below:

- *Measuring innovation and innovative capabilities (“MiiF”)*, a 3-year project financed by the Swedish Governmental Agency for Innovation Systems (Vinnova). The project studied challenges in measuring innovation, innovation auditing, what and how to measure innovation, as well as the process of implementing measurement. Five interviews conducted at LKAB, a leading producer of upgraded iron ore products, were particularly helpful to better understand dominant types of innovation in mineral and metallurgical processing and their measurement and impact.
- *Managing the fuzzy front end during product- and process development in process industry*, a 4-year project financed by the Swedish Governmental Agency for Innovation Systems (Vinnova). The project studied idea- and concept creation for new products and processes in mineral- and metallurgical processing. In total, 68 interviews were conducted at LKAB, Höganäs (world-leader in powder metallurgy), Boliden (global firm in mining and metallurgical processing), and SSAB (a world-leading company in the niche of high-strength steels). These interviews produced insights into key activities of innovation processes in these firms, the influence of external factors on innovation (including policy decisions), and barriers to innovation and creativity.
- *Models and best practices for effective management of innovation and collaboration between firms in process industry and equipment manufacturers (“Maelis”)*, a 3-year project financed by the Swedish Governmental Agency for Innovation Systems (Vinnova). In total 39 interviews were conducted at Höganäs and LKAB and eight of their suppliers of process equipment/technology that focused on drivers/motives/challenges in external collaboration and open innovation. In addition, the project supplied data from a survey of 51 international collaborative R&D projects conducted by four firms in mineral- and metallurgical processing and 29 of their suppliers worldwide (with 251 responses to three different surveys in total). This project benefitted deliverable 4.1 with insights into open innovation processes, which types of innovation that firms in the mineral- and metallurgical processing domain pursue, as well as insights into the roles of various actors in the innovation system (in particular process firms, suppliers of equipment, and division of labour between them).
- *Improving the process development process at LKAB*, a 2-year project financed by the Swedish Foundation for Strategic Research (SSF). About 30 interviews and 20 workshops with managers, engineers and R&D specialists on challenges, design & implementation of innovation processes for process development/innovation in mineral and metallurgical processing. In particular, the project contributed with insights into how innovation processes are designed and implemented at LKAB and at other firms active in mineral- and metallurgical processing.
- *Mapping the Nordic mining and metal industry (NMC)*, a 6-month pre-study financed by the Nordic Ministry Council/Nordic Innovation. Some 20 interviews with R&D professionals & policy makers about innovation challenges in the mining- & metals sector (with a focus on

mining). This study provided insights into innovation challenges in the Nordic mining industry, including policy challenges. Interviews were performed with respondents from Denmark, Finland, Sweden and Norway.

- *Business model renewal and raw materials management in the process industry*, a 3-year project financed by the KK-foundation. About 25 interviews at Höganäs and Raw Materials Group (a leading consultancy company in the area of mineral- and metallurgical processing and policy analysis). This project provided input on innovation types, especially process development, and strategic challenges and opportunities in mineral- and metallurgical processing.
- Then in next step (2nd part of this report): Series of interviews with R&D and innovation managers (Expert crowd) to identify relevant innovation process models and organizational structures that are applied on firm level within different segments of the mining and mineral industry (producers, equipment suppliers, service providers, researchers, policy makers).

2.2 Innovation processes in mineral and metallurgical processing

Companies in mineral and metallurgical processing may focus on being efficient commodity producers, or producers of so-called functional products, or both. Regardless of their focus, however, an efficient production process is paramount to keep production costs low. Low production costs may be the key predictor of profit margins, and makes such firms less price sensitive (Lager and Frishammar, 2010). Innovative efforts of firms in mineral and metallurgical processing are therefore primarily directed to lowering direct costs of production, or increasing volume outputs (which lowers indirect or so-called “fixed” costs of production) by allowing these to spread over a larger production volume.

This fact makes process innovation the most important type (complemented by product innovation and organizational innovation). According to the MIN-Guide D1.1 (Bicket and Watson, 2016), process innovation is the implementation of a new or significantly improved production or delivery method, e.g. techniques, equipment, software. Major and radical leaps in process innovation may be taken when new production plants are built. However, at least as important are the subsequent investments and continuous innovation conducted *after* a plant is built, which may continue over many decades. That is, innovation is often incremental and conducted through a learning-by-doing logic where processes are improved over time (D1.1). Aylen (2012) refers to such process innovation as “stretch” as it stretches the production capacity of a plant through development and installation of new software and hardware, and ways of operating the plant, which in some cases can triple the initial production volumes from a given plant.

Innovation in mineral and metallurgical processing is a complex task with multiple actors involved, Figure 3 (Lager, 2002). New process innovations in hardware are seldom manufactured by process firms themselves. Rather, equipment manufacturers tend to do a lion’s share of development of equipment and then supply it. There is a capability-based explanation for this: Equipment manufacturers have core competencies in developing new process technologies, while the core competencies of firms in mineral and metallurgical processing tends to be in producing those materials. Process innovation then determines the preconditions for product innovation (i.e. which new products that can be developed and produced is contingent on which process technologies and

factories are available). There may also be innovation at the interface between firm-internal product development and the customers to a firm in mineral and metallurgical processing, e.g. in the form of new services or when the producing firm helps their customers to make more efficient use of input materials for producing e.g. steel (among industrial firms, this is often referred to as application development as it refers to developing the application of the customer, e.g. a steel plant, but is in fact a type of product or service innovation).

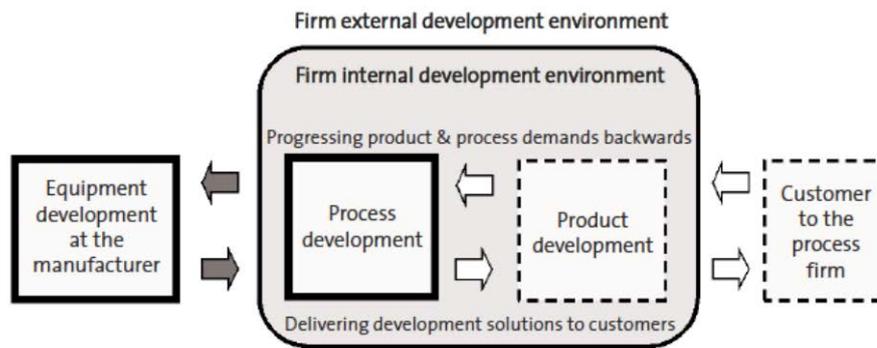


Figure 3. Stakeholder involvement and complexity of innovation in mineral and metallurgical processing (adopted from Lager, 2002).

