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MIN guide

Minerals Policy Guidance for Europe

Innovative Processing

Deliverable 4.2

Report on Innovation Promotion and Inhibiting Factors and Examples of Best Practices

Version 1, July 2017

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1 Introduction

1.1 MIN-GUIDE: A brief introduction

The Horizon2020 project MIN-GUIDE aims at supporting a secure and sustainable supply of minerals in the EU, as discussed in the 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, has been recognised both on EU level and in many of its Member States (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.

Table 1. MIN-GUIDE structure and work packages

Type	WP #	Description
Common Approach	WP1	Minerals policy guide development and conceptual basis
Core Content	WP2	Stock-taking of EU and EU MS mineral policy and legislation
	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

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), and a 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.

1.2 Scope of Work package 4

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 'Minerals Policy Guide' developed in WP1 and 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 and metal producers in the context of mineral processing and metal production and to study which impact the policy and legislation framework has on these processes.

At first, this requires 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 both actors and this part of the value chain overall. Based on this, a number of concrete innovations are used as case studies in order to exemplify the links to various policies and qualitatively evaluating the roles of both policy and non-policy factors as barriers and enablers for innovation.

1.3 Objectives of Work package 4

The aim of WP4 "Innovative Processing" is to elucidate how innovations in mineral and metallurgical processing are generated or taken up in different EU Member States and on EU-level and how this is either facilitated or inhibited by policies and legislation on national or European level. The work within WP4 also fosters dissemination of identified good practices and the investigation of factors which can enhance the transferability of such practices across the EU.

The objectives of WP4 can, therefore, be summarised as follows:

- Identify 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 project reports D4.1 and D4.2 are provided as two separate but interlinked reports:

- D4.1 provides a topic overview of innovation case examples within minerals and metallurgical processing as well as a mapping of the relevant policy framework and an analysis of the impact on innovation. D4.1 is based mainly on literature surveys and preliminary case studies and analysis.
- D4.2 extends this approach through a more in-depth analysis of different innovation cases and their links to different policy and non-policy catalysing and inhibiting factors. In addition to further literature investigations, the work is complemented by interviews and questionnaires with industry representatives. A workshop (MIN-GUIDE Policy Laboratory 3) was held in Luleå, Sweden 18-19 May 2017, and attracted about 45 stakeholders from

industry, policy-making and research organisations. Additional input obtained during that meeting was also used as background material for this deliverable.

1.4 Terminology and stakeholder network

Within the MIN-GUIDE project, a number of innovation types or categories have been defined based on the MIN-GUIDE Common Approach D1.1 (Bicket and Watson, 2016). Specific to WP4, the stakeholder network involving the value chain constituents relevant for minerals and metallurgical processing was defined within the previous report, D4.1. For the benefit of this report, the innovation categories and stakeholder network are again briefly summarised. The innovation types considered within the project are as follows:

- **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 material or new use for a material (e.g. tailings).
- **Process** innovation: implementation of a new or significantly improved production or delivery method, e.g. techniques, equipment, software. Also within this broader category **input** innovation (new sources of inputs as for instance mining waste) is included and highlighted.
- **Marketing** innovation: implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing (e.g. new communication tools for raising awareness and building public acceptability).
- **Organisational** innovation: implementation of new organisational methods in business or policy practices, workplace organisation or external relations (e.g. environmental management and auditing systems; supply chain management; industrial symbiosis; closer cooperation between different ministries on minerals policy design and delivery).
- **System** innovation: E.g. innovations which result in significant improvements in more than one step of the supply chain, or in another sector.

The stakeholder network considered within the work package is illustrated in Figure 1. The core of the stakeholder system is mining companies and metal producers. Within the mining companies, however, 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, although being integral parts of mine and metallurgical plant operation, will not be under consideration within this report as they are covered by WP5. The focus of this study is consequently limited 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 and fluxes), process equipment, as well as service providers and consultants (either technical or non-technical) can be distinguished. 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. The role of policymakers in the system is complex and therefore indicated by brackets, covering the full value chain. Policymakers have influence on each individual actor in the value chain, and therefore on the entire system. Furthermore, policymakers are not only influencing, but also influenced by all other actors. For further clarifications on the stakeholder network, the reader is referred to the previous project report D 4.1 (Sand et al., 2016).

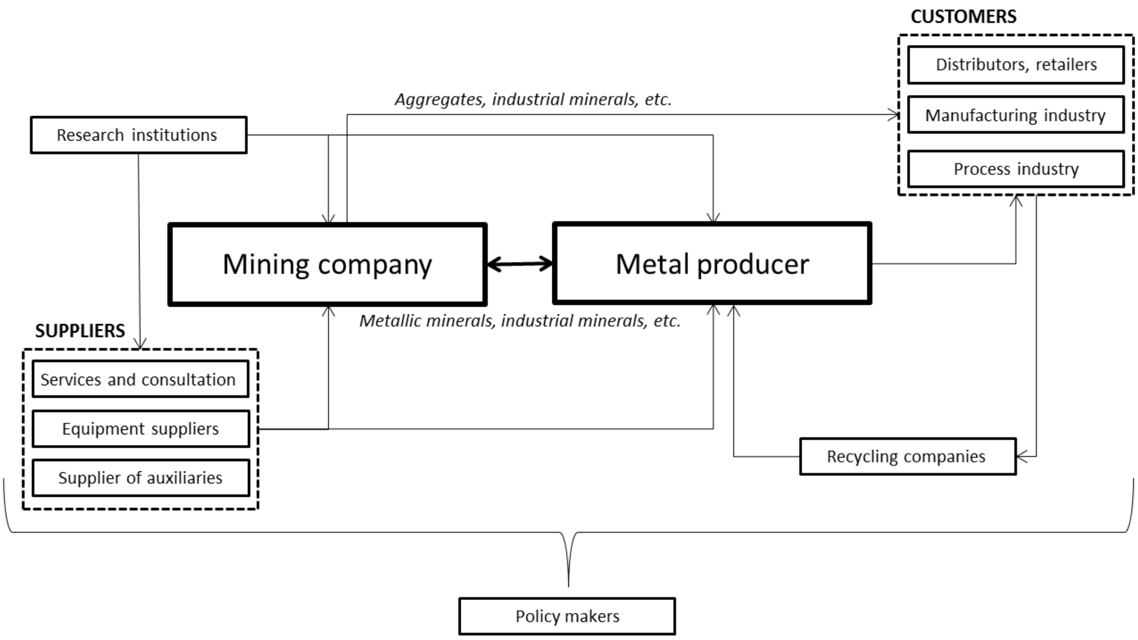

Figure 1. Stakeholder network in mineral and metallurgical processing.

