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International Raw Materials Observatory

Fostering international raw materials cooperation

Analysis of Research and Innovation

Operational report

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Abstract

This report contains the operational analysis of research and innovation for the five reference countries of INTRAW (the U.S., Canada, South Africa, Australia and Japan). It describes and compares the different innovation systems, comprising – among others - the main role players, institutions and policies that drive research and innovation in the raw materials sector.

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1. Executive summary

The aim of this report is to describe and evaluate the INTRAW reference regions, namely Australia, South Africa, Canada, the United States (U.S.) and Japan with respect to their research & innovation (R&I) activities.

The report applies the concept of 'Innovation Systems' for its investigation. This concept stresses the fact that innovation is not only the result of new knowledge creation, but rather of knowledge being 'used' in a variety of ways and by different actors. It puts emphasis on the quality and depths of interactions and the efficiency of knowledge creation and knowledge diffusion among the relevant organizations. Among these actors one will find companies of various types and sizes that interact with their customers and suppliers in the raw materials supply chain, organisations for research and education (e.g. universities, research centres) and various kinds of intermediate organisations (funding agencies etc.). All of them act in an environment that is shaped by the national innovation policy and the regulations that affect research and innovation.

After defining some basic terms (research & innovation, innovation measurement) and describing innovation in the mining industry, each reference country's research and innovation performance is described and measured in qualitative and quantitative terms in a separate chapter. Eventually, all the countries are compared against each other. It is worth mentioning that there is no such thing as an ideal innovation system. It is helpful, though, to compare them and to initiate reflection why some systems work better (or worse) than others (Edquist, 2001).

The main findings can be summarised as follows:

- R&I in mining is a complex subject, because there are drivers that push R&I in mining, while others are barriers to R&I and stakeholder interests often diverge. From a government perspective, for instance, increased R&I could drive higher levels of automation, which would increase productivity and raise the competitiveness of the mining industry in times of low mineral prices. Increased levels of automation, however, could also reduce the required manpower to run a mine, leading to more unemployment. Given the characteristics of mining (long cycle times, high investments), developing or adopting something 'new' is very expensive and risky for mining companies, which is why mining can be considered a rather conservative business in terms of R&I.
- R&I in mining takes place, but it happens in a complex interplay of different organisations (miners, suppliers, service providers, research organisations, government bodies) and it has proved difficult to identify clear patterns of R&I. Recent studies suggest, for instance, that bigger mining companies have a more structured approach to research & development than smaller miners. They have the resources to pool innovation efforts, to build innovation centers and to make use of the results on a global scale.
- From the perspective of the INTRAW reference regions, there are significant differences in the innovation systems, which firstly depend on the countries' individual challenges related to mining. Japan stands out as the country with virtually no domestic metals production. Yet it has found a unique and successful strategy, which is strongly driven by the government, to secure access to mineral resources and to maintain a highly productive knowledge base that drives R&I. Conversely, we find that that there are countries with significant mineral endowments - and even very similar starting points in history, i.e. U.S. and Canada - that have developed different approaches to support R&I in mining.

- Globally speaking, we see that countries that have a strong manufacturing industry try to limit the impact of potential supply shortages (esp. Japan, U.S.). These countries have defined policies on how to avoid shortages (e.g. through funding international mineral exploration) and they have defined R&D policies that are supposed to reduce dependencies on materials (especially Rare Earths) in the long-run (e.g. through recycling, substitution of critical materials).
- Australia's situation is somewhat similar to Canada's, as both countries seek to maintain investment in the mining industry, while promoting sustainable development practices in mining. Both are vast countries, in which the federal states (or provinces/territories) play a strong role. They often operate mines in remote locations and have developed a capable mining equipment, technology and service sector. Both countries need to prepare for a number of challenges (lowering production costs, lack of skilled workers, decreasing ore grade, to name a few), which force them to re-think the current mining policies and, among others, to reinforce research and innovation.
- The United States is a country with significant minerals endowments and a strong processing industry, however, the relative share of the mining industry is smaller than in Canada, Australia and South Africa. With the exception of the DOE's policies to secure the provision of critical and strategic materials, the U.S. pursues a less explicit raw materials strategy. The major agencies involved in minerals and materials (DOI, DOE, DOD) sponsor R&D projects, but there are no comprehensive research & innovation programs especially designed for the mining sectors. Much of the R&I in minerals is driven by industry.
- South Africa represents a resource-abundant country, but has a very different historical background impacting R&I. Its main objective is to reduce unemployment, inequality and poverty through developing the minerals value chain, especially by having more minerals processed before they are exported. During its long history of mining, the country has developed a competitive level of know-how and a remarkable industry of suppliers of mining equipment and services. Innovation-wise, though, the country has seemingly come to a standstill. There is little industry engagement with research and a significant decline of personnel and (publicly funded) mining research programs.

2. Purpose and content of this document

The report is based mainly on desktop research utilising existing research publications and policy reports, as well as economic, science and technology data that is publicly available or that was made available to the authors by the respective partners in the reference regions.

After the introductory notes in chapter 1 and 2, chapter 3 describes the technical terms and relevant frameworks to describe and evaluate R&I. Chapter 4 is dedicated to the description of the mining value chain, chapter 5 outlines the methodology used in this report to describe R&I.

The chapters 6 to 10 are devoted to the operational analysis of the innovation systems found in each reference countries. This chapter considers especially the following indicators / dimensions to describe R&I performance.

Chapter 11 contains a comparative evaluation of the R&I performance of each country.

Chapter 12 provides references to the sources used in this report.

3. Methods to measure research and innovation

3.1 Definitions of research & innovation

Research and innovation (R&I) activities have become a substantial pillar in the attempt to explain the competitiveness of firms, industries and economies. Historically, technological progress happened more or less in a random manner as it was regarded mainly as the result of geniuses such as Thomas Edison or James Watt, who invented ground-breaking new products that led to a substantial increase of productivity and output in manufacturing. Research was not always a predecessor to an invention (for instance, much of the progress in aerodynamics came after the Wright brothers successfully built their first 'flying machine'), but the accumulation of knowledge, especially in physics and chemistry, led to more systematic attempts to create new knowledge, new technologies and new products. In the first half of the 20th century, big research projects driven by the state, firms and science resulted in many more important innovations (explosives, rockets, computers), however, it was only until the 1950's and 1960's that corporate research and development (R&D) as we know it today, was established.

In the past 50 years, there has been a growing interest in the economics of innovation and technical change. It is now widely accepted that research, science and technology are vital to ensure national competitiveness. Governments across the globe are searching for ways to encourage investments in science and technology as they are expected to have a positive impact on a country's economy. To elaborate on the nature of R&I in the raw materials industry, we firstly define the key terms and the main approaches to measure R&I performance on various levels (e.g. industry-level, company-level), before diving deeper into the specifics of R&I in mining.

Research, Development and Innovation

The terms 'research' and 'development' can be explained by the 'linear model of innovation'. This model postulates that technological change is dependent upon, and generated by, prior scientific research (Mahdjoubi, 1997), new ideas are developed in academic and other research institutions, after which they may be passed on to companies (e.g. through publications and patents) and eventually embedded in new products and services (***Figure 1***).

Figure 1: Linear Model of Innovation.

Basic research → Applied research → Development → Production and Diffusion

The stages in the linear model of innovation are defined as follows (OECD, 2015):

- Technological innovation starts with **basic research**, which has little or no regard for commercial applications. This kind of work is usually attributed to universities and other academic institutions. According to the Organisation for Economic Co-operation and Development (OECD) Frascati definition, basic research comprises *"[…] experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view."*
- This knowledge is then transformed in a phase of **applied research** to answer specific questions that have direct applications to the world. Applied research *"[…] is also original*

investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective."