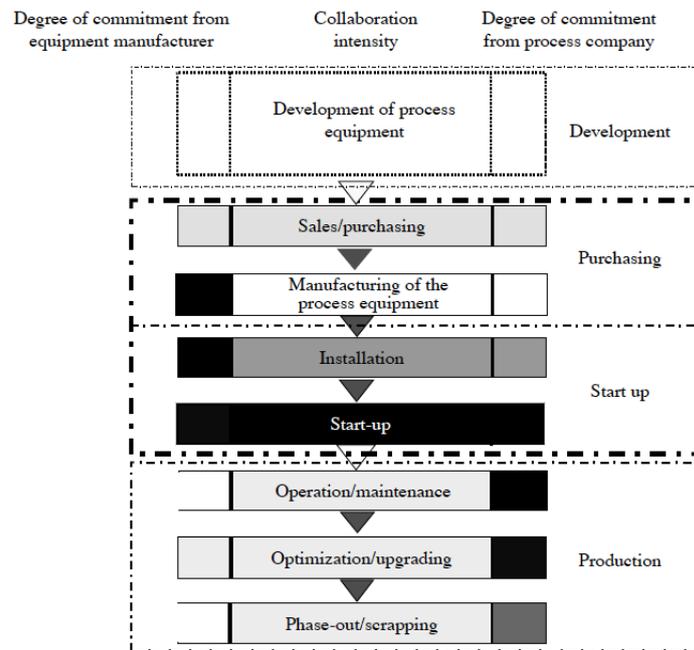
In pursuing innovation, various types of pilot- and demonstration plants are the key to progress new technology along the technology readiness level (TRL) scale (Hellsmark et al., 2016; Klar et al., 2016). Firms in mineral and metallurgical processing are risk averse, for good reasons. There are multiple examples of premature innovations being installed into factories, with production disturbances, loss of volumes, and customer dissatisfaction as results. Therefore, pilot- and demonstration experiments at different scales (bench-scale, small-scale, pilot plant, demonstration plant, and tests in full-scale production) are critical to thoroughly test new product and process concepts, and make sure these concepts are “flight proven” (i.e., TRL9) before installed. These tests are necessary because when moving between these different scales, some product or process properties may be added, and others lost (Kurkkio et al., 2011). For example, process parameters such as humidity or heat may play out completely different at the bench scale vs. in a demonstration plant, which may cause uncertainty and greatly affect product properties). Pilot- and demonstration plants may therefore be seen as a substitute for a design office in manufacturing of conventional goods, and the process of developing new products or processes in these is iterative and characterized by a learning-by-doing logic (Frishammar et al., 2015). The next section describes the current innovation process models and extent of collaboration in mineral and metallurgical processing, both across firms and within firms.

2.2.1 Identification of relevant innovation process models and extent of collaboration (organisational structures)

Innovation in the mineral and metallurgical sector is surprisingly open, meaning that information, knowledge, technology and intellectual property may be transferred in and out of the innovation process in a mineral and metallurgical company as the innovation process unfolds (c.f. Chesbrough, 2003). The main reason for this “open” approach to innovation is the strong collaboration required to innovate new processes and products, in particular between manufacturing firms and suppliers of

process technologies (Rönnerberg Sjödin et al., 2011). In addition to these actors, others such as plant contractors, consultants and research institutions may also participate (Hutcheson et al., 1995). Thus, multiple competences need to be pooled to create the desired innovation.

Because process innovation (and in extension also product innovation and organizational innovation) requires innovating the process technologies (hardware and software) of a mineral and metallurgical firm, the full life cycle of process equipment may be useful to picture the extent of “openness” and collaboration throughout the various phases, from ideas created in the so-called fuzzy front end, until the new technology is operational. Figure 4 from Lager and Frishammar (2010) provides a visual representation of this process. As can be seen, collaboration may be most intense on both parties in the start-up and installation phases, whereas development of the equipment may be pursued without much collaboration with a mineral and metallurgical firm. By contrast, the mineral and metallurgical firm may be extremely committed in the production phase (in which the commitment from the equipment manufacturer is lower).



Notes: During each stage of the equipment's life cycle, the degree of commitment from the equipment manufacturer, the degree of commitment from the process company and the collaboration intensity (the area in between), have been illustrated with different shades; a white area symbolizes a very weak commitment or collaboration intensity, while a black area symbolizes a very strong commitment or collaboration intensity

Figure 4. Openness and degree of collaboration during various phases of process technology innovation (Lager, Frishammar 2010).

While this model may display the overall logic and “flow” of innovation in the mineral and metallurgical sector, it is not capable of picturing how actual innovation projects are being executed. Like in most other settings, most firms in the mineral and metallurgical sector use some sort of stage-gate methodology to execute process innovation or product innovation in practice (Figure 5).

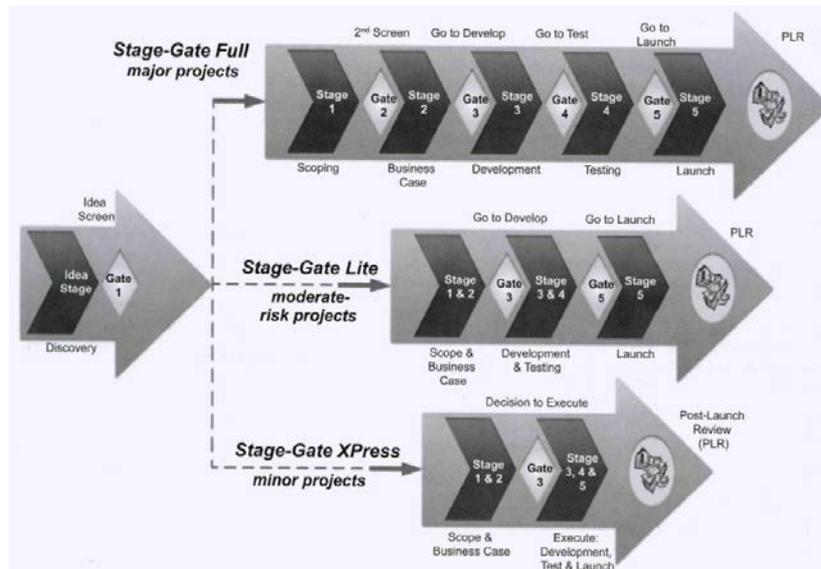


Figure 5. Stage-gate process for process and product innovation (adopted from Cooper, 2014).

The stage-gate process is a means to create order in the sometimes “chaotic” process of innovation. It consists of a series of stages where actual engineering work is done (i.e. idea study, pre-study, and so forth). Here is where the work is done. Between these phases are evaluation points where projects are reviewed to make sure they meet stipulated criteria (so-called gates). A given firm may run multiple versions of this stage-gate process along the ideas in the figure above, where larger projects follow a full version of the stage-gate, and smaller projects a more condensed one (in order not to overburden such projects with excess administration).

In the mineral and metallurgical sector, most companies follow a “traditional” stage-gate model, as to our knowledge. The reason is that they operate on mature markets, customers and technology are rather well known, the rate of product renewal is slow, and customer’s needs are well known and rather stable over time. Moreover, the market is well known, competition is “Red Ocean” rather than “Blue Ocean”, and technology maturity is high. There may be significant risks in development, but these are seldom addressed by means of more current updates, such as agile principles. That is, the stage-gate system in most companies in the mineral and metallurgical sector is well defined and traditional, stages are laid out in a linear fashion, activities are pre-specified for each stage of the process, and standard deliveries are defined with templates for each gate. Finally, go/kill criteria are clear and consistent (Cooper, 2014). However, that is not to say that all work is done internally within a single firm. In fact, the principles of open innovation, i.e. active transfer of technology and IP across organizational- and project boundaries, may characterize many types of stage-gate process in the process industries (Grönlund et al., 2010).

2.2.2 Dominant modes (types) of innovation and examples

According to the MIN-GUIDE common approach (D1.1), the MIN-GUIDE innovation categories are product innovation, process innovation, marketing innovation, organizational innovation and system innovation. Most of these apply to the mineral and metallurgical sector, but with different gravity.

Process innovation, i.e. the implementation of a new or significantly improved production or delivery method, is the prime innovation type. It is critical to competitive advantage as it can lower costs, increase production volumes, or both. It can also lead to sustainability outcomes. Process innovation is also *systemic* (Gopalakrishnan, Damanpour, 1994). This means it may affect many things in a company beyond the manufacturing or production processes, like HRM policies or reward systems. The view on process innovation also depends on which actors are asked. For example, a company producing metals typically views new process equipment as process innovation, whereas the manufacturer of that same equipment may view it as product innovation). Figure 6 below is one example of process innovation outcomes and the key antecedents that allow firms to innovate their processes to achieve those outcomes.