2 Approach

2.1 Data sources

Deliverable D4.2 is based both on secondary and primary data. Secondary data from prior research projects were used to understand types of innovation in mineral and metallurgical processing, value chains, overall development logic, and to shed light on factors that catalyse or inhibit innovation. Most of this secondary 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. As a complement, work was also build on related scientific literature and the MIN-GUIDE deliverable D1.1 (Bicket and Watson, 2016), which provides the innovation framework for D4.2.

Primary data was collected as a series of interviews with highly qualified engineers, R&D and innovation managers as the expert crowd in order to identify factors that catalyse or inhibit innovation in mineral- and metallurgical processing. Interviews were conducted with representatives from LKAB, Boliden AB, Stena Metall AB, Outotec Oy, Sandvik Mining and Rock Technology, Wardell Armstrong International with focus on particular innovation cases (see section 4.3). These interviews were complemented by additional data in the form of presentation slides and notes taken at the MIN-GUIDE Policy Laboratory 3, held in Luleå in May 2017. This data complemented the case descriptions received via interviews with regards to insights into the policy framework, policy- and non-policy catalysing and inhibiting factors, etc. In particular, the discussions at the MIN-GUIDE policy laboratory allowed a broader perspective on innovation in mineral and metallurgical processing, where policy makers, industry, academy and NGO opinions all were aired.

Further, secondary data from a project called "*Measuring innovation and innovative capabilities (MiiF)*", a project financed by Vinnova, was used. In particular, five interviews conducted at LKAB, a leading producer of upgraded iron ore products, were helpful to better understand dominant types of innovation in mineral and metallurgical processing and their measurement and impact. Second, a large set of interview data was used from a Vinnova-project called *"Managing the fuzzy front end during product- and process development in process industry"*. In total, 68 interviews were conducted at LKAB, Höganäs (a world-leader in powder metallurgy), Boliden AB (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, including the influence of external factors on innovation, such as policy factors.

The project "*Models and best practices for effective management of innovation and collaboration between firms in process industry and equipment manufacturers (Maelis)"* was particularly valuable. 39 interviews were conducted at Höganäs and LKAB and eight of their suppliers of process equipment/technology. 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 world-wide (with 251 responses to three different surveys in total). Many of these suppliers were located in various European countries. These interviews and survey data focused on drivers/motives/challenges in external collaboration and open innovation, and pictured both policy and non-policy catalysing and inhibiting factors.

The project *"Improving the process development process at LKAB"*, financed by the Swedish Foundation for Strategic Research (SSF), provided 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 on firm level.

Finally, the project *"Mapping the Nordic mining and metal industry (NMC)"* financed by the Nordic Ministry Council provided 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 mining industry, including policy challenges. Interviews were performed with respondents from the Nordic countries Denmark, Finland, Sweden and Norway.

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 innovation focus, however, an efficient production process is paramount for keeping costs low. This fact makes process innovation the most important type (complemented by product innovation and organizational innovation as well as system innovation).

Furthermore, innovation in mineral and metallurgical processing is a complex task involving multiple actors (see Figure 2, adopted from Lager, 2002). Processing companies themselves seldom manufacture new equipment for process innovations. Rather, equipment manufacturers tend to do a lion's share of development of equipment and then supply it to the processing companies. Process innovation then determines the preconditions for product innovation, i.e. which new products can be developed and produced depends on available process technologies and factories. There may also be innovation arising 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 processing firm helps their customers to make more efficient use of input materials for producing e.g. steel.

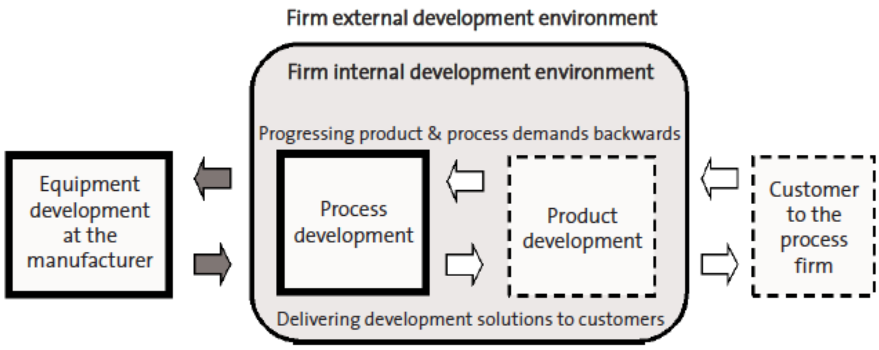

Figure 2. Stakeholder involvement in mineral and metallurgical processing (adopted from Lager, 2002).

In pursuing innovation, various types of pilot and demonstration plants are the key to moving new technology further up on the TRL technology readiness level scale (Hellsmark et al., 2016; Klar et al., 2016). 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).

2.2.1 Identification of innovation process models and 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 (compare Chesbrough, 2003). The main reason for this "open" approach to innovation is the strong collaboration required to innovate new processes and products (Rönnberg 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).

Like in many other settings, most firms in the mineral and metallurgical sector use some sort of stage-gate methodology (i.e. where the process is divided into distinct stages with decision points or gates in between) to execute process innovation or product innovation in practice. In the mineral and metallurgical sector, most companies follow this traditional process model. 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. Therefore, the stage-gate system in most companies of 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 for innovation are clear and consistent (Cooper, 2014).