- The outcome of this phase will then be used in the **development** of a product or service, usually by companies. Often a series of prototypes is needed to develop a product until it is mature enough to be ready for production. Development is described as "*[…] systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed […]*".
- Eventually, products and services will be **produced and diffused** on their respective markets.

It is important to note that innovation is more than an invention. **Inventions** can be defined as "*… an idea, a sketch of a model for a new improved device, product process or system*" (Freeman, 1974). However, inventions do not have an impact on technological change as long as they are not commercialised and adopted on a wider scale. Thus, an innovation describes a profitable invention, an invention that is capable of being adopted by a firm, by helping to maximize its profits (Oliverira, 2014). According to the OECD and EUROSTAT's definition, innovation is defined as

- "*[…] the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations.*" (OECD, 2015)

3.2 Innovation measurement approaches

3.2.1 Quantitative measurement approaches

The Frascati and the Oslo Manual

The first attempt to collect data on innovation was made in the 1962, with the OECDs Frascati Manual[1] written by and for the experts in OECD member countries. At that time, the comparison of R&D performance was almost impossible as a shared model of analysis did not exist and precise terms of reference (What is research? What is development?) did not exist.

The Frascati Manual was the first to provide a basic definition and conventions on how to measure R&D-related indicators to produce statistics with a high validity. It is, as the name suggests, a manual, so it can be adapted to fit the needs of the respective country or region. There is an active community of experts developing the manual further to include the latest developments, e.g. to capture the role of venture capital in R&D or the use of novel software. The most recent (the 7th) edition was published in October 2015.

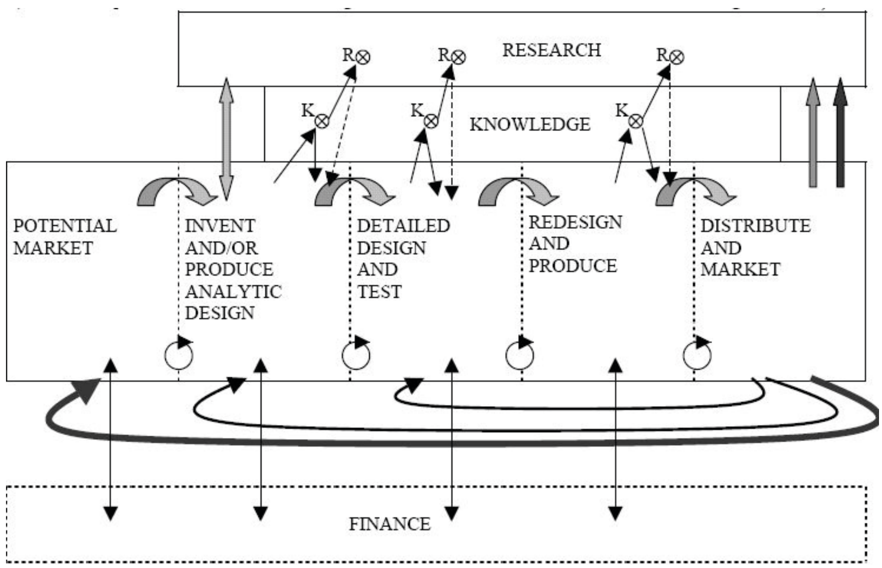
Over the years, the number of indicators has grown and the views on R&D and innovation evolved as well. A presumption of the Linear Model of Innovation, which the Frascati Manual is based on, was that if firms do not undertake R&D, they cannot generate the necessary knowledge for innovation and thus face higher barriers to the development of new products or production methods. However, this was – to some extent – contradicted by statistical data (Som & Kirner, 2015). The dissatisfaction with R&D indicators eventually led to the creation of the Oslo Manual in 1992, which proposed harmonized guidelines to collect and interpret innovation-related measures. The Linear Model of Innovation was abandoned in favor of the Chain-Linked Model of Innovation (Kline & Rosenberg, 1986) (***Figure 2***).

This model emphasized the socio-technical nature of technology and the necessity to look at innovation as a complex system. The first key difference is that, at the firm level, the innovation process starts with a market finding phase, followed by design, production, marketing, distribution and use. All of these activities are additional determinants of innovation success (not only R&D). Research is not necessarily the initiating step; companies can also be innovative by making use of new combinations of components

1 http://www.oecd.org/sti/inno/frascati-manual.htm

and practices in the existing stock of knowledge. The second difference is that a firm's innovation processes are usually linked to the scientific and technological knowledge that surrounds the firm. Firms usually don't innovate in complete isolation. The access to external knowledge (e.g. via universities, suppliers, consumers) and the embeddedness in a system of innovation becomes another important determinant for innovation success. While the Oslo Manual doesn't strictly adhere to the chain-link model of innovation, it acknowledges that this model has been influential and that measuring innovation performance requires the consideration of multiple dimensions and perspectives.

Figure 2: Chain Link Model of Innovation.



Source: Kline & Rosenberg, 1986

Application of the Oslo Manual - the Community Innovation Survey (CIS):

The Community Innovation Survey (CIS) is a harmonized effort of the European Commission to measure innovation activities in enterprises. The first edition of the survey was run in 1992, now it is done every second year. The CIS is used by all EU member states and some candidate/associate countries, however compiling CIS data is voluntary, which means that in different survey years, different countries are involved.

The purpose of the CIS is to provide information on the innovativeness of sectors by type of enterprises, on the different types of innovation and on various aspects of the development of an innovation, such as the objectives, the sources of information, the public funding, the innovation expenditures etc. The survey is harmonized to be able to compare data in longitudinal analysis, but it includes some ad-hoc modules to measure specific aspects of innovation. Descriptive survey results and aggregate data are available through EUROSTAT, the statistical office of the European Union. More detailed data is available upon request from the national statistical offices.

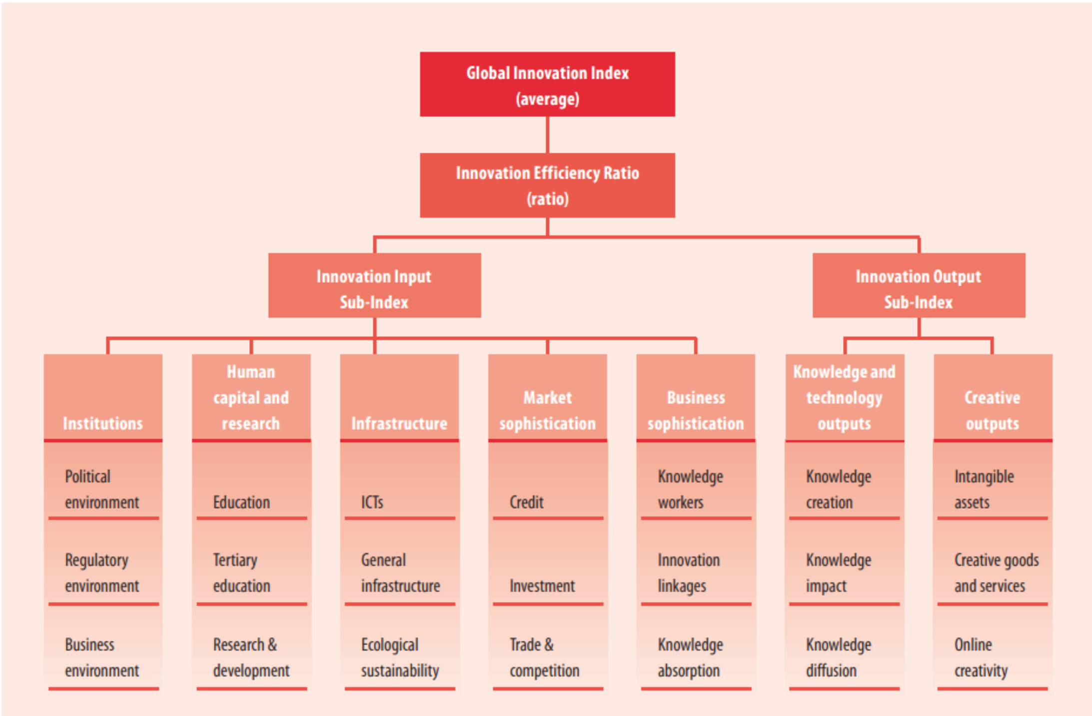
Innovation Scoreboards

Innovation Scoreboards are attempts to summarize innovation indicators in order to compare the innovation performance of countries, regions and sectors. Probably the three most well-known scoreboards are the Global Innovation Index (world-wide coverage), the European Innovation Scoreboard (European countries) and the OECD's Science, Technology and Industry Scoreboard (world-wide coverage). To give an idea about the approach and the indicators used, we provide a short description of each Scoreboard.