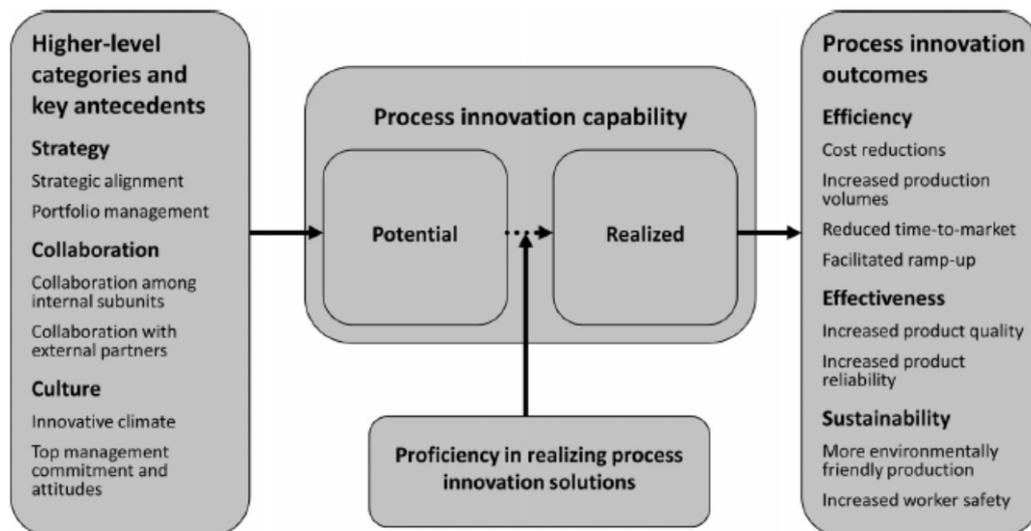


Figure 6. Categories and key antecedents and their links to process innovation outcomes (Frishammar et al., 2012).

Product innovation, i.e. the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses, may be important but is typically attached less significance than process innovation. The reason is that products in the mineral and metallurgical sector to a large extent are standardized, i.e. for many companies there is not that much opportunity to differentiate products. However, equipment suppliers currently try to differentiate their products by moving away from transaction-based sales of hardware to more relation-based business models where these companies provide results or functions instead of products (Reim et al., 2015). This trend is typically referred to as “servitization of manufacturing” (Baines et al., 2009).

Marketing innovation, i.e. the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing. In the mineral and metallurgical industries the predominant innovations in this respect is expected to be related to product design and pricing, and in some cases packaging.

Organizational innovation, i.e. the implementation of new organizational methods in business or policy practise, workplace organization or external relations. One example of this is the increasingly “open” type of collaboration between producing firms in mineral and metallurgical processing and their equipment manufacturers.

System innovation, i.e. innovations which result in significant improvements in more than one step of the supply chain, is typical for *process innovation*. Because a production process is organized into so-called “unit operations”, changes in one such unit operation may often affect others. This is also an example of the systemic nature of process innovation.

3 Catalysing and inhibiting elements in innovative mineral and metallurgical processing

Key reasons for why innovation does not happen (or fails to materialise) are inhibiting factors or so-called barriers to innovation. These factors are “the flipside of success” (Hueske and Guenther, 2015). For example, absence of capital to make necessary investments can be a barrier to innovation, while access to sufficient capital for investments can be a catalysing element. The discussion below mainly reflects on the inhibiting factors (hereafter referred to as barriers).

Barriers to innovation are factors which impede, delay or block innovation. Some of these factors are soft (such as culture or team climate) whereas others are harder (i.e. access to capital or state interventions to regulate markets). In pursuing the discussion about innovation barriers, we depart from the MIN-GUIDE definition of innovation, and in particular from the types of innovation that is most prevalent in the mineral and metallurgical sector, namely process innovation and product innovation.

The discussion is organised around the framework proposed by Hueske and Guenther (2015) and Hueske et al. (2015) that organised barriers to innovation into four different levels: 1) External environment, 2) Organisation, 3) Group, and 4) Individual. This way of viewing barriers to innovation fits the mineral and metallurgical industry and the MIN-GUIDE project overall, because it can stimulate a discussion and empirical data collection about barriers in this context. Barriers in the external environment are clearly external to a given focal firm or organisation, i.e. outside its boundaries, and may relate to supply, demand, environmental issues, policy, legislation, etc. The remaining three categories are firm-internal, i.e. they materialise inside a given organisation. Figure 7 below gives a visual representation of these barriers.

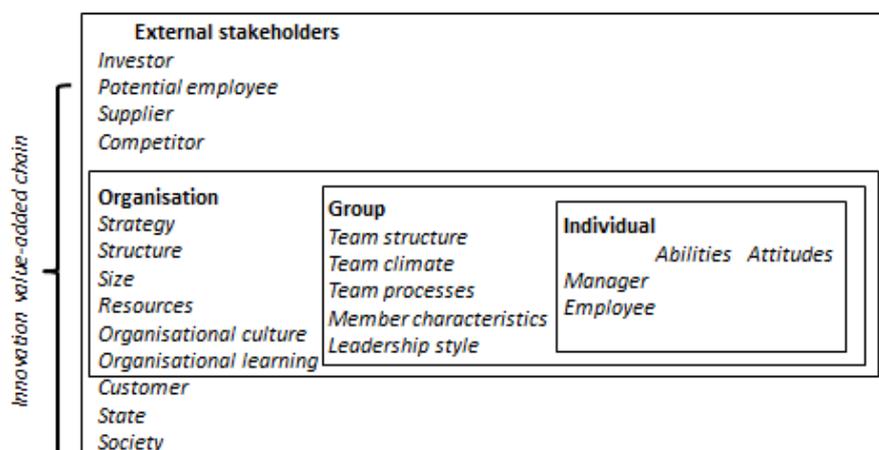


Figure 7. Various levels and categories of barriers to innovation (adapted from Hueske and Guenther, 2015 and Hueske et al., 2015).

3.1 Barriers to innovation

3.1.1 External barriers to innovation

There are multiple stakeholders outside an organization that may influence its ability to innovate. These include actors in the value chain of a company in the mineral and metallurgical sector, such as suppliers or customers. These barriers may also centre on other actors in the broader ecosystem, such as suppliers of process equipment and technology (Lager and Frishammar, 2010) who are critical to create innovation. Beyond the intermediate value chain, actors such as investors, state and society at large are critical. For example, the state may impose public policy instruments that both inhibit and catalyse innovation through e.g. regulatory frameworks (Muench et al., 2014). In the systematic literature review provided by Hueske and Guenther (2015), there were eight sub-categories of external barriers to innovation:

- Investors. One example of this barrier is funding difficulties, which relate to the stakeholder “investor”. This may be particularly challenging in cyclical industries with high needs for up-front investment and which are very capital intensive (which is true for the mineral and metallurgical processing sector).
- Potential employees. This barrier focuses on the difficulties in recruiting and attracting future talent. This may clearly be a barrier in mineral and metallurgical processing. For example, the sector is traditionally male dominated and has a problem in attracting a sufficient number of females. In addition, young people may view this sector as old-fashioned and too traditional, which makes it less attractive in comparison with alternative career paths.
- Suppliers. Supplies of primary and secondary raw materials may also be a barrier, such as when these actors fail to make sufficient investments into their own R&D to improve materials properties, or when they fail or else cannot supply the materials needed for downstream products.
- Competitors. Competitors often raise barriers to innovation in the value-chain through market power (i.e. their product solutions). Another example may be intellectual property rights held by competitors, which makes it difficult for a focal firm to innovate. Competitors may however also copy or imitate innovation from focal firms through knowledge leakage, as formal IP seldom constitute sufficient protection for firms in mineral and metallurgical processing (Frishammar et al, 2015).
- Customers. Customers may indeed be a driver of innovation. One example is the world automotive industry and their need to continuously push weight of vehicles down, which have triggered major investments into R&D of steel companies (both conventional steel manufacturers and those active in powder metallurgy). However, customers are also causing innovation barriers. The process technologies used by customer firms, such as automotive manufacturers, tends to be highly specific which forces steel manufacturers to always consider this “process window” of the customer when innovating.
- Partners. Partners (or lack thereof) may be a barrier to innovation as multiple partners are typically needed to implement the products and processes of firms in mineral and metallurgical processing (Rönnerberg-Sjödin et al., 2016). Suppliers of technologies may be a

particularly important barrier to innovation, for capability-based reasons. Suppliers are often experts in developing the new technologies needed new product- and process innovation, so their participation needs be ensured (Lager and Frishammar, 2010).