2.2.2 Dominant 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. Process innovation is also *systemic* (Gopalakrishnan & Damanpour, 1994). This means it may affect many activities in a company beyond the manufacturing or production processes,
- *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. many firms there are for not that many opportunities to differentiate products.
- *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 new types of packaging.
- *Organisational innovation*, i.e. the implementation of new organisational methods in business or policy practice, workplace organisation or external relations. One example is the increasingly "open" type of collaboration between producing firms in mineral and metallurgical processing and their equipment manufacturers. This is facilitated by the fact that the mineral properties affecting the process are usually very specific.
- *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 is one such unit operations may often affect others.

3 Factors that enable or inhibit innovation in mineral and metallurgical processing

Why does innovation in mineral- and metallurgical processing fail to happen? Or why does it happen? Key reasons for why innovation 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, tough environmental legislation may push capital and investments away, but, on the other hand, may also enable innovation in new products or processes. The discussion below focuses largely on policy and non-policy prohibiting factors.

Starting from the MIN-GUIDE definition of innovation, and in particular from the types of innovation that are most prevalent in the mineral and metallurgical sector, namely process innovation and product innovation, and using the framework proposed by Hueske and Guenther (2015) and Hueske et al. (2015) the barriers to innovation can be organised into four different levels:

1) External environment
2) Organization
3) Group and

4) Individual

This way of viewing inhibiting factors fits the mineral and metallurgical industry and the MIN-GUIDE project. Barriers in the external environment are clearly external to a given focal firm or organization, i.e. outside its boundaries, and may relate to supply, demand, environmental issues, policy and legislation, etc. Policy related enabling and prohibiting factors are especially important in this category, and will be discussed in a separate chapter. The remaining three categories are firm-internal, i.e. they materialise within a given organisation, and constitute the non-policy enabling and prohibiting factors, see **Figure 3**.

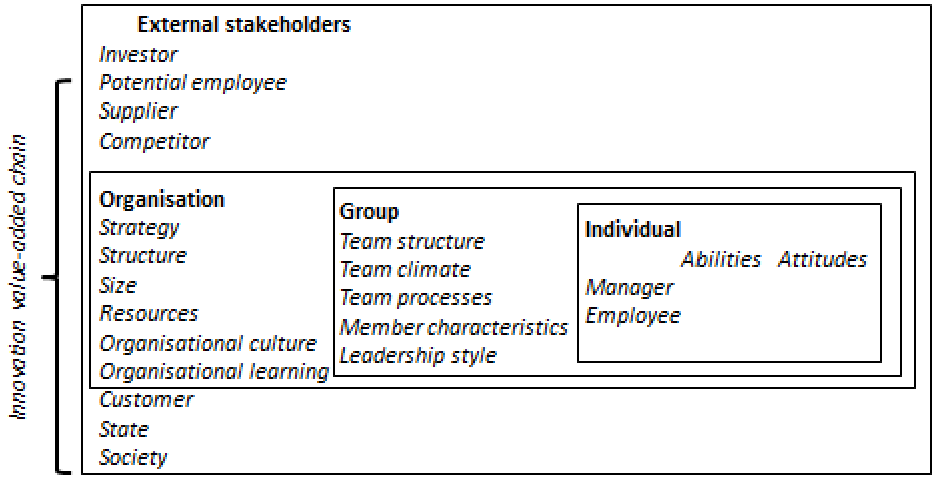

Figure 3. Various levels and categories of barriers to innovation (adapted from Hueske and Guenther, 2015 and Hueske et al., 2015).

3.1 Non-policy inhibiting and enabling factors

3.1.1 External inhibiting and enabling factors

There are multiple actors 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 refer to other actors in the broader ecosystem, such as suppliers of process equipment and technology (Lager and Frishammar, 2010) who are critical to create innovation. In the systematic literature review provided by Hueske and Guenther (2015), there were eight sub-categories of external barriers to innovation (inhibiting factors), where the six that focus on non-policy issues are discussed here:

- 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 is considered to be a barrier in mineral and metallurgical processing. For example, the sector is traditionally male dominated and has a general problem with attracting female employees. 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. Data from the Nordic ministry council clearly indicate a trend in this regard.

- Suppliers. Suppliers of primary and secondary raw materials may be a barrier, in case these actors fail to make sufficient R&D investments to improve materials properties, or fail to supply the materials needed for downstream products. The importance of suppliers, competitors and customers as both enabling and prohibiting innovation factors is strongly supported in data from several of the prior Vinnova-funded projects.
- 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). To be successful these competitors need to be fast in following up.
- Customers. Customers may indeed be a driver of innovation. One example is the world automotive industry and their need to continuously decrease vehicles weight, which has 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, tend 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 typically are needed for innovating products and processes of firms in mineral and metallurgical processing (Rönnberg-Sjödin et al., 2016). Technology suppliers may be a particularly important partner for innovation, for capability-based reasons. Technology suppliers are often experts in developing the new technologies and therefore needed in new product- and process innovation, i.e. their participation needs be ensured (Lager and Frishammar, 2010).

3.1.2 Organisational inhibiting and enabling factor

Organisational barriers to innovation often focus on a lack of (or deficiencies in) capabilities at the organizational level. Barriers at the organizational level also centre on 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). 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 firms which 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 (like shown in the previous studies of LKAB).

- Structure. This barrier refers to inconsistencies among existing processes and rules, bureaucracy or performance measurement (e.g. companies lack processes for conducting innovation, or fail to measure innovation outcomes). Some of the prior empirical studies (see section 2.1) highlight this type of barrier.
- 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. the scale of these companies is too small. However, very large companies may also fail to innovate as they become overly formalized and rigid.
- Resources. This barrier refers to 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).
- Organisational culture. A very common barrier to innovation is when 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.
- Organisational learning. Organisational learning as a barrier refers to lack of training and learning difficulties. In prior innovation management research, this barrier manifests in the difficulties of established firms to change when radical technology innovation and substitute products alter the competition.

3.1.3 Group inhibiting and enabling factors

Barriers to innovation may also exist on the group level. Groups are embedded in the larger organizational 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 related 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. Similarly, of course, appropriate team structure can be a major enabler of innovation.
- Team climate. Team climate is also an important barrier to innovation, and may inhibit 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, i.e. 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.
- Team members' characteristics. This is also an important barrier to innovation that may act to impede group work, such as when perceptions of the members' goals 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 it to succeed. This can be difficult in many firms in the mineral and metallurgical processing sector whose core competences are in production of standardized goods rather than innovation.