- **Global Innovation Index**[2]: The Global Innovation Index (GII) ranks the world's economies in terms of innovation capabilities and results. The latest (2015) report is the 8th edition, jointly published by Cornell University, INSEAD and the World Intellectual Property Organization (WIPO, an agency of the United Nations). It covers the largest number of countries (141), which represent 95.1% of the world's population and 98.6% of global GDP. The GII ranking is based on a hierarchy of two sub-indexes (innovation input and innovation output), which are in turn, split into seven pillars and 21-subpillars, containing a total of 84 innovation indicators (***Figure 3***).

2 https://www.globalinnovationindex.org/content/page/GII-Home

Figure 3: Structure of Global Innovation Index.



Source: GII, 2015, p. 9

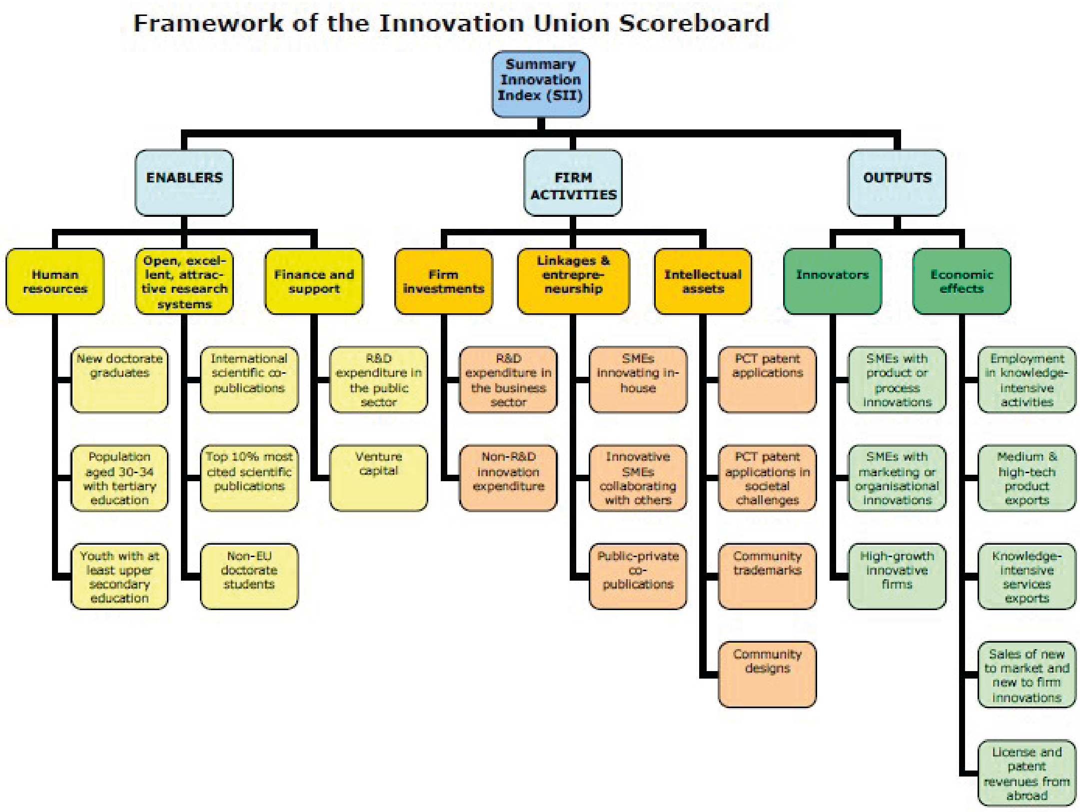
- **European Innovation Scoreboard**[3]: The main purpose of the European Innovation Scoreboard (EIS) is to benchmark the innovative capabilities of member states and to provide indicators that complement on-going policy developments within the European Commission. The latest edition was published in 2015. The scoreboards help countries and regions identify the areas they need to address. The EIS has produces a single composite index that summarizes indicators across 3 main categories of innovation (enablers, firm activities and outputs), 8 innovation dimensions and 25 innovation indicators (***Figure 4***).
- **OECD Science, Technology and Industry Scoreboard**[4]: The OECD Science, Technology and Industry (STI) Scoreboard is published on a biennial basis. The most recent STI report includes roughly 180 indicators (with about 35 related to innovation), which are summarised in five thematic chapters: a) Investing in knowledge, talent and skills, b) connecting to knowledge, c) unlocking innovation in firms d) competing in the global economy and e) empowering society with science and technology. Most of

3 http://ec.europa.eu/growth/industry/innovation/facts-figures/scoreboards/index_en.htm

4 http://www.oecd.org/sti/scoreboard.htm

the innovation-related indicators are found in the chapters 'Connecting to knowledge' and 'Unlocking innovation in firms' (Hollanders & Janz, 2013). In contrast to other Innovation Scoreboards, the STI report doesn't rank or benchmark countries using composite indicators.

Figure 4: Structure of EIS.



Source: European Commission, 2015

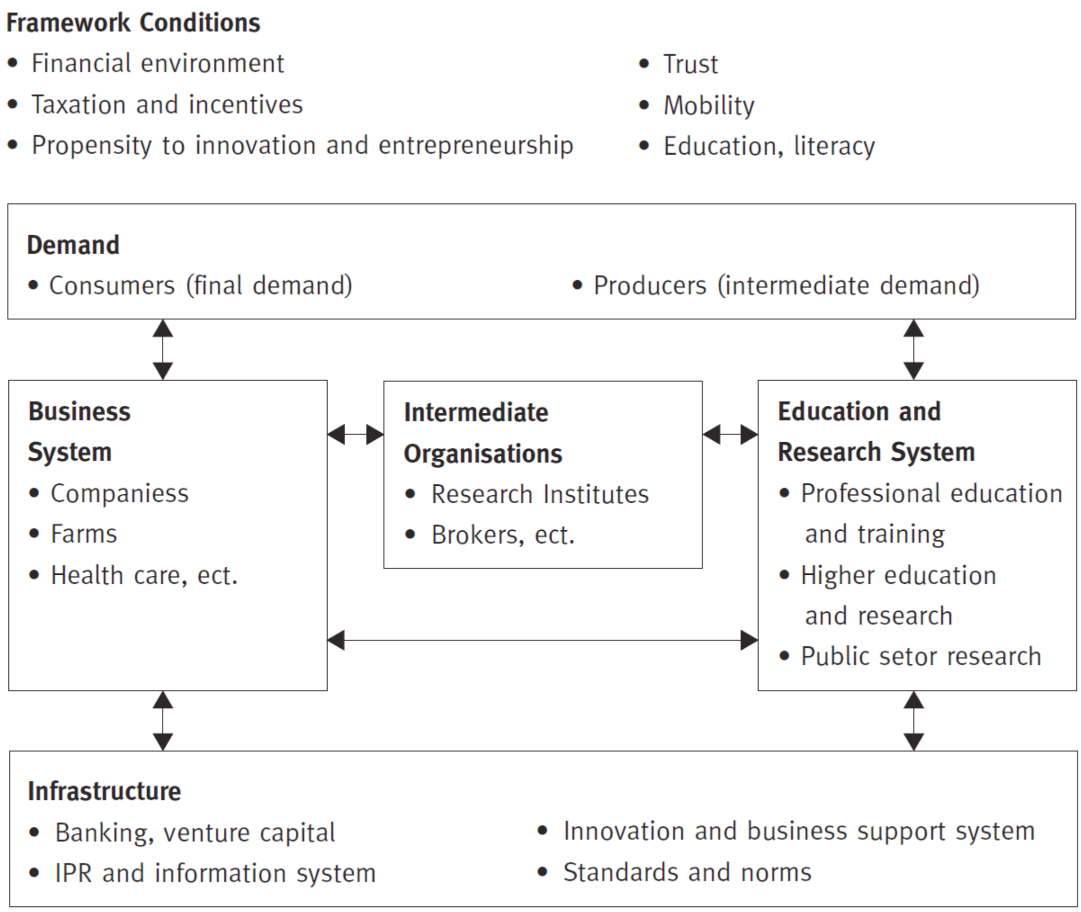
3.2.2 Qualitative descriptions of Innovation Systems