- **State.** Innovation barriers may be caused by regulatory constraints imposed by the state as well as unclear and unstable public policy. For example, taxation policies may drive away investments in innovation, as may governmental regulations and standards. However, public policy may also act to spawn innovation, for example when national states invest in large-scale R&D-programmes in the area of sustainable technologies as a response to so-called system failures (Bergek et al., 2008), i.e. when private actors are unwilling or incapable of incurring the costs for basic R&D that is needed by society at large.
- **Society.** Society may act as a barrier to innovation as the public may have particular opinions about the suitability or usefulness of certain technologies, or innovations. For example, there may be a lack of “societal readiness” (Lam & Mackenzie, 2005) or the “social licence to operate” a plant may not be there, although the legal permits are.

3.1.2 Organizational barriers to innovation

Organizational barriers to innovation may be equally important to understand, and often focus on a lack of (or deficiencies in) capabilities at the organizational level. Barriers at the organizational level also refer to issues such as resources, learning, culture, and structure. For example, structural barriers may institutionalize some work related practices in organizations that act as barriers to innovation. This may be particularly common in old and traditional industries, such as in mineral and metallurgical processing (see Kurkkio et al., 2014). This group of barriers thus highlights the need for innovative efforts in process and product development to be supported by strategy, structure, culture and appropriate learning processes. Similarly, these elements may need to change as innovative efforts unfold. For example, if steel manufacturers in the future are to succeed with current (early) ambitions to produce steel without CO₂ emissions, their strategies clearly need to change. According to Hueske and Guenther (2015), there are six sub-categories of organizational barriers to innovation:

- **Strategy.** These barriers refer to cases where firms are too short-term oriented or even lack a strategy for innovation, which is true for many companies in the mineral and metallurgical processing sector. Another example is unclear priorities and roles in innovation.
- **Structure.** This barrier relates to inconsistencies with existing processes and rules, bureaucracy or performance measurement (such as when companies lack processes for conducting innovation, or fail to measure innovation outcomes).
- **Size.** Size can be a barrier to innovation in two different ways. Firstly, a company that is too small (i.e. SMEs) may suffer from a lack of resources and capabilities, which acts as barriers to innovation, i.e. their scale is too small. However, very large companies may also fail to innovate as they become overly formalized and rigid.

- **Resources.** This barrier centres on financial resources, but also problems or shortages of time and staff and deficiencies in resource allocation (e.g. absence of effective principles for portfolio management).
- **Organizational culture.** A very common barrier to innovation is that the culture of a firm prohibits innovation, i.e. the norms and routines that encourage innovation, risk-taking, experimentation and creation of new ideas for new products and processes are not present to the degree necessary.
- **Organizational learning.** Organizational learning as a barrier refers to a lack of training and learning difficulties. In prior innovation management research, this barrier manifested in the difficulties of incumbent firms in a variety of different settings to change as radical technology and substitute products alter competition.

3.1.3 Group barriers to innovation

Barriers to innovation may also exist on the group level. Groups are embedded in the larger organisational context (Anderson et al., 2004), for example the cross-functional groups or teams that are typically used when firms try to create new processes or products. According to Hueske and Guenther (2015), there are five sub-categories of group barriers to innovation:

- **Team structure.** Team structure can act as a barrier to innovation if the team or group devoted to innovation is too small or too large or if the people engaged in innovation have too divergent or different goals (for examples, see e.g. Eriksson et al., 2016). Personnel shortage may thus materialize also on the group level.
- **Team climate.** Team climate is also an important barrier to innovation, and may prohibit innovation when it is settled on protecting the interests of the own group and reinforce work unit thinking. In particular, there are the problems of the negative value toward using external knowledge, that is, the not-invented-here (NIH) syndrome (Katz and Allen, 1982). The second is a similar negative bias against external exploitation of internal knowledge assets, that is, the not-sold-here (NSH) syndrome (Chesbrough, 2003).
- **Team processes.** Team processes can hamper innovation through a lack of team building through e.g. joint problem solving (see Rönnberg Sjödin et al., 2016), or when objectives become too diverse, or through a lack of communication.
- **Members' characteristics.** This is also an important barrier to innovation that may act to impede group work, such as when perceptions of goals of members become too diverse, or when knowledge and skills of members are not appropriate.
- **Leadership style.** Finally, managers must show leadership and commitment towards innovation for innovation efforts to succeed. This can be difficult in many firms in mineral and metallurgical processing sector whose core competences are in production of standardised goods rather than innovation.

3.1.4 Individual barriers to innovation

Finally, some barriers to innovation reside on the individual level as innovation is largely contingent on abilities and attitudes of employees. According to Hueske and Guenther (2015), there are four sub-categories of organisational barriers to innovation:

- Managers' abilities. These refer to manager expertise, management and leadership style. This is clearly a critical barrier to innovation in many companies.
- Managers' attitudes. These barriers centre on managers attitudes, especially lack of commitment to innovation. For example, prior research show that managers need to provide active support and be committed for innovation results to materialize (Kim and Wilemon, 2002).
- Employees' abilities. Also for employees, knowledge, experience and skills may be insufficient for innovation to happen. This barrier may be particularly important in responding to technical changes, where employees may not have the right skillset or "absorptive capacity" to answer.
- Employees' attitudes. This barrier is centred on resistance to change and unawareness and/or lack of understanding about the usefulness of an innovation.

3.2 Reflections on the mineral and metallurgical processing sector

The large number of barriers identified, along with examples out of the mineral and metallurgical processing context, stresses the need for context specific analysis through further empirical investigation. Ideally, each stakeholder type could be asked or surveyed for her/his opinions of barriers. Different types of stakeholders need to be involved (such as focal producing firms, equipment manufacturers, customers, and policy makers). This can be an important exercise to include at the policy workshop on innovative processing at Luleå University of Technology (i.e. on identifying barriers, and thoughts about how to overcome them). Another aspect to think about is that barriers at different levels may influence one another. For example, individual-level barriers may cause group-level problems.

4 Innovation in mineral and metallurgical processing and links to policy and legislation

4.1 Identification of relevant innovation cases

In the following, a selection of recent innovation cases within minerals and metallurgical processing are listed. These cases are partly obtained from desktop research and literature surveys, but also partly from interviews with industry professionals. The innovation cases are categorised and briefly described in Table 5 (mineral processing-related innovations) and Table 6 (metallurgical processing-related innovations). The selection illustrates the bandwidth of innovations, involving equipment, methodical approaches and concepts, process modifications, process control technology.