3.1.4 Individual inhibiting and enabling factors

Finally, some barriers and enablers of 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 organizational barriers to innovation:

- Managers' abilities. These refer to managing expertise, general management skills and leadership style. This is clearly a critical factor to innovation in many companies.
- Managers' attitudes. These refer to management attitudes, especially lack of commitment to innovation. For example, prior research shows 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 factor may be particularly important in responding to technical changes, where employees may not have the right skillset or ability to recognize the value of new information, assimilate and apply it ("absorptive capacity").
- Employees' attitudes. This factor is centred on resistance to change and unawareness and/or lack of understanding about the usefulness of an innovation.

3.2 Policy inhibiting and enabling factors

Beyond the actors connected to the value chain, actors such as various levels of government (i.e. state, EU, etc.) are critical. For example, the state may impose regulations and policy initiatives that either inhibit or catalyse innovation through e.g. regulatory frameworks (Muench et al., 2014). Innovation policy instruments are thus selected to influence innovation, e.g. process innovation, product innovation, or some other type. In doing so, they may inhibit or enable innovation.

Factors inhibiting innovation may be caused by regulatory constraints imposed by the state as well as unclear and unstable legislation. For example, taxation policies may drive away investments in innovation, as may governmental regulations and standards. However, policy initiatives may also act to spawn innovation, for example when a state invests in large-scale R&D-programmes in the area of sustainable technologies as a response to so-called system failures (Bergek et al., 2008). Wider society may also 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" may not be there, although the legal permits are.

There are three categories of instruments used in innovation policy: (i) regulatory instruments, (ii) economic and financial instruments, and (iii) soft instruments (Borras and Edquist, 2013).

3.2.1 Regulatory instruments

Regulatory instruments use legal tools where government defines framework conditions. These framework conditions set boundaries for what is allowed, and for what is not allowed. Measures are obligatory and backed by sanctions when firms fail to comply with whatever the instrument stipulates, e.g. laws, rules, directives and others. Sanctions may, for example, include fines, or temporary withdrawal of rights. According to Borras and Edquist (2013), regulatory instruments are often used for the definition of market conditions for innovative products and processes. Regulatory instruments may enable innovation by e.g. assuring intellectual property rights to innovators through patents, or through sector-specific regulations. For the mineral- and metallurgical processing sector, environmental regulation may e.g. act to spawn investments into better production processes (i.e. process innovation). However, they may also cause compliance costs and large transaction costs, which inhibit innovation, especially for newcomers who do not have the large resource pool of incumbent firms.

3.2.2 Economic and financial instruments

The purpose of economic and financial instruments is to incentivise (or discourage specific industry activities. For example, policy instruments could provide means in terms of money or in terms of in-kind, i.e. subsidies or cash transfer. One example is public support to universities and research organizations to spawn knowledge in basic R&D, product- and process innovation. A sector-specific policy instrument example enabling innovation, is the Swedish initiative "Strategiskt gruvforskningsprogram" (Strategic programme for research in mining); for similar examples, see also MIN-GUIDE deliverable 3.2. Another example is the so-called PFE system in Sweden, which offered a tax reduction in return for firm investments in energy reduction (Energimyndigheten 2016).

3.2.3 Soft instruments

By contrast, soft instruments are being voluntary and non-coercive (Borras and Edquist, 2013). Firms exposed to these are thus not subjected to obligatory measures. The soft instruments rather provide recommendations and make normative appeals or offer contractual agreements. Some examples include codes of conduct, governmental recommendations, voluntary agreements and public-private partnerships, which all may act to spawn innovation. Soft instruments are often used in combination with policy initiatives from the two categories above in order to serve a common goal within a kind of policy mix.

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

4.1 Identification of relevant innovation cases

In the following, a number 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 the Tables 2 to 4.

Table 2. Examples of innovations in mineral processing

Field	Innovation	Short description
Comminution	HPGR	High pressure grinding rolls 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 optimization	Energy and capacity optimization 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. 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 pilot 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 collisions.
	Sulphidisation of oxide ores for flotation	Recovery and selectivity in oxide mineral flotation are improved by sulphidising the surface of the oxide minerals using a sulphidisation 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.
	Pre-concentration close to the mine production face	Concepts for reducing the material amount taken to the surface or out of the pit. This involves crushing and grinding as well as different separation processes (e.g. sensor-based sorting, SBS) operated in the mine.
	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.

Table 3. Examples of innovation in process analysis and control and environmental management

Field	Innovation	Short description
Analysis and control	XRF online analysers	Flotation processes are dynamically controlled by means of XRF analysers for float and sink product.
	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	Tailings desulphurisation	Tailings desulphurisation by flotation and/or physical separation methods for reducing the 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.

Table 4. Examples of innovations in metallurgical processing

Field	Innovation	Short 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.

4.2 Summary of relevant policies and legislation

As part of the previous MIN-GUIDE report (D4.1), an identification of policies and legislation relevant to mineral and metallurgical processing was conducted based on the stock-taking of data carried out for the Mineral Policy Guide in Work package 2. This included EU and Member State level mineral policy documents, as for instance mineral strategies, and also a list of relevant legislation. The overview is divided into 3 main categories, covering policies and legislation linked to (i) permitting procedures and social aspects, (ii) emissions and waste prevention and handling, and (iii) resource use (e.g. water, energy, land). Tables 5-7 summarise the results of this work and provide the background input to the policy links as described in the case examples in section 4.3.