Apart from the work that has been done to capture innovation via adequate metrics, a fairly big amount of research has been dedicated to the explanation of the role of external factors that determine the degree of innovation on a firm level. The Chain-Link-Model put forward the idea that innovation is not only the result of new knowledge creation, but rather of knowledge being 'used' in a variety of ways and by different actors. As a consequence, the idea of 'innovation systems' has emerged, putting more emphasis on the quality and depths of interactions within the system and the efficiency of knowledge creation and knowledge diffusion among the relevant organizations (Freeman, 1994) (Nelson, 1993). The diffusion of knowledge can happen in a variety of ways (David & Foray, 1995), e.g.

- Distribution between universities, research institutes and firms
- Distribution within a market or along the value chain
- Re-use and combination of knowledge
- Distribution between dispersed R&D projects
- Dual technological developments between industry and government.

To describe and evaluate the complex phenomenon 'innovation' Arnold and Bell (2001) suggest to identify the main building blocks of an innovation system and to understand how the system works as a whole. Their view on a national innovation system, which explains a country's overall innovation performance, includes six main elements that collectively constitute a national system (***Figure 5***).

Figure 5: Major Components of a National Innovation System.



Source: Arnold & Bell, 2001

They stress, however, it is not just the actors in the 'boxes', but the arrows that determine the performance of an innovation system. The key elements include:

- **The Business System**: This subsystem is of particular importance, as in most countries, the great majority of R&D is financed and performed within the business sector. Firms interact with their customers and suppliers in a supply chain.
- **Demand:** the sophistication of consumers' and companies' demand has a strong impact on the need to innovate to meet those demands. Also, the government itself is in many cases an important customer for research (e.g. think of the research for defense purposes in the U.S.).
- **Education and Research:** Whereas standards in the Business System are set by competition, standards in education and research are set by science. There is a certain consensus that a basic science component is important in advanced industrial economies.
- **Intermediate Organizations:** 'Intermediate institutions' such as applied research institutes and research associations are frequently under-estimated as they have a lower status and are less visible than universities. These institutions, which usually depend on a mixture of core state funding and contract work for firms, provide important R&D and technical support activities, too.
- **Framework conditions and Infrastructure:** Obviously there are other factors that play a role in fostering or hampering innovation, such as fiscal and taxation policies, levels of trust (and the absence of corruption), levels of education and literacy, national propensity to entrepreneurship, availability of venture capital etc.

The concept of National Innovation Systems (NIS) has also been adopted by the OECD (OECD, 1997) for their country reports on innovativeness. The fact that NIS describe rather the qualitative nature of innovation systems doesn't mean that it is not possible to describe a NIS with the aid of indicators. For instance, the interaction of industry with universities can be investigated by analysing patent databases or publication databases for co-publications (***Figure 6***).

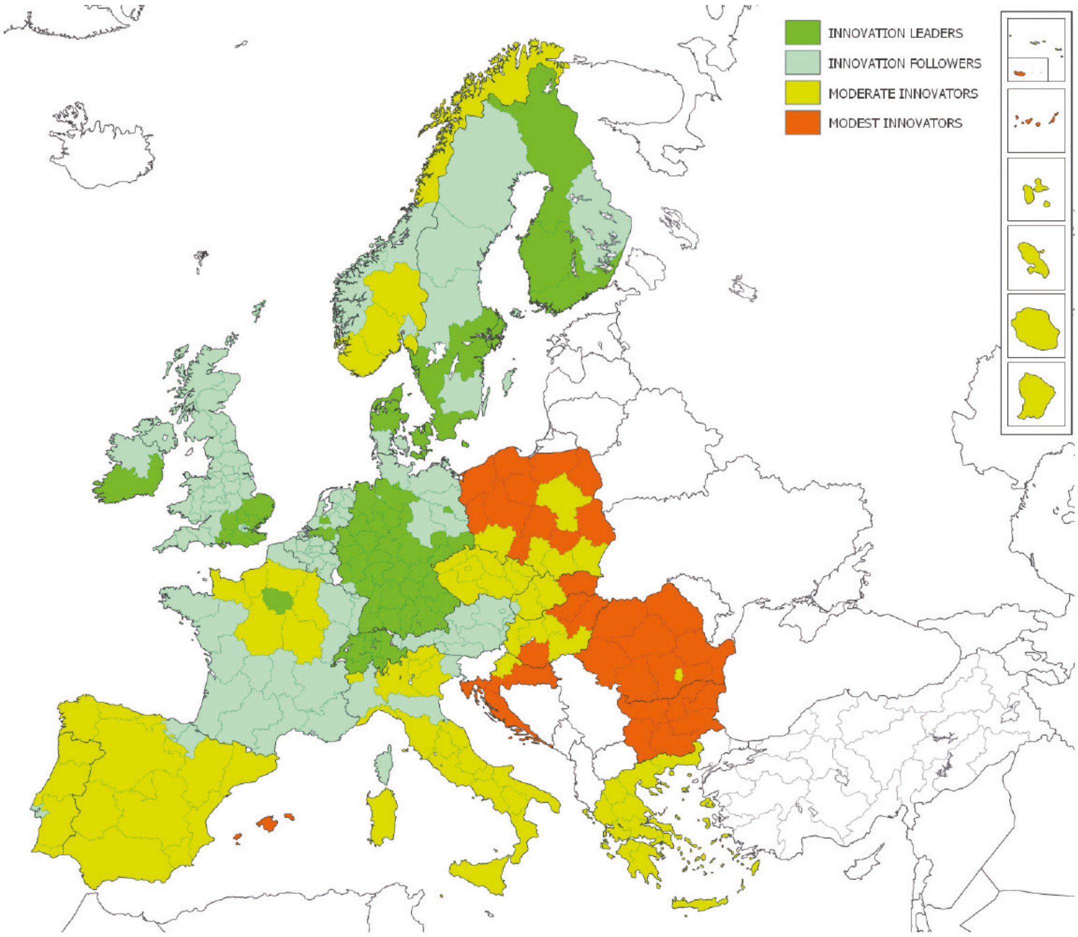
Figure 6: Core knowledge flows in national innovation systems.