There are a number of publications which can be examined for further information on some of the specific invention and innovation examples listed in the tables. For instance Napier-Munn (1997),

discusses multigravity techniques such as the Kelsey centrifugal jig, Knelson, Falcon and Mozley concentrators as recent examples of innovations in unit operations. Jebrak and Vaillancourt (2012) lists 100 innovations within various parts of the value chain of the mining industry.

Table 2. Examples of innovations in mineral processing

Field	Innovation	Description
Comminution	HPGR	High pressure grinding rolls (HPGR) are known to be more energy-efficient due to particle bed breakage. Further, it involves dry processing in size ranges between crushing and grinding.
	IsaMill	The IsaMill is a large-scale implementation of stirred media mills used for efficient, very fine grinding, which are otherwise applied in small capacity industrial mineral production.
	Mine to mill optimisation	Energy and capacity optimisation is done for the entire fragmentation chain from blasting via crushing to grinding.
	Comminution modelling	Modelling of comminution processes using computational physics as, e.g. discrete element method (DEM) in combination with other numerical methods for describing fluid flow, is used to optimise charge motion with respect to efficiency, energy and wear.
	Electro fragmentation	Pulsed high voltage fragmentation of mineral particles produces highly liberated daughter fragments in an energy efficient way. The technology has been established at lab and smaller production scale. Equipment for higher capacities is under development.
Separation	Flotation reagent	Continued development and innovation of selective flotation reagents for different mineral systems, involving design of molecules, substitution of hazardous or toxic reagents, biologically sourced reagents etc.
	Jameson flotation cell	The Jameson cell has been developed to improve fine particle flotation by intensifying the process (i.e. high turbulence and small bubble sizes) in order to increase particle bubble collision rate.
	Sulphidization of oxide ores	Recovery and selectivity in oxide mineral flotation are improved by sulphidising the

for flotation	surface of the oxide minerals using a sulphidization agent before applying sulphide collectors.
Automatic pressure filtration	Automated pressure filters achieve lower concentrate moistures of typically <10% compared to vacuum filters and can be operated unattended.
Underground pre-concentration	Concepts for reducing the material amount taken to the surface. This involves crushing and grinding as well as different separation processes, e.g. sensor-based sorting (SBS) operated underground.
Sensor-based sorting	Adaption of sorting machines developed for secondary material sorting to mineral processing applications: pre-concentration, final product upgrade, separation of feed into high/low grade.
RE magnetic separators	Dry magnetic separators with permanent magnets from alloys involving rare-earth elements provide a high magnetic flux applicable to separation of paramagnetic minerals
Modular processing plants	Cost efficient design concepts for modular (and often mobile) plants for mining small-scale deposits or satellite deposits.
Multigravity separation techniques	Techniques for enhanced gravity separation by centrifugal treatment of materials (particle sedimentation in the centrifugal field with several "g").

Table 3. Examples of innovations in metallurgical processing

Field	Innovation	Description
Pyrometallurgy	Pelletization of iron ore fines	Iron ore pellets are produced in a balling drum or on a pelletizing disk instead of using sintered material. The iron ore pellets also contain other compounds/minerals than iron oxides, which provide certain functionality, e.g. slag builders/fluxes etc.
	Natural gas based direct reduction	Instead of metallurgical coke, synthesis gas (H ₂ and CO, e.g. from reforming of natural gas) is

		used a reducing agents.
	Flash furnace for copper smelting	Flash smelting with oxygen-enriched air uses energy contained in the ore concentrate in order to provide energy to the furnace.
Hydrometallurgy	Biohydrometallurgy	Substitution of chemical extraction processes by using microorganisms: utilization of microbial metabolism as source of acids that dissolve metals (bioleaching), enhanced metal recovery by microbial decomposition of minerals (bio-oxidation)
	High pressure acid leaching (HPAL)	Process intensification of chemical leaching is done by increasing pressure and temperature compared to conventional acid leaching.
	Alternatives to cyanide in leaching	In order to replace the toxic cyanide in gold leaching several alternative leaching solutions are available, with tiosulphate salt solutions being the most promising one.

Table 4. Examples of innovation in process analysis and control and environmental management

Field	Innovation	Description
Analysis and control	XRF online analysers	Flotation processes are dynamically controlled by means of XRF analysers for float and sink products.
	Automated mineralogy	Mineralogical analyses are efficiently conducted by combining advanced SEM-based analytical methods with modern image analysis in automated multi-sample scans.
	Geometallurgical modelling approach	Geological information is combined with process mineralogical properties in one spatial deposit model and then used as the input to the process model that describes the mineral processing flowsheet.
	Portable process control technology	Portable XRF analyser for rock surface reduces sampling effort and test work in mineral exploration.
	Sonar flow meters	Contactless sonar-based measurement of multiphase material flow (solids/liquids).

	Scanning image analysis	Contactless measurement of material flow and material properties (particle size and shape, colour) based on scanning and image processing.
Environmental issues	Desulphurisation	Tailings desulphurisation by flotation and/or physical separation methods that reduce the acid mine drainage (AMD) risk from processing rejects.
	Process water treatment by Fenton's reagent	Hydrogen peroxide solution is used for catalytic oxidation of flotation circuit effluents (by destroying organic compounds).
	Dry stacking	Flotation tailings are dewatered in order to facilitate depositing of processing rejects and reduce land use and environmental impact.

4.2 Identification of relevant policies and legislation

The EU has adopted a Raw Materials Initiative (Raw Materials Initiative, 2008) pointing out the critical importance of raw materials for its economy. Internal market access to raw materials, security of supply from abroad and resource management aspects are key issues discussed within this document. More importantly, however, the initiative constitutes an important recognition of the importance of the European raw material producers, including mining and metallurgical industries, for the European economy. This has later been followed by additional policies and policy-related documents, such as the Strategic Implementation Plan on Raw Materials and the National Minerals Policy Indicators (EIP SIP Raw Materials, Part I, 2013; National Minerals Policy Indicators – Framework conditions for the sustainable supply of raw materials in the EU, 2014). Several Member States, including Finland, Sweden, Austria, The Netherlands, Germany, and France, have also adopted their own mineral or raw material strategies (A Review of National Resource Strategies and Research, 2012; Der Österreichische Rohstoffplan, Weber et al., 2012; Sweden's Mineral Strategy, 2013). The purpose of these policies is to frame national perspectives, challenges, and endeavours with regard to mineral and metal supply and raw material management issues. The overarching policies as listed above are setting the scene for both EU and national-level ambitions towards improving framework conditions and addressing challenges and obstacles for increasing European production of raw materials.

On the other side, there are both EU directives and national legislation which in various ways impact the permitting, operation and end-of-life planning for mining projects, mineral processing plants and metallurgical installations. With regard to processing alternatives, e.g. selection of unit operations, processing flow sheets, production of by-products and rejects handling, the main impact of policies and legislation can be derived from broader societal challenges, for instance related to resource efficiency, permitting aspects, emissions, handling of hazardous materials and wastes, as well as health, safety and risk management aspects. Policies and legislation within these categories typically, but not always, impose various restrictions on the industrial operations.

Other factors strongly influencing particularly the mining industry include national levels of taxation, land use legislation and compensation to landowners, both national and EU funding schemes for research projects, RDI programmes, and coordination and support actions, government-controlled public acceptance promotion campaigns, etc.

Further complexity arises where policies on a broader level, or mainly targeting other fields, have a direct or indirect influence on the minerals and metals industry. This includes EU-wide, national or regional policies which influence the ability of the industry to conduct their operations in terms of producing, refining or marketing its products. Examples that could be mentioned in this context include the Waste Framework Directive (2008/98/EC), Restriction of Hazardous Substances Directive RoHS (2002/95/EC), Waste Electrical and Electronic Equipment Directive (2002/96/EC), Integrated Pollution and Prevention Control Directive (2008/1/EC), Water Framework Directive (2000/60/EC) and sustainability policies at various levels (King et al. 2016).