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

Typical challenges	Categories and examples of policies/legislation
Permitting procedures and licensing	UNEP Goals and Principles of EIA (1987) Environmental Impact Assessment Directives 2011/92/EU and 2014/52/EU Directive on the conservation of wild birds 2009/147/EC (EU) Act on Environmental Impact Assessment Procedure 468/1994 (Finland) Mineral Raw Materials Act BGBl. I 80/2015 (Austria) Environmental code 1998:808 (Sweden) Federal Mining Law Art 4 § 71 of BGBl. I S. 3154 (2013) (Germany) Mining Code Act 950/2009 (Denmark) Law on Industrial Licensing 169/2012, 73/2015, 278/2015 (Portugal)
Health and Safety	Council Directive Concerning Minimum Requirements for Improving the Safety and Health Protection of Workers in the Extractive Industries 1992/91/EC 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 Occupational Health and Safety Act 1996 (Estonia) General Regulation of Mining Basic Safety 863(1985) (Spain) Health and Safety at Work Act 1974 (United Kingdom)

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

Typical challenges	Categories and examples of policies/legislation
Reduction and handling of wastes **(incl. hazardous substances)**	Waste Framework Directive 2008/98/EC Directive on the Control of Major Accident Hazards Involving Dangerous Substances 2012/18/EU Restriction of Hazardous Substances Directive RoHS 2002/95/EC Waste Electrical and Electronic Equipment Directive 2002/96/EC PolicyA5 Mines / Regulation for the prevention and surveillance of mining

	risks Planning (Hazardous Substances) Act 1990 (United Kingdom) Regulation on Maximum Limits of Hazardous Substances in Soil and Ground Water 8/1999 (Estonia)
Management of processing rejects	Directive on the Management of Waste from Extractive Industries 2006/21/EC Dam Safety Act 494/2009 (Finland) PolicyA4 / Mines Law on liability for damage resulting mining and the prevention of mining risks after the end of operation (France) Management of Extractive Industries Wastes and Protection and Reclamation of Land Affected by Mining Operations 975(2009)/777(2012) (Spain) Waste Act RT I 2004,9,52 (Estonia) Act on Waste Deposits 420/1990 (Denmark) Law on Waste Management 238/1991, 255/1993 (Slovakia)
GHG and other emissions	Integrated Pollution and Prevention Control Directive (2008/1/EC) Federal Emission Control Act 3830(2002)/1163(2010) (Germany) Act on Pollution Prevention and Control 16(2002) Spain Air Pollution Act (The Netherlands) Regulation on Limit Values of Pollutants in Air 133/2005 (Croatia)

Table 7. Challenges and examples of policies/legislation related to use of resources

Typical challenges	Categories and 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 EU 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 summarising the analysis of policies and legislation conducted within WP4 and based on the Mineral Policy Guide developed within WP2.

4.3 Description and analysis of selected innovation cases

In order to evaluate the connection between particular innovation cases within mineral and metallurgical processing and the policy and legislation factors that may have had an influence within the particular cases, an analysis has been conducted for a number of selected innovation cases.

4.3.1 Case A: High Pressure Grinding Rolls (HPGR)

Table 8. Analysis sheet HPGR

Description	It is known from comminution research already from the 1970s that inter-particle breakage in a particle bed provides enhanced energy efficiency when fracturing brittle material under high compressive forces (K. Schönert, TU Clausthal). The breakage principle resulted in Schönert's invention of the high pressure grinding rolls (HPGR) and their implementation by different equipment manufacturers. While the patent was first licenced to Polysius and KHD only, later also Koppers, FLSmidth and Alpine acquired a licence. After solving wear-related operational problems the HPGR have become widely used in the cement industry and are now also more and more adapted to ore grinding. The benefits of HPGR are • Production of more fine material at a given crush size than in conventional crushers • Formation of micro-cracks in the crushed rock particles - beneficial for subsequent grinding (weakening) and for downstream leaching (increased surface area) • Generation of less noise and dust compared to conventional cone crushers • Consumption of approximately 20% less power per tonne compared to conventional crushing plants producing the same product. • Dry processing • In some case improved liberation, e.g. diamonds

Type of innovation	Product innovation: Depending on the application the HPGR provides a novel fragmentation principle with the potential for significant energy savings. Process innovation: As the HPGR produces more fines compared to conventional crushing, their utilisation (in size ranges between crushing and grinding) requires structural changes in the process flowsheet.
Part of the value chain	Mineral processing
Member states covered	Germany (origin of the inventor and the initial equipment suppliers)
Year of implementation	1982 Patenting of the invention 1985 First implementation in the cement industry 1987 First implementation in the diamond industry 1995 First trials with hard rock comminution 2006 First installation in hard rock ore processing (Cerro Verde copper mine, Peru)
Example of good practice for	Resource security (less need for energy raw materials) Economic sustainability (reduced costs for energy) Environmental sustainability (less emissions from energy production and HPGR production)
Innovation success indicators	Reduced specific energy consumption Increased fines Number of installations
Drivers for the innovation	Energy efficiency and reduction of related GHG emissions Market competition
Barriers for this innovation	Technical barriers due to the problem of increased wear, solved by changed design and better materials IPR protection by the inventor and his initial industrial partners restricted the dissemination of the technology
Link to European and MS policies	Strategic Implementation Plan on Raw Materials (with respect to novel application areas for this technology)
Link to European and MS legislation	Energy taxation Emissions/emission rights, EU Emission Trading System (EU ETS) EU water directive Water recirculation directives (in later processing)
Transferability aspects	Technical solution: Further development was necessary in order to adapt the technology to other application areas Innovation process: Specific case of an inventor at university that starts from fundamental research and in the end provides a practical industrial method. That the IPR stays with an academic researcher is not common in all MS.