Type of knowledge flow	Main indicator
Industry alliances	
Inter-firm research co-operation	Firm surveys Literature-based counting
Industry/university interactions	
Co-operative industry/University R&D Industry/University co-patents Industry/University co-publications Industry use of university patents Industry/University information-sharing	University annual reports Patent record analysis Publications analysis Citation analysis Firm surveys
Industry/research institute interactions	
Co-operative industry/Institute R&D Industry/Institute co-patents Industry/Institute co-publications Industry use of research institute patents Industry/Institute information-sharing	Government reports Patent record analysis Publications analysis Citation analysis Firm surveys
Technology diffusion	
Technology use by industry Embodied technology diffusion	Firm surveys Input-output analysis
Personnel mobility	
Movement of technical personnel among industry, universities and research	Labour market statistics University/Institute reports

Source: OECD, 1997

While the national level is relevant due to the role of country-specific interactions in creating a climate for innovation, it is not sufficient to explain innovation success in every respect. Other authors claim that innovation is more likely to happen within geographical concentration and proximity (often regions) as the result of the interplay of specialized resources, skills, institutions and the share of common social and cultural values, as found, for example, in the Silicon Valley. Thus, 'regional systems of innovation' have also been the subject of research and policy-making. The European Union, for instance, regularly reports on the performance of 190 regions in its Regional Innovation Scoreboard and classifies them into four innovation performance groups (***Figure 7***).

Figure 7: Regional Innovation Performance Groups.



Source: European Commission, 2014, p. 4

The latest development has been to look at the properties of sectors as sources of innovation. This seems to be a valid point of view since national boundaries seem to play a less important role. International technology flows and collaborations frequently transcend national boundaries and depend much less on national and local conditions. In addition, national institutions (e.g. regulations such as property rights) can affect sectors differently. They may be advantageous for one sector, but hampering for another. Malerba (Malerba, 2005) argues that since knowledge and technologies are often available from anywhere in the world, new patterns of interactions between the players in a sector arise. This implies that policy-makers would require a good understanding of a sector before thinking about the right policy interventions.

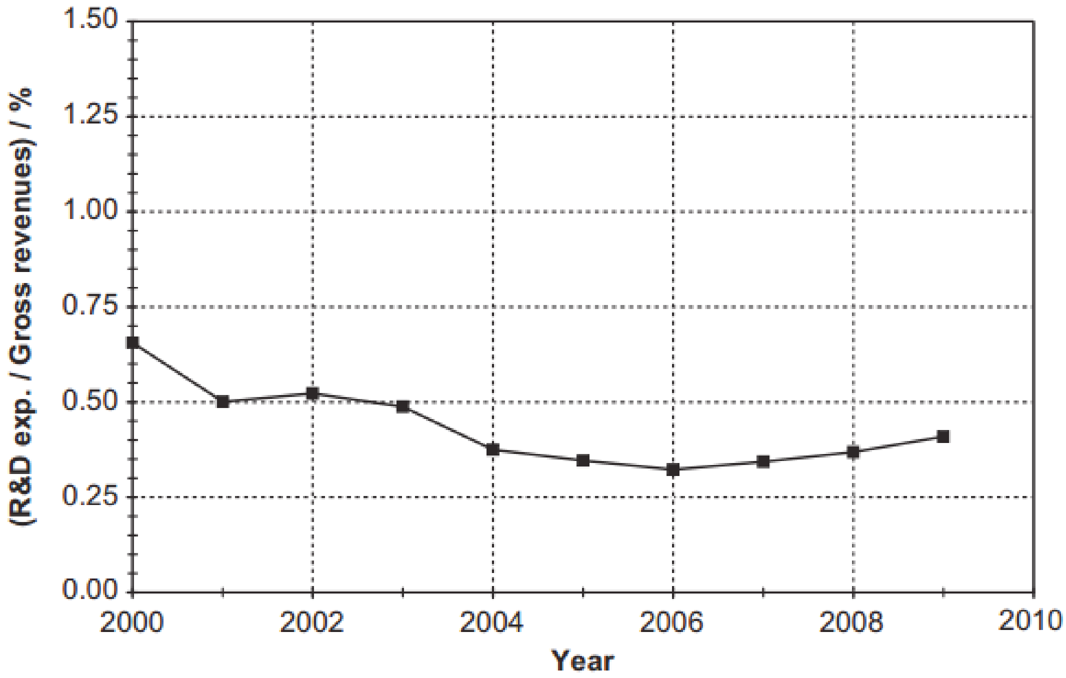
3.3 Research and innovation in mining: overview of the state of practice

3.3.1 Technology development in the mining context[5]

To understand the role of research and innovation in mining, one has to understand the nature of mining and the technical requirements that go along with it. First of all, mining is one of the oldest industries; the earliest known mines are several thousand years old. Due to its nature, mining has always relied on the use of technology and there has been a permanent search for technologies that improve productivity, safety and health in mining. However, compared to other industries, R&D spending in mining and metals companies has always been relatively low. Only few mining and metal companies spent more than 0.5% of their revenues on R&D (***Figure 8***), which is well below the average investment rate found in other industries.

5 Please note that the following section on R&I focuses primarily on data from companies (and less government/university funded work) to emphasize the specific characeristics of R&I mining industry. The intensity of government/university interaction with industry is also subject of the INTRAW report on education and outreach.

Figure 8: Consolidated R&D intensity of twelve mining and metals companies (Alcoa, Anglo American, Arcelor/Mittal, BHP Billiton, Boliden, Cameco, Codelco, Eramet, Iluka, Rio Tinto, Sumitomo Metal Mining and Teck).



Source: Filippou & King, 2011

Arguably, these numbers may not reflect the total research effort. Upstill and Hall (2006) argue that

- indirect non-R&D expenditures such as design and engineering activities, plant experimentation are mostly ignored in R&D statistics,
- mineral producers rely heavily on equipment manufacturers and engineering firms for new technology, and that
- mineral producers are often big corporations with several affiliates and subsidiaries. R&D expenditures may occur in different sites and may never be included in the consolidated financial statements of the parent company.

In general, mining is a mature industry and therefore considered to be rather a follower than a pioneer in R&D. This doesn't mean, though, that the mining industry and its use of technology doesn't evolve. Especially during the past two decades, mining has gone through a significant transformation process. As mining companies fought for dominance in commodities, the mining industry underwent a strong consolidation process, affecting both operating firms and technology suppliers. As big mining companies acquired smaller businesses, the number of miners declined and mining became a truly global industry. This consolidation had an impact on mining size and age. With fewer small and medium-sized firms, developing smaller deposits and niche-operations became less likely. The rising demand during the last decade, notably from China, led to a further focus on the increase of output at comparably low risk. As a consequence, R&D spending declined even further.[6]

In theory, consolidation could have had a positive impact on technology development in mining (Peterson, et al., 2001). Consolidation among suppliers typically results in economies of scale in R&D. As mining becomes more complex and costly as it progresses to greater depths and larger scale, it requires, for instance, more innovative designs to ensure the stability of the mine structure. Consolidation should have also led to increased spending for R&D. History shows, however, that technology development in mining actually slowed down (Peterson, et al., 2001). Mining companies tend to put more emphasis on finding new, higher-grade ore deposits than finding better ways to mine them. This trend, however, is currently changing as exploration expenditure has collapsed.

6 Strictly speaking, R&I is always difficult to pinpoint to a single country. Due to ongoing globalisation/internationlisation, companies could be classified either by their place of origin, their place of ownership, or their place of actual R&I activity. For example, in mining software development, the USA was the leader (almost the only player) in the 1970s, with R&D done by mining companies and large computer suppliers. It was only in the 1980s that new developers - mostly micro-companies - set up in UK, Canada, and Australia, challenged this position. Those companies have grown and merged, and there is now another generation of star-up businesses doing R&D in the same field - but with much of their own R&D being done in China and India.

Table 1: Some technologies for unit operation in mining.