The tables below (Table 5-7) categorise examples of policies and legislation on EU-wide and national levels by different industry and society challenges posed to mineral and metallurgical processing, which are expected to affect innovation in the sector.

Table 5. Examples of policies/legislation related to permitting procedures and social aspects

Challenges	Examples of policies/legislation
Permitting procedures and licensing	<p>Environmental Impact Assessment Directives 2011/92/EU and 2014/52/EU</p> <p>Directive on the conservation of wild birds 2009/147/EC (EU)</p> <p>Act on Environmental Impact Assessment Procedure 468/1994 (Finland)</p> <p>Mineral Raw Materials Act BGBl. I 80/2015 (Austria)</p> <p>Environmental code 1998:808 (Sweden)</p> <p>Federal Mining Law Art 4 § 71 of BGBl. I S. 3154 (2013) (Germany)</p> <p>Mining Code Act 950/2009 (Denmark)</p> <p>Law on Industrial Licensing 169/2012, 73/2015, 278/2015 (Portugal)</p>
Health and Safety	<p>Council Directive Concerning Minimum Requirements for Improving the Safety and Health Protection of Workers in the Extractive Industries 1992/91/EC</p> <p>Council Directive on the Minimum Requirements for Improving the Safety and Health Protection of Workers in Surface and Underground Mineral Extracting Industries 1992/104/EEC</p> <p>Occupational Health and Safety Act 1996 (Estonia)</p> <p>General Regulation of Mining Basic Safety 863(1985) (Spain)</p> <p>Health and Safety at Work Act 1974 (United Kingdom)</p>

Table 6. Examples of policies/legislation related to emissions and wastes

Challenges	Examples of policies/legislation
<p>Reduction and handling of wastes</p> <p>(incl. hazardous substances)</p>	<p>Waste Framework Directive 2008/98/EC</p> <p>Directive on the Control of Major Accident Hazards Involving Dangerous Substances 2012/18/EU</p> <p>Restriction of Hazardous Substances Directive RoHS 2002/95/EC</p> <p>Waste Electrical and Electronic Equipment Directive 2002/96/EC</p> <p>PolicyA5 Mines / Regulation for the prevention and surveillance of mining risks</p> <p>Planning (Hazardous Substances) Act 1990 (United Kingdom)</p> <p>Regulation on Maximum Limits of Hazardous Substances in Soil and Ground Water 8/1999 (Estonia)</p>
<p>Management of processing rejects</p>	<p>Directive on the Management of Waste from Extractive Industries 2006/21/EC</p> <p>Dam Safety Act 494/2009 (Finland)</p> <p>PolicyA4 / Mines Law on liability for damage resulting mining and the prevention of mining risks after the end of operation (France)</p> <p>Management of Extractive Industries Wastes and Protection and Reclamation of Land Affected by Mining Operations 975(2009)/777(2012) (Spain)</p> <p>Waste Act RT I 2004,9,52 (Estonia)</p> <p>Act on Waste Deposits 420/1990 (Denmark)</p> <p>Law on Waste Management 238/1991, 255/1993 (Slovakia)</p>
<p>GHG and other emissions</p>	<p>Integrated Pollution and Prevention Control Directive (2008/1/EC)</p> <p>Federal Emission Control Act 3830(2002)/1163(2010) (Germany)</p> <p>Act on Pollution Prevention and Control 16(2002) Spain</p> <p>Air Pollution Act (The Netherlands)</p> <p>Regulation on Limit Values of Pollutants in Air 133/2005 (Croatia)</p>

Table 7. Examples of policies/legislation related to use of resources

Challenges	Examples of policies/legislation
Energy conservation and efficiency	Law Establishing Centre for Energy Efficiency and Mining Development 11(1981) (Spain)
Water management	Water Framework Directive 2000/60/EC (EU) Water Act 264/1961 (Finland) Regulation on Maximum Limits of Hazardous Substances in Soil and Ground Water 8/1999 (Estonia) Federal Water Resources Management 2585(2009)/1163(2010) (Germany) Water Supply Act 130/1999 (Denmark) Water Resources Act 1991 (United Kingdom) Law on the Management of Water Resources 1739/1987 (Greece)
Land management and ownership of resources	Policy1A Mines / Mining Code (France) Environmental code 1998:808 chapter 3-4 (Sweden) Act on the Land Information System and Related Information Service (Finland) Land Use and Building Act 132/1999 (Finland) Ownership Act (Bulgaria) Land Tax Act RT I 1993, 24, 428 (Estonia) Spatial Planning Act 763/2002 (Denmark) Local Government, Planning and Land Act 1980 (United Kingdom) Law of Property Act 1925 (United Kingdom)

Sometimes various directives and legislation can overlap between different categories/challenges. For instance reduction of emissions to water can be considered both a water resource management issue and an issue of avoidance, reduction or immobilisation of hazardous wastes. It should be noted that these examples are part of a preliminary analysis of policies and legislation based on the Mineral Policy Guide developed within WP2 and will be further complemented and expanded with respect to mineral and metallurgical processing for the next project report (deliverable D4.2).

4.3 Preliminary analysis of innovation cases

In order to test the concept of evaluating the connection between specific innovations in mineral and metallurgical processing and public policy aspects which may have had an influence within the

particular case, a preliminary analysis (based on desk research) is here conducted for a few of the innovation cases given in section 4.1. This involves:

- Analysis of the innovation cases with respect the different innovation types as defined within MIN-GUIDE, see Table 8. It has to be annotated that the same innovation case can be interpreted as different innovation types. This refers to the different perspectives of suppliers versus mineral producers. Further, as processing is usually done in several steps, an innovation in one step (e.g. changing to a mill type that allows finer grinding) will always affect the processing system (the design of the entire grinding circuit) and even downstream processing (improved beneficiation due to increased liberation).
- Analysis of relevant public policy and legislation relevant to the innovation case, as described in section 4.2, see Table 9. This first analysis is done via linking the innovation cases to the societal and industry challenges and related policies and directives. In the continuation it is foreseen to extend this view towards other links (legislation, instruments like RDI programmes), and also to match public policy against the barriers and facilitators for innovation (section 3). By doing so, it should be possible to establish a causal chain between innovation cases, the challenges (or drivers) and public policies with their effective direction (barriers/facilitators) in order to identify good practices in policy making.

The analysis and evaluation concept utilised within this report will be further developed with added input on public policies from WP2 and by involving the expert crowd (interviews and policy lab for WP4). This continued work will be reported within the upcoming report part 2 (deliverable D4.2).

Table 8. Innovation cases and MIN-GUIDE innovation types

Innovation type	Innovation case:			
	Sensor Based Sorting (SBS)	High Pressure Grinding Rolls (HPGR)	Bioleaching	
Product innovation	Implementation of new sensor types for mineral separation, adaption of equipment to harsh processing conditions (equipment supplier view)	Adaption of mill type to medium hard and hard minerals, improved wear protection as a consequence (equipment supplier view)	Adaption of heap and reactor leaching technology to bio-processing	
Process innovation	Integration of SBS into pre-concentration concepts including by-product production (producer perspective)	Size reduction in the transition between crushing and grinding, changes to flowsheets (producer perspective)	Bio-heap leaching for extracting metals from low grade ores, with less severe process conditions	
Marketing	Less fines production, less energy consumption for grinding	Energy efficient comminution	Environmentally friendlier process	
Organisational	-	-	-	
System innovation	Dry processing option, reduction of material to be ground, reduction of fine tailings, option for back-filling or utilization	Dry processing option, weakening by induction of microcracks, microcracks for improved leaching, in some cases improved mineral	More simple process design and thereby cheaper than chemical leaching	

liberation

Other

Table 9. Innovation examples and link to policies, etc.