4.3.2 Case B: Jameson flotation cell

Table 9. Analysis sheet Jameson

Description	The Jameson cell has been developed to improve fine particle flotation by intensifying the froth flotation process (i.e. high turbulence and small bubble sizes for increased particle bubble collision rate). Opposite to conventional cells the air is entering the cell together with the pulp via a so-called down-comer where fine bubble generation and intensive mixing takes place. The innovation was initiated by an R&D project ordered by the mining company Mount Isa Mines from the inventor Jameson, a researcher at University of Newcastle. The development was further supported by the company through financing pilot-scale testing and the ordering of initially two full-scale cells. Areas of application comprise: • Concentration of metal bearing minerals • Coal cleaning • Waste water treatment
Type of innovation	Product innovation: A novel method for fine particle flotation that allows for process innovation in the design of beneficiation plants for different minerals.
Part of the value chain	Mineral processing
Member states covered	N/A – The invention originated from Australia (University of Newcastle), further developed and implemented by the Glencore group (now owning Mount Isa Mines).
Year of implementation	1986 Patent application 1988 First installation at Mount Isa lead–zinc concentrator 1989 first installation in a coal flotation plant Since then further optimisation (models 1994, 2000, 2009). Today the patent is owned and marketed worldwide by Glencore Technology.
Example of good practice for	Resource security (recovery of fines, feasible concentration of very fine grained ores, also solids removal in wastewater treatment) Economic sustainability (less losses of valuables)
Innovation success indicators	Increased recovery Number of installations (>330 worldwide in 2015)
Drivers for the innovation	Efficiency problems in the Mount Isa Mill production (Australia)
Barriers for this innovation	There seem not to be any barriers. The collaboration between inventor/university and company has been fruitful during implementation and further worldwide marketing.
Link to European and MS policies	N/A
Link to European and MS legislation	N/A
Transferability aspects	Technical solution: Given. Continued development for product

	improvement and new application areas Innovation process: N/A

4.3.3 Case C: Biotechnological extraction of secondary minerals from mine water

Table 10. Analysis sheet Bio-oxidation of iron in mine water

Description	Removal of iron from mine waters by a microbial process for the treatment of lignite mine water with high concentrations of sulphate and iron using naturally occurring microorganisms. As a result of the microbial oxidation process the mineral schwertmannite (an iron-oxyhydroxysulphate) precipitates as a solid compound. The schwertmannite can be used e.g. in ceramics production. Further sulphate is partly removed from the mine water together with the schwertmannite, which replaces lime in the further treatment of the acid mine water. Process development started with the identification and classification of suitable microorganisms in a collaboration of GEOS, a German-based engineering company, and the Technical University BA Freiberg. After initial tests with a smaller oxidation basin, a continuous pilot-scale test facility was designed. Testing and optimisation were conducted in a joint RD&I project together with the lignite mine owner Vattenfall, with funding from the German state during 2005-2007.
Type of innovation	Product innovation: Design of a water treatment plant Process innovation: Design of a microbial water treatment of acid and iron-bearing mine waters Marketed today as a service product
Part of the value chain	Bio-hydrometallurgy
Member states covered	Germany
Year of implementation	2005 Initial testing of reactor 2006 Start pilot testing of bio-oxidation 2006-2008 Test work on utilisation of schwertmannite
Example of good practice for	Resource security (recovery of dissolved iron as secondary minerals) Environmental sustainability (water treatment)
Innovation success indicators	Number of installations Iron and sulphate removal
Drivers for the innovation	Legislation on water resources Licence to operate (conflict areas: drinking water supply to Berlin and Frankfurt/Oder, aggressiveness towards concrete structures, impact on eco-system)
Barriers for this innovation	Capacity requirements

Link to European and MS policies	Water Framework Directive Industrial Emissions Directive
Link to European and MS legislation	German Federal Water Resources Act – WHG Regional Water Act (German Federal State Saxony) – LWG German Wastewater Levy Act – AbwAG German Waste Water Regulations – AbwV German Groundwater Ordinance – GrwV Council Directive 78/659/EEC (Fish directive) – German FischgewV Building permit pilot plants (several regulations) Operating licence pilot plants (several regulations)
Transferability aspects	Technical solution: Given. Selection of microorganisms, design and process control parameters need to be adapted to other similar cases. Innovation process: Example for how public funding in combination with effort by industrial partners can provide a solution

4.3.4 Case D: MIDREX RHF ("nugget") process

Table 11. Analysis sheet MIDREX RHF

Description	The process uses a coal-based direct reduction concept in combination with a rotary hearth furnace (RHF) and has been developed by Midrex Technologies Inc. and Kobe Steel Ltd. The feed to the RHF consists of agglomerates (pellets or briquettes) composed of iron oxides (primary ore or by-products) and a carbon source (coal, BF dust, charcoal or other). The agglomerates stay on the hearth furnace for one revolution. During this time the charge is heated to reduction temperature from above. The products are (i) direct reduced iron pellets or briquettes, (ii) hot metal or (iii) nuggets (as pig iron). Depending on the three cases different flowsheets are used (FASTMET, FASTMELT, ITmk3 processes). Due to reduced temperatures during reduction and full fuel utilisation the process is considered being more energy-efficient and environmentally friendly than conventional blast furnace ironmaking.
Type of innovation	Process innovation: Utilization of a known furnace technology in a novel process
Part of the value chain	Metallurgical processing
Member states covered	N/A – The invention originated from Japan
Year of implementation	1995 First FASTMELT plant in operation 2000 First FASTMET plant in operation 2010 First ITmk3 plant in operation
Example of good practice for	Resource security (reduced consumption of energy resources

	compared to blast furnace) Environmental sustainability (reduces CO_2 emissions, by products from iron and steelmaking as feed – in-plant recycling) Economic sustainability (energy costs)
Innovation success indicators	Number of installations Reduced energy demand and CO_2 emissions
Drivers for the innovation	Cost reduction (energy costs, capital costs) Replacing natural gas by coal as carbon source for reduction (for countries without access to natural gas) High flexibility
Barriers for this innovation	Supply and price of natural gas (effect of fracking today would have been a significant barrier)
Link to European and MS policies	N/A (otherwise in line with European commitments to reducing CO_2 emissions)
Link to European and MS legislation	N/A
Transferability aspects	Technical solution: Applicable to process low grade iron ore fines, pulverised coal as energy carrier and carbon source Innovation process: N/A