CRITICAL TECHNOLOGIES FOR MINING	EXAMPLES OF TECHNOLOGICAL PROGRESS
Drilling, blasting, cutting and excavating	e.g. improved rock-cutting technologies, blast accuracy and safety (e.g. with the aid of programmable electronic detonators)
Ground control	e.g. improved rock bolts
Loading and hauling	e.g. increased use of autonomous vehicles
Materials processing	e.g. leaching processes for minerals extraction, improvements in efficiency, reduction in both power and water

Source: Peterson, et al., 2001

Peterson et al. (2001) stress that innovation in mining mainly takes place as incremental improvements, occasionally punctuated by the development of significant new system innovations (which he refers to as 'systems'). There are various reasons that the pace of technology development differs in the minerals industry (Bartos, 2007):

- Mining has difficult entry conditions, as the start-up costs can be enormously high. In remote locations, it is necessary to build the entire infrastructure (roads, rails, power) more or less from scratch.
- Mining offers little room for product differentiation and price control. The product of mining is usually a commodity. Mining can be profitable when prices are high, but there is a lot of price fluctuation.
- Mining companies take a rather conservative business approach. They have to decide where to take risks and technology. Mines have big plants, large fleets of vehicles and

so adopting something 'new' is very expensive. Replacing equipment with a slightly better performance is not an option. Adoption occurs periodically during new mine builds, major expansions, after acquisitions, etc.
- Innovation is sought after in specific areas, and especially in those that guarantee the continuous operation of a mine. For instance, innovation related to monitoring and control technologies is more appreciated as technologies for optimizing the ore extraction. Generally, there seems to be a higher interest in improving downstream operations. A 1-2 percent productivity gain in metals processing can be equivalent to a 20-30 percent productivity gain in underground mining.
- Bigger, more systemic innovations require collaboration across different types of organizations (e.g. machinery producer, sensor technologies, software companies). Such alliances or partnerships are pursued if there is additional funding from the public sectors, but public funding for mining has been reduced in many areas.
- Due to group-wide sourcing, some miners tend to seek single equipment suppliers and common technologies, and thereby may overlook technologies that may be more innovative.
- Logistical constraints limit the ability to implement cutting-edge technology, especially in remote and poorly serviced locations

In its recent Global Metals Outlook, the consulting company KPMG estimated that approximately one third of the metals companies are planning to spend more than 6% of revenues on R&D over the next year. However, for mining companies, which are currently in crisis mode due to falling commodity prices, they recommend to focus on incremental innovations which are not too hungry for time and resources[7].

A study carried out by Boudreau et al. (2014) points out that introducing new equipment in mining is not necessarily synonymous with gain, even in the long term. There is often a trade-off between the gains provided by an innovation and the costs associated with its implementation and use. More specifically, negative aspects of may include

- Poor operator acceptance
- Long adaptation periods due to inadequate training
- Skill deficiencies
- Over-reliance on technologies
- Characteristics or functions that differ from those of standard equipment

They come to the conclusion that fewer than half of the projects examined in their study led to significant improvement. Even though different types of equipment were studied (e.g. bolters, trucks), it is difficult to generalize these results.

Another barrier for the diffusion of innovation is that governments see mines as drivers of economic development and particularly high wage employment. Any new technology that reduces jobs is usually resisted by governments (who threaten problems in license renewals) and unions, and in many cases it is impossible to introduce. In some countries this prevents innovation in others it has led to strikes, luddites and even violence.

3.3.2 Factors that Support Innovation in Mining

As Mining is costly and mining companies have to satisfy investors, who seek a competitive return on their investment. Twigge-Molecey (Twigge-Molecey, 2011) comes to the conclusion that innovation in mining and metals can be categorized by its drivers:

- Disaster-driven innovation: An innovation becomes a necessity due to disastrous experiences with the use of existing and possibly outdated technology. Often this includes new legislation which a mine must comply with.
- Project-driven innovation: A mine requires particular solutions that cannot be met with existing technologies. This innovation is driven by external constraints.
- Engineer-driven innovation: An

7 http://www.kpmg.com/ca/en/industry/mining/insights-into-mining/pages/insights-into-mining-newsletter-5.aspx (Jan 2016)

innovation is put forward by professional engineering consultants, who have intensive operating and research experience.

Hollitt (Hollitt, 2012) points out that transformational, systemic innovations occur only rarely in mining. They are only viable if one or more of the following criteria is met:

- Attachment of the innovation is possible, at good value, to at least one new resource project or significant expansion (there is no need for "creative destruction" of existing capital),
- The new approach is critical to the fortunes of at least one such project or expansion (i.e. there is no other possibility of a satisfactory or sufficient project), or
- The new approach is uniquely suited to avoiding loss of previous gains, including continued growth from resource acquisition or market options, which gains are otherwise under clear threat (the strategic imperative),
- It is expected that these necessary conditions will still be present in future business cycles in the light of other industry or regulatory developments,
- Sufficient finance or operating cash flows are available (equity rather than debt-backed investment) to provide for development across several business cycles.

3.3.3 Examples of recent mining innovations

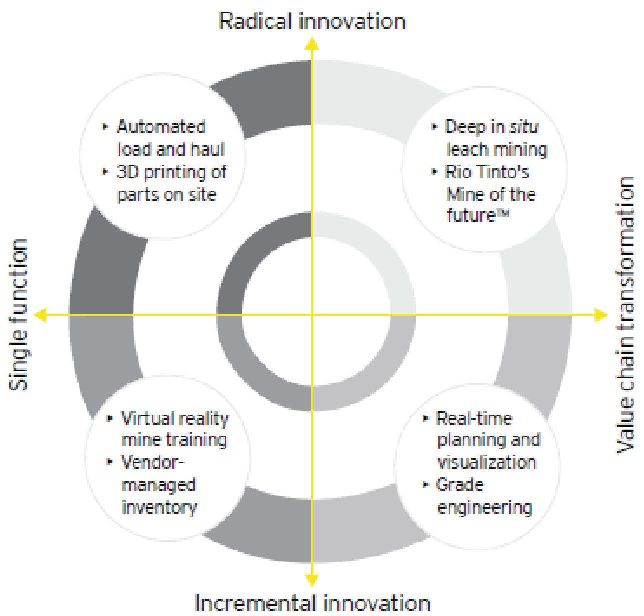
In a recent survey on the role of innovation in mining among 200 global mining executives, respondents said that innovation would have the greatest impact during the next 15 years in the following areas[8]:

- Automation - leading to the removal of people from the working area, enhanced safety, and lower cost
- Reducing energy consumption
- Resource extraction - by reducing distribution and improving recoveries
- Data and analytics - for process optimization and enhanced decision-making
- Processing - reducing material movements, increasing efficiency and recoveries

In a study carried out by the consulting company Ernst & Young (EY, 2014) on productivity in mining, innovation is presented as a major lever to improve productivity. Some innovations focus on single-point solutions, while others have the potential to change productivity levels at multiple points in the value chain (***Figure 9***).

8 http://govci.com/what-we-do/innovation/state-play-2/, 2014 (Jan 2016)

Figure 9: Mining Innovation Matrix.