Connections to policies etc.	<u>Innovation case:</u>			
	Sensor Based Sorting	High Pressure Grinding Rolls (HPGR)	Grinding	Bioleaching
Policy and directives	<ul style="list-style-type: none"> • Council Directive Concerning Minimum Requirements for Improving the Safety and Health Protection of Workers in the Extractive Industries 1992/91/EC • Environmental Impact Assessment Directives 2011/92/EU and 2014/52/E • Directive on the Management of Waste from Extractive Industries 2006/21/EC 	<ul style="list-style-type: none"> • Council Directive Concerning Minimum Requirements for Improving the Safety and Health Protection of Workers in the Extractive Industries 1992/91/EC • Environmental Impact Assessment Directives 2011/92/EU and 2014/52/E • Integrated Pollution and Prevention Control Directive (2008/1/EC) 		<ul style="list-style-type: none"> • Council Directive Concerning Minimum Requirements for Improving the Safety and Health Protection of Workers in the Extractive Industries 1992/91/EC • Environmental Impact Assessment Directives 2011/92/EU and 2014/52/E • Directive on the Control of Major Accident Hazards Involving Dangerous Substances 2012/18/EU • Directive on the Management of Waste from Extractive Industries 2006/21/EC • Integrated Pollution and Prevention Control Directive (2008/1/EC) • Water Framework Directive 2000/60/EC (EU)
Legislation	•	•		•
RDI programmes 1)	<ul style="list-style-type: none"> • FP7 (I2Mine project with more than 20 participants) 	•		<ul style="list-style-type: none"> • FP7 (BioMine project with more than 30 participants)
Documents	•	•		•

1) H2020, EIT KIC, ERA-MIN, National research programmes

5 Conclusions

A general observation regarding policy initiatives related to mineral and metallurgical processing is that the sentiment amongst policy makers towards the raw materials industry has significantly improved over the last 5-10 year. This can be noted on EU level through a number of strategic policy initiatives supporting the industry in terms of recognising the importance of a secure and safe supply of raw materials, produced in an environmentally responsible and sustainable manner, and also increasingly taken from domestic sources. The use of raw materials from secondary sources is identified as a natural part of the life cycle of materials, and the need for improved collection, recycling and substitution is emphasised.

Innovation in all parts of the value chain is a critical factor for success. These ambitions on EU level are further reflected in many national and regional mineral and raw material strategies, which take into account industry-related prerequisites, challenges and opportunities specific to the national and regional context. To some extent, the above-discussed ambitions are backed by other policy-type elements as for instance research funding schemes, tax incitements, etc.

On the legislation side, the main contribution of this type of policy towards innovation is resulting from imposing various types of restrictions, which in turn might drive companies towards process improvements, more environmentally sound operations, etc. Although this often has adverse effects on the economy of operations, the impact in terms of driving innovation in industry can thus still be net positive. A more critical obstacle, which can act as a barrier to industry innovation and development, achievement of strategic goals set by policy makers and economic development in general, is the quantity of policy initiatives and legislation. This leads to much more complicated and time-consuming permitting procedures, lowers predictability, and in some cases causes unacceptably high economic commitments by industry. This not only concerns policies and legislation directly addressing the minerals and metals industry, but also the complex interaction with various less related policies and legislation for which the industry is also fully accountable (Black, 2016).

The analysis of innovation cases within mineral and metallurgical processing and their possible interaction with policies and legislation indicate that most innovations within this part of the value chain, with some exceptions, mainly relate to policies and legislation linked to general challenges of society such as energy and resource efficiency, waste management, emissions to air and water, and hazardous substances. In this respect, policy and legislation mainly appear to act as indirect drivers for innovation in industry. This can for instance entail application of pre-concentration methods such as sensor-based sorting for producing less problematic processing rejects, application of flotation or other separation methods for separating hazardous waste components from non-hazardous ones, using alternative reducing agents in metallurgy for reducing GHG emissions, etc. The main challenges for industry innovation seem to be barriers within the respective organisations and barriers arising through external conditions only remotely linked to policies and legislation. This could for instance include labour market constraints, access to funding for implementing new technologies, and constraints imposed by suppliers or customers (e.g. requiring certain product specifications).

The case analysis will be furthered within the coming phase of the MIN-GUIDE project, as a more detailed knowledge base is formed partly through the continued work related to the stocktaking and

systematisation of policies and legislation and partly through more specific input related to innovation cases. In addition to continued literature research, further input on innovation cases will be obtained through interviews and/or questionnaires with policy makers, innovation experts and professionals within industry, as well as a workshop-type Policy Lab with direct focus on mineral and metallurgical processing.

6 References

A Review of National Resource Strategies and Research (2012). Department of Environment, Food and Rural Affairs, downloaded 2014-01-16. <http://www.defra.gov.uk>

Anderson, N., De Dreu, C. (2004). The routinization of innovation research: a constructively critical review of the state-of-the-science. *Journal of Organizational Behavior* 25, 147-173.

Anderson, C., Dunne, R., Uhrig, J. (Eds.) (2014). Mineral Processing and Extractive Metallurgy – 100 Years of Innovation, Society for Mining, Metallurgy & Exploration (SME), ISBN 978-0-87335-371-7.

Aylen, J. (2012). Stretch: How innovation continues once investment is made. *R&D Management* 43: 271–287.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy* 37: 407-429.

Baines, T.S., Lightfoot, H.W., Benedettini, O., Kay, J.M. (2009). The Servitization of Manufacturing: A Review of Literature and Reflections on Future Challenges. *Journal of Manufacturing Technology Management* 20: 547-567.

Bicket, M., Watson, T. (2016). The MIN-GUIDE Common Approach D1.1, Version 1. <http://www.min-guide.eu/project-results>

Chesbrough, H. (2003). *Open Innovation – The New Imperative for Creating and Profiting from Technology*. Boston, MA: HBS Press.

Cooper, R.G. (2014). What's Next? After Stage-Gate. *Research-Technology Management* 57: 20-31.

Ericsson, M. (2014). Supply and Demand: Innovation Drivers in the Minerals Industry, In: Mineral Processing and Extractive Metallurgy – 100 Years of Innovation, Society for Mining, Metallurgy & Exploration (SME), pp. 3-13.

Eriksson, P.-E., Patel, P., Rönnberg-Sjödén, D., Frishammar, J., Parida, V. (2016). Managing Interorganizational Innovation Projects: Mitigating the Negative Effects of Equivocality Through Search Strategies. *Long Range Planning* (in press).

Finland's Mineral Strategy (2010). Kirjapaino Keili Ltd, Vantaa, ISBN 978-952-217-134-4, www.mineraalistratégia.fi

Flanagan, K., Uyerra, E. (2016). Four dangers in innovation policy studies – and how to avoid them, *Industry and Innovation* 23:2, 177-188.

Frishammar, J., Ericsson, K., Patel, P. (2015). The Dark Side of Knowledge Transfer: Exploring Knowledge Leakage in Joint R&D Projects. *Technovation* 41-42, 75-88.

Frishammar, J., Kurkkio, M., Abrahamsson, L., Lichtenthaler, U. (2012). Antecedents and Consequences of Firm's Process Innovation Capability: A Literature Review and Conceptual Framework. *IEEE Transactions on Engineering Management* 59: 519-529.