4.3.5 Case E: Sensor-based sorting (SBS)

Table 12. Analysis sheet SBS

Description	The innovation is the replication of the human hand-picking process by automatisation of the individual steps (i) detection, (ii) classification and (iii) ejection of particles. Initially developed for mainly sorting secondary materials from recycling, the sorting technology has nowadays been adapted to mineral processing applications: pre-concentration, final product upgrade, separation of feed into high/low grade. Areas of application comprise: • Secondary raw materials (recycling) • Industrial minerals • Precious minerals • Base metals • Diamonds • Coal
Type of innovation	Product innovation: Entire sensor-based sorting systems as well as various sensors (optical sensors, X-ray etc.) Process innovation: Replacement of other unit operations for enrichment, utilisation of SBS within pre-concentration flowsheets for coarse particle separation
Part of the value chain	Mineral processing and recycling
Member states covered	Germany (at least representing a large number of the initial SBS

	system market players)
Year of implementation	First mechanisation of hand-picking already in the 1920s Further developed to "automated hand-picking" (in size ranges of ca 10-300 mm) during the 1990s when fast computing power and high resolution cameras became available. From the early 2000s applications in the mineral industry connected to the development of new sensor systems.
Example of good practice for	Resource security (related to primary and secondary raw materials) Environmental sustainability (waste reduction, recycling, reduced energy for grinding and reduced water for wet processing when applied within pre-concentration)
Innovation success indicators	Number of installations Number of different applications
Drivers for the innovation	Demand for automated picking of coarser particles/objects Demand for dry processing Reduction of throughput in downstream units due to efficient removal of waste at particle coarser sizes (also causing reduced water and energy consumption)
Barriers for this innovation	Technical barriers as availability of sensors for certain mineral systems, limitations with respect particle range (effect on capacity), rough environment
Link to European and MS policies	Strategic Implementation Plan on Raw Materials (with respect to novel application areas in mineral beneficiation) EU Action Plan for the Circular Economy
Link to European and MS legislation	Different waste directives: Waste Framework Directive, WEEE Directive Legislation referring to water utilisation and mine waste
Transferability aspects	Technical solution: Given, technology has been transferred to different countries and different application areas. Innovation process: Innovation fell in a period where European societies started striving for waste treatment and recycling. This was reflected by launching policies and legislation on European and national level

4.3.6 Case F: Geometallurgical programmes

Table 13. Analysis sheet GeoMet

Description	Geological information of the ore is combined with mineral processing properties in one spatial deposit model and subsequently used as the input to the numerical process model that describes the mineral processing flowsheet. Such an integrated and multi-disciplinary approach requires resource characterisation by process mineralogy, particle-based modelling and simulation as well as an economic evaluation.

Type of innovation	Process innovation: Flowsheets are designed and optimised with respect to process structure, unit operations and the selection of process design and control parameters System innovation: Optimization along the value chain with respect to variations of the ore body
Part of the value chain	From mine to mill
Member states covered	All MS with active mining
Year of implementation	While individual concepts have been known for long the integrated geometallurgy approach as known today became established during the early 2000s. In the beginning development was dominated by Australian, South African and North American researcher groups. Since 2010 also European institutions are part of that. Since then several concepts and methods have been developed and are partly established as services (consulting companies) or as implemented in the business processes of mining companies and mine project developers
Example of good practice for	Resource security (increased recovery, enhanced energy utilisation) Economic sustainability (optimisation of net present value for production chain) Environmental sustainability (input to EIA Environmental impact analysis, EMP Environmental management plan)
Innovation success indicators	Number of process implementations Increase in NPV
Drivers for the innovation	Need for improved resource efficiency Consideration of ore variability Need for improved communication between the different departments in a mining company (breaking silos)
Barriers for this innovation	Silo mentality Cost for implementation
Link to European and MS policies	Strategic Implementation Plan on Raw Materials National mineral strategies
Link to European and MS legislation	Permitting legislation Environmental Impact Assessment Directives Mining waste related directives
Transferability aspects	Technical solution: Given, generic approach that responds to the requirements formulated in different MS Innovation process: Parallel development in several countries / continents

4.3.7 Additional cases (3rd Policy Laboratory on Processing)

The following tables refer to recent innovation cases that were discussed during the Policy Laboratory on Innovation and Supporting Policies for Mineral and Metallurgical Processing, compare MIN-GUIDE 3rd Policy Laboratory report.

Table 14. Outotec's OreMet Optimizer

Description	A software innovation that uses the company's process simulator as the backbone for conducting geometallurgical studies. The product allows optimization of the processing routes for variations of the ore properties, leading to improved resource efficiency and increased operating profit. It can also be a valuable tool in environmental impact assessment.
Non Policy Factors	a) Intention to guide company decision-making for long term mining project development b) Data availability for input into the ore assessment • In-house • External/confidential
Transferability Aspects	a) Proof of compatibility in different context, country specific environmental legislation b) Guidance to data access/availability needed • Manual for use/ what the calculation should include • Broad acceptance standards • Standards for lab test work, up-scaling
Supporting Policies	a) Requirements of environmental impact assessment legislation b) Legislation that regulates/defines use of standards, transparency, objectivity
Transferability Aspects	a) Authorities need to accept modeling tools based on experimental data • Trusted methodology b) Standard/guidance needed for reporting, analysis and process calculation • Integration into the legislation • Metallurgical laboratory • Exploration data, quality • Role of competent/qualified person

Table 15. Sandvik's Eco-Efficiency in Comminution framework

Description	An integrated approach to equipment design, material selection, process control, etc., in order to improve crusher circuit performance.
Non Policy Factors	a) Competition in the market leads to innovation b) Talented humans with the ambition to provide smart products ("Thinking better")
Transferability Aspects	a) Easily transferrable

	b) Easily transferrable
Supporting Policies	a) RDI and infrastructure for research in joint ventures industry / academia • Today less than 1% • Evaluation by independent external experts • Fiscal stimulus b) Environmental policies and legislation (reduced emissions)
Transferability Aspects	a) Yes, possible by • Partnership with others • International/national research programmes • Centres of excellence b) Yes

Table 16. NOx reduction in LKAB's pellet production plant KK4

Description	Solution for reduction of NOx emissions in iron ore pellet production adopted and adjusted from another process industry to fit pelletizing at the KK4 pelletising plant in Kiruna
Non Policy Factors	a) Platform of exchange to build trust (engineering, technical, political, local interest groups) b) Business case a driver for LKAB
Transferability Aspects	a) National strategic policy, company(ies) one-stop-shop b) Authorities to "allow" a development phase to figure out what is technically possible and feasible to achieve
Supporting Policies	a) National emission ceiling directive (NEC) b) National legislation (limiting NOx emissions)
Transferability Aspects	a) Harmonized implementation across EU b) Global competitiveness & playing field