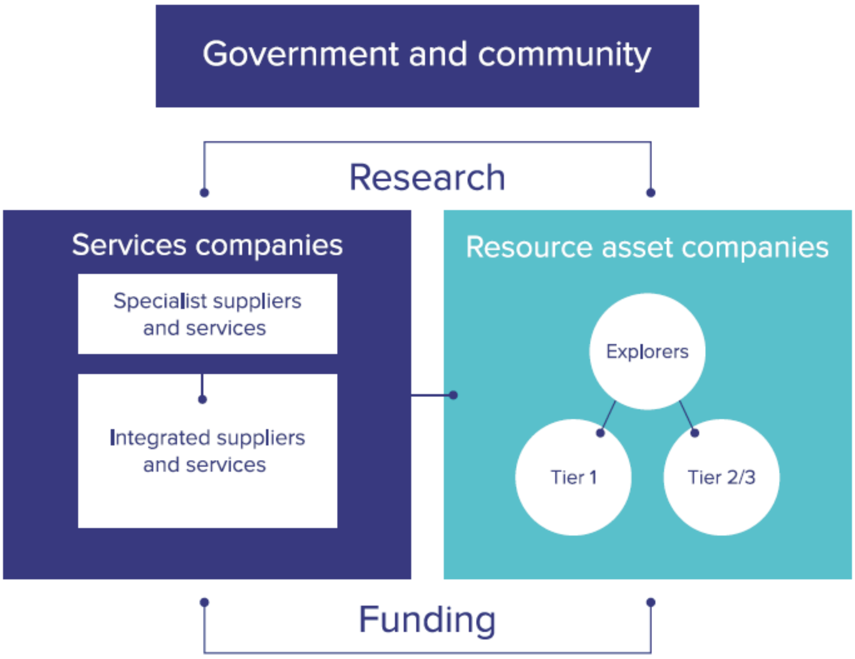
Source: EY, 2014

3.3.4 Selected Results on Mining Innovation

A study carried out by VCI (and co-sponsored by the University of Western Australia) is especially noteworthy as it is one of the few comprehensive attempts to capture innovation activities in mining, since it is based on over 200 responses from 25 countries (including more than 50 mining companies and more than 50 service companies).

Their attempt is remarkable in various ways. First, they map the eco-system of the mining industry and note that it is an amalgam of a multitude of players, such as suppliers, service providers, start-ups, research institutions, governments etc. (***Figure 10***) Respondents agreed that this eco-system should evolve as a whole. Future mining challenges such as low-impact mining and fully autonomous value chains require 'a need for coalition' and a shared vision. However, the mining industry has not been able to collectively develop such a vision, although other highly competitive industries such as telecommunications and semiconductors are able to do so (VCI, 2014).

Figure 10: The Mining Innovation Eco-System.

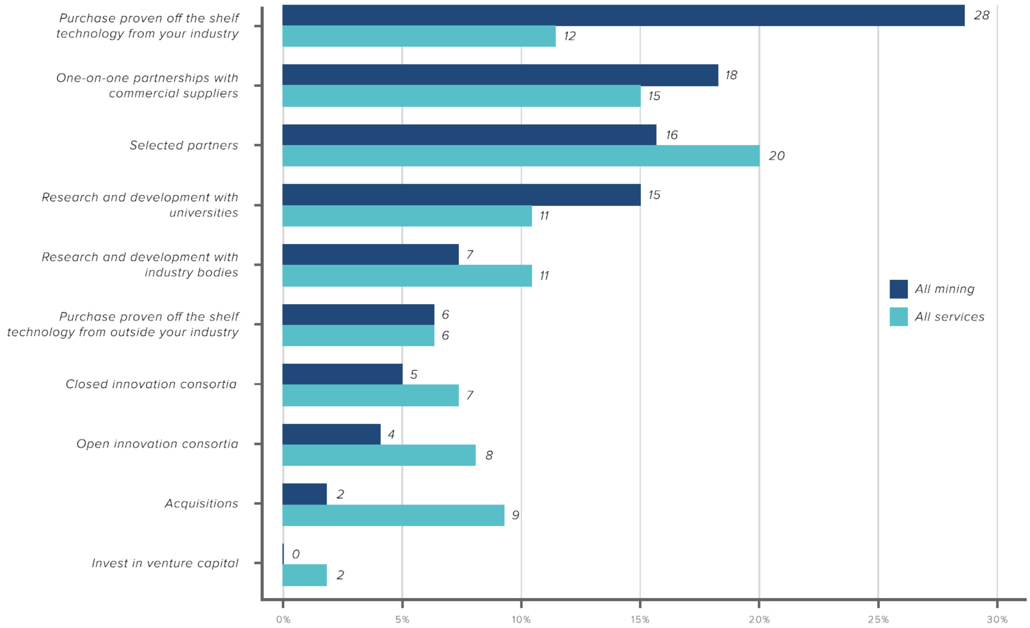


Source: VCI, 2014

Secondly, the survey confirms that miners have a preference for in-house or closed innovation (***Figure 11***). They tend to purchase off-the shelf technology or develop new technologies with commercial suppliers. Service companies, which tend to be smaller in size, are increasingly pushing for more integrated design approaches with mining companies. Their preferred way to develop technologies is through partnerships (***Figure 11***).

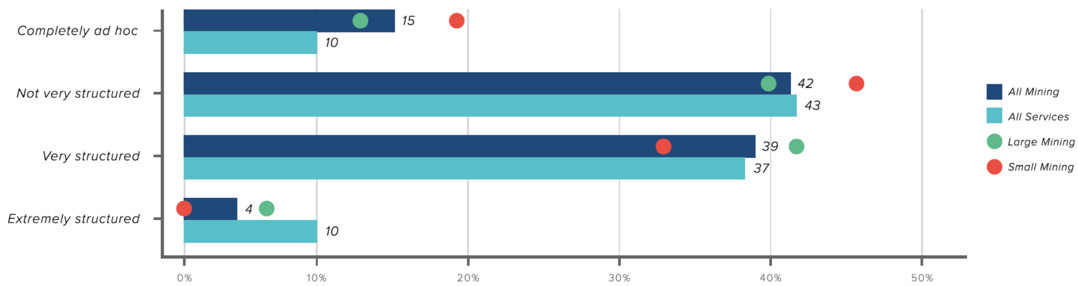
Thirdly, the results show that innovation behavior also depends on company size (***Figure 12***). Bigger mining companies have a more structured approach than smaller miners. They have the resources to pool innovation efforts, to build innovation centers and to make use of the results on a global scale. Accordingly, their success rate in the implementation is higher. Smaller companies tend to apply ad-hoc approaches, initiating innovation projects when there is a need to.

Figure 11: Innovation methodologies and partnership options ("How does your company primarily develop required technology?").



Source: VCI, 2014

Figure 12: Implementation of innovation ("How structured is your approach to implementing innovations in your company?").



Source: VCI, 2014

4. The mining value chain

4.1 Value chain analysis as a means to analyze an industry

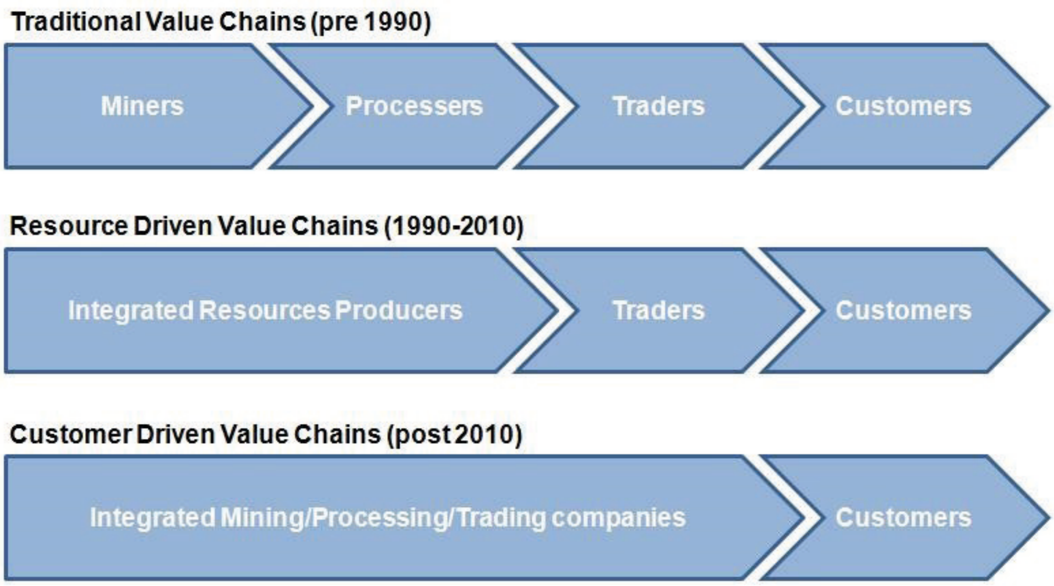
The concept of the **value chain** was first described by Michael Porter (Porter, 1985). A value chain represents all activities a company engages in to produce goods and services. Porter distinguishes between two different types of activities:

1. **Primary activities** add value directly to the final product as they are involved with the physical creation and delivery of the product. Primary activities include activities such as inbound logistics, operations, outbound logistics, marketing & sales and services.
2. **Support activities** add value in an indirect way (e.g. activities related to human resource management), they typically feed into primary activities. Support activities include technology development, procurement, human resource management and firm infrastructure (i.e. support functions such as finance, planning, quality control).