Frishammar, J., Söderholm, P., Bäckström, K., Hellsmark, H., Ylinenpää, H. (2015). The Role of Pilot and Demonstration Plants in Technological Development: Synthesis and Directions for Future Research. *Technology Analysis & Strategic Management* 27: 1-18.

Gopalakrishnan, S., Damanpour, F. (1994). Patterns of generation and adoption of innovation in organizations: Contingency models of innovation attributes. *Journal of Engineering and Technology Management*, 11: 95-116.

Grönlund, J., Rönberg Sjödin, D., Frishammar, J. (2010). Open Innovation and the Stage-Gate Process: A Revised Model for New Product Development. *California Management Review* 52: 106-131.

Hellsmark, H., Frishammar, J., Söderholm, P., Ylinenpää, H. (2016). The Role of Pilot and Demonstration Plants in Technology Development and Innovation Policy. *Research Policy* 45: 1743-1761.

Hueske, A.-K., Guenther, E. (2015). What hampers innovation? External stakeholders, the organization, groups and individuals: A systematic review of empirical barrier research. *Management Review Quarterly* 65, 113-148.

Hueske, A.-K., Endrikat, J., Guenther, E. (2015). External environment, the innovating organization, and its individuals: A multilevel model for identifying innovation barriers accounting for social uncertainties. *Journal of Engineering and Technology Management* 35, 45-70.

Hutcheson, P., Pearson, A., Ball, D. (1995). Innovation in Process Plant: A Case Study of Ethylene, *Journal of Product Innovation Management* 12, 415-430.

Jarvis, D., Raabe, D., Singer, R., van Houtte, P., Vahlas, C., Alford, N., Kurzydowski, K., Nieminen, R., Mortensen, A., Gleiter, H., Loretto, M., Brechet, Y., Fecht, H.-J. (2012). Metallurgy Europe –A Renaissance Programme for 2012-2022, Jarvis, D. (Ed.), Materials Science and Engineering Expert Committee (MatSEEC) report, www.esf.org/matseec

Jebrak, M., Vaillancourt, J. (2012). *100 Innovations in the Mining Industry*, Minalliance. ISBN 978-2-9812840-3-7.

Katz, R., Allen, T.J. (1982). Investigating the Not Invented Here (NIH) Syndrome: A Look at the Performance, Tenure, and Communication Patterns of 50 R&D Project Groups. *R&D Management* 12: 7-20.

Kim, J., Wilemon, D. (2002). Focusing on the fuzzy front-end in new product development, *R&D Management* 32(4): 269-279.

King, A., Bartels, W., Fogelberg, T., Hoballah, A., Malan, D., van der Lugt, C. (2016). Carrots and Sticks – Global Trends in Sustainability Reporting Regulations and Policies. <http://www.sseinitiative.org/wp-content/uploads/2016/05/Carrots-Sticks-2016.pdf>

Klar, D., Frishammar, J., Roman, V., Hallberg, D. (2016). A Technology Readiness Level Scale for Iron and Steel Industries. *Ironmaking & Steelmaking* 43: 494-499.

Kurkkio, M., Frishammar, J., Lichtenthaler, U. (2011). Where Process Development Begins: A Multiple Case Study of Front End Activities in Process Firms. *Technovation* 31: 490-504.

Kurkkio, M., Frishammar, J., Söderholm, P., Ejdemo, T. (2014). Mapping the Nordic Mining and Metal Industry for the Purpose of Enhancing and Developing its Innovative Capability. Report for Nordic Innovation/The Nordic Council of Ministers.

Lager, T. (2002). Product and process development intensity in process industry: A conceptual and empirical analysis of the allocation of company resources for the development of process technology. *International Journal of Innovation Management* 6: 105-130.

Lager, T., Frishammar, J. (2010). Equipment Supplier/User Collaboration in the Process Industries: In Search of Enhanced Operating Performance. *Journal of Manufacturing Technology Management* 21: 698-720.

Lam, D.M., Mackenzie, C. (2005). Human and organizational factors affecting telemedicine utilization within U.S. military forces in Europe. *Telemed E Health* 11: 70-78.

Laranja, M., Uyarra, E., Flanagan, K. (2008). Policies for Science, Technology and Innovation: Translating Rationales into Regional Policies in a Multi-Level Setting, *Research Policy* 37: 823-835.

Muench, S., Thuss, S., Guenther, E. (2014). What hampers energy system transformations? The case of smart grids. *Energy Policy* 73, 80-92.

Napier-Munn, T.J. (1997). Invention and Innovation in Mineral Processing. *Minerals Engineering* 10(8):757-773.

National Minerals Policy Indicators – Framework Conditions for the sustainable supply of raw materials in the EU (2014). European Commission, Brussels.

Reim, W., Parida, V., Örtqvist, D. (2015). Product-Service Systems (PSS) Business Models and Tactics – A Systematic Literature Review. *Journal of Cleaner Production* 97: 61-75.

Rönnerberg Sjödin, D., Eriksson P.E., Frishammar, J. (2011). Open Innovation in Process Industries: A Life-cycle Perspective on Development of Process Equipment. *International Journal of Technology Management* 56: 225-240.

Rönnerberg Sjödin, D., Frishammar, J., Eriksson, P.E. (2016). Managing Uncertainty and Equivocality in Joint Process Development Projects. *Journal of Engineering and Technology Management* 39: 13-25.

Strategic Implementation Plan for the European Innovation Partnership on Raw Materials, Part I (2013). http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/eip-sip-part1_en.pdf

The German Government's Raw Materials Strategy –Safeguarding a sustainable supply of non-energy mineral resources for Germany (2010). Federal Ministry of Economics and Technology, downloaded 2014-01-15. <http://bmwi.de>

The Raw Materials Initiative (2008). Communication from the Commission to the European Parliament and the Council, The Raw Materials Initiative - Meeting Our Critical Needs for Growth and Jobs in Europe. SEC(2008)2741.

Sweden's Minerals Strategy. For sustainable use of Sweden's mineral resources that creates growth throughout the country (2013). Ministry of Enterprise Energy and Communications, www.regeringen.se/mis

Vidal, O., Weihed, P., Hagelüken, C., Bol, D., Christmann, P., Arndt, N. (2013). *Era-Min Research Agenda.* <http://www.era-min-eu.org/about/era-min-roadmap>

Weber, L. (Ed.) (2012). Der Österreichische Rohstoffplan – Archiv für Lagerstättenforschung, 26, Geologische Bundesanstalt, downloaded 2016-12-16. <http://opac.geologie.ac.at>

7 Appendices

7.1 List of Abbreviations

AMD	Acid Mine Drainage
DEM	Discrete Element Method
EIA	Environmental Impact Assessment
EIP	European Innovation Partnership
ETS	Emission Trading System in the European Union (EU ETS)
GHG	Greenhouse Gases
HPGR	High Pressure Grinding Rolls
HPAL	High Pressure Acid Leaching
IEEE	Institute of Electrical and Electronics Engineers
LKAB	Luossavaara-Kiirunavaara Aktiebolag (Swedish mining company)
PGE	Platinum Group Elements
R&D	Research and Development
RDI	Researcher Development Initiatives
RE	Rare Earth
REE	Rare Earth Elements
RoHS	Restriction of Hazardous Substances (EU Directive)
SBS	Sensor Based Sorting
SIP	Strategic Implementation Plan
SME	Society for Mining, Metallurgy and Exploration
SSAB	Svenskt Stål Aktiebolag (Swedish steelmaking company)
SSF	Stiftelsen för Strategisk Forskning (Foundation for Strategic Research)
TRL	Technology Readiness Level
UNEP	United Nations Environment Programme

WEEE Waste Electric and Electronic Equipment

WP Work Package

XRF X-Ray Fluorescence