Table 17. A novel process for treating e-waste at Boliden AB

Description	A novel solution at the Rönnskär copper-smelter for treating E-waste by metallurgical processing where iron sand is received as a by-product. Iron sand has been "re-classified" as waste rather than by-product, which implied a completely new set of legislations that apply.
Non Policy Factors	a) Definition & interpretation of risk (risk reduction) b) Knowledge asymmetries (as inhibiting factor) c) Business case: Technical feasibility vs. economic possibilities d) Process iron from iron sand or remove impurities
Transferability Aspects	a) Competitors for e.g. students and architects (to get new ideas for new products from waste materials) b) Work with completely new types of companies to find novel applications for iron sand (one idea was table-tops)
Supporting Policies	a) Wish for harmonized EU legislation for waste/by-products b) Financing/government funding for development phase (re.

	iron sand applications) c) Better coordination of multiple levels of government
Transferability Aspects	a) Clearer rules & more transparent standards in non-ferrous industries b) Deployment policies for effective scale-up (EU-level) c) Involve authorities in continuous discussions

Table 18. Innovation in tailings handling, Wardell Armstrong International

Description	Paste-making and backfilling as a case on innovative tailings handling for the mining industry.
Non Policy Factors	a) Public aspects (high social acceptance for backfilling) b) Sustainability (mine and resource recovery)
Transferability Aspects	a) Easily transferrable – possibly seen as beneficial – reduce subsidence in built-up areas b) Possibility of storing waste from other sources, no national boundaries c) Maximise resource recovery d) Potential for processed reject to be used as a resource (now or later)
Supporting Policies	a) MWEI Policy (Management of Waste in the Extractive Industries Directive) b) Equator Principles (better access to funding)
Transferability Aspects	a) Yes, but intrinsic difficulties in "translating" policies b) Lack of transparency – also an obstacle to innovation c) Yes, in principle but not easy due to conservative attitude of industry d) Company policies more easily implemented trans-nationally

Table 19. Sensing and robotic sorting of end of life products at Stena Metall

Description	An integrated machine vision-based system for sensing and robotic sorting of end of life electronic products
Non Policy Factors	a) Had the right partners in the value chain (magnet producer) b) Demand for specific waste fraction (hard drive magnets) c) Wanted to ensure/explore long term security of supply d) Private owner – opportunity for strategic decision making, financial resources, ability to focus longer term
Transferability Aspects	a) Demand can be created by other means, (e.g. landfill taxes, incentives, …) b) Create long-term demand c) World-accepted index for price/quality such as introduction on LME (London Metal Exchange) d) Key stakeholders: private + public e) One needs to find the appropriate/ strongest lever for your context

Supporting Policies	a)	CO2 footprint reductions and supporting instruments encouraging move from fossil fuels, energy efficiency
	b)	FP7 – for the partners collaboration (across borders and markets)
	c)	(few producers/manufacturers in SE)
	d)	Raw Material Initiative (could there be an end material initiative?)
Transferability Aspects	a)	These factors are probably all fully transferrable, but need to consider scope for extending more broadly around the world (e.g. including engagement, collaboration with Chinese, industry, etc.)
	b)	Need to break down silos, harmonise objectives and support rather than to complicate

5 Conclusions

The study indicates that both policy-related and non-policy factors have an influence on innovation in the mineral and metallurgical processing sectors. The evaluation of these factors is, however, in some cases not straight forward, i.e. there might be factors that can be both, catalysing and inhibiting depending on the case. Also, some factors can act as drivers in one part of the value chain, while being barrier in another, and vice versa.

From the conducted studies and the several interviews (including the results from the MIN-GUIDE Policy Laboratory 3) the following conclusions can be drawn with respect to innovation drivers and barriers related to mineral and metallurgical processing:

Table 20. Innovation drivers and barriers (unranked) related to mineral and metallurgical processing

Innovation drivers	• Productivity increase: increasing throughput, decrease losses • Cutting production costs • Competition (in particular for service and equipment providers to the process industry) • Trend towards deposits with lower ore grades and more complicated mineralogy • Energy efficiency and reduction of related greenhouse gases • Efficient use of process water (reduction of water consumption, dry processing options) • Reduction of emissions (to air, water, soil) and waste (tailings, slags) from processing • Receiving the “licence to operate” (with respect to environmentally sound and socially accepted technical solutions) • Changes in legislation (e.g. related to changed definition of certain processing waste) • Policy framework, e.g. mineral strategies and implementation

	plans leading to financial support for related RD&I by public funding • New developments in mining production that impact downstream processing • Strong partnerships between processing companies and innovators (equipment suppliers, individual researchers/inventors)
Innovation barriers	• Conservative sector, usually low willingness to take risks (related to the processing companies but also to investors/financiers of new mining projects); this in particular holds for periods of low prices, decreased raw material demand and or oversupply • High capital investment for production plants combined with long plant life spans • Long innovation times versus shorter planning periods in the companies' innovation strategies (often due to changes in the management) • Negative social perception towards some types of innovations, e.g. chemical leaching • Non-predictable development of legal systems and lack of transparency • Tedious permitting routines, involving different legislation and several authorities • Need for stepwise upscaling of new technology from lab scale via pilot testing to full scale • Availability of skilled and experienced personnel (effects from "retirement tsunami" but also layoffs during economic downturn periods and difficulties in attracting young persons to the sector) • Silo mentality in companies

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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
IEEE	Institute of Electrical and Electronics Engineers

IPR	Intellectual Property Rights
LKAB	Luossavaara-Kiirunavaara Aktiebolag (Swedish mining company)
MS	Member State
NPV	Net present value
PFE	Programme for energy effectivisation in energy intensive industry
PGE	Platinum Group Elements
R&D	Research and Development
RDI	Researcher Development Initiatives
RMI	Raw Materials Initiative
RE	Rare Earth
REE	Rare Earth Elements
RoHS	Restriction of Hazardous Substances (EU Directive)
SBS	Sensor Based Sorting
SIP	Strategic Implementation Plan
SME	Small and Medium sized Enterprises
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