Firms can develop a competitive advantage by purposely designing the steps in a value chain. For instance, a cost advantage can be gained by addressing especially those activities that represent the major sources of cost.

The **value chain analysis** is a generic method to break down all value-adding activities in order to understand the activities that have the potential to create a competitive advantage. It can be carried out on the company level (internal value chain), but also on the industry level ("industry value chain", "extended value chain" or "value system" as it was named by Porter). The industry value chain describes how value is generated in an entire industry. It provides a useful model to understand the players that operate in it. Industry value chains constantly change due to competitive moves, but also due to the growing division of labour, the global dispersion of production, deregulation of industries etc., resulting in vertical and horizontal integration (or disintegration). In mining, for instance, steelmakers have tried to secure supply of resources through buying mines and mining companies. It is even expected that vertical integration will include trading as the next steps (The Business of Mining, 2010) (***Figure 13***).

Figure 13: Vertical Integration in Mining.



Source: The Business of Mining, 2010

It is important to note that mining itself is a business that features a range of different organisations of different size and with different objectives. For instance, there are large global and medium companies with projects in one country/region, medium companies with projects all over the world, small companies with one or two projects in one or more countries, companies that are commodity specific, government owned companies, privately owned companies etc. The largest 150 companies are, somewhat arbitrarily, called majors. All other producing companies are mid-tiers and the non-producing companies are called juniors. The majors represent a few per cent only of the total number of companies in the sector globally, but they control approximately 85% of total global mineral production. Larger companies are likely to invest more in R&D as smaller mining companies (Ericsson, 2012).

4.2 The mining value chain and the mineral value chain

For the purpose of this deliverable two different concepts - the mining value chain and the mineral value chain – are relevant. The mining value chain is a string of activities on a mine geared towards converting mineral resources to mineral reserves and processing mined reserves into minerals or concentrates of a saleable value. Activities include

- Exploration & evaluation (locating & evaluating)
- Mining (establishing, mining & transporting)
- Mineral beneficiation (extraction, concentration & refining)
- Sales (marketing & divestment)
- The mineral value chain is a string of companies working together to add value to the mined mineral. Activities include
- Exploration
- Mining (winning of mineral from earth)
- Metallurgy (extraction and concentration)
- Refining
- Fabrication
- High value intermediary & end products
- Sales

In the following sections we focus on the activities, where innovation plays an important role. The later stages of the mining and minerals value chain (especially sales) are less relevant from a point of view of technological innovation, whereas especially the early and middle stages are more interesting. These are therefore the main activities considered in the report:

1. **Exploration and evaluation:** The action of locating a deposit and proving it is technically and financially feasible to mine.
2. **Mine planning and design**
3. **Extraction:**
- Mine Development: The action of setting up a mine production system (e.g. open pit or tunneling, transportation system, power supply, drainage, ventilation, communications…)
- Mining: The action of producing ore (including, for instance, breaking, loading & hauling, conveying, crushing, stockpiling)
4. **Processing / Smelting and refining:** The action of converting the primary product into a bulk tonnage intermediate product (e.g. usually a mineral concentrate, then via smelting and refining into a metal or metal alloy), and of converting the intermediate product into a product suitable for purchase by sub-sequent industries (worked shapes and forms).
5. **Closure / Rehabilitation:** The action of restoring the post-mined landscape to the intended land use.

Probably one the most important drivers of technology development for the past 30 years has been the objective to achieve economies of scale in mining. Mines are often enormous operations, no other industry moves solid material on the scale of mining. The introduction of larger equipment, based on tried and true technologies, has been a significant lever to increase output and a good reason to justify capital expenditure in mining.

To illustrate some of the most recent mining innovations (mostly from the past 10 years), the Prospectors and Developers Association of Canada (PDAC) and the Mining Association of Canada have compiled 100 practical innovations from the world's principal mining regions and grouped them according to the main mining stages (exploration, mining, remediation) (***Table 2***)[1].

1 http://www.oma.on.ca/en/ontariomining/resources/Minalliance_100_innovations_en.pdf (Jan 2016)

Table 2: Examples of Innovation in the Mining Industry.

PHASES	EXAMPLES
Exploration	• Portable Analyser • Airborne electromagnetic surveys • Ore deposit definition • Hyperspectral imagery • 3-D Geological models • Owl head assembly
Mining	Ore extraction • Hybrid bolt • Inspection cameras • Cavity measuring • … Transport & communications • Truck tracing • Underground communications • Road-trains Ore processing • Sonar flowmeter • Underground preconcentration • Ore grinding monitoring Health and safety • Gas detection devices • Fenix capsule • Risk-area maps
Remediation	• Biodegradable explosives • Geotextile separators • Constructed wetlands

5. Operational analysis of research and innovation - the methodology

To understand the R&I performance of each reference country (US, Canada, Australia, South Africa & Japan), we apply the concepts 'National Innovation System' and 'Sectoral Innovation System' in a simplified way. As the purpose is to capture the characteristics of each country, we will describe elements of the national R&I system and as we target the sectors of minerals and mining, our analysis obviously includes some sectoral aspects, too.

The chapters follow the same structure (***Table 3***). The first chapters are descriptive to explain how the R&I system actually works. The last section contains a selection of quantitative measures that can be used to judge the intensity of R&I in the country.

Please note that the purpose of this structure is to provide a holistic understanding of 'how R&I really works' in each of the countries portrayed in this report. It should be noted, however, that it is not possible to create one ideal system of innovation. It is helpful, though, to compare them, to initiate reflection and to argue why one system performs better than others (Edquist, 2001).

Table 3: Structure of the R&I Country Analysis.

CHAPTER	SUB-AREAS / EXPLANATION	LEAD QUESTIONS (EXAMPLES)
The big picture of innovation in raw materials and mining		• Which role does mining play in the country? (e.g. in terms of GDP contribution), Is the country a net exporter or importer of mining products? • Which role do mining products play in the country? • Drivers for R&I in mining/raw materials
The mining innovation system	**Raw materials strategy and priorities** National innovation policies directly influence the framework conditions of an innovation system.	• Is there an explicit raw materials strategy that is pursued by the country? • If so, what are the key R&I-related policies? Is there an implementation plan for the policies? • Which official policy documents exist?
	Key actors and organizations[1] Organizations contribute to technological progress, as developer, adopters, or indirectly, as regulators, financers etc. Firms represent the main unit of analysis in sectoral systems of innovation. They have cooperative and competitive relationships.	• Who are the main actors in the mining landscape (Governmental bodies, Industry, Support Organisations ...)? • How they behave within the context of market? • Which actors in the system are the most influential?

	Knowledge base for research and innovation A sectoral knowledge base describes how knowledge is shared by the industrial actors of the sectoral system through communication / exchange / cooperation with other players in the industry. A rich and multi-source knowledge base has an impact on the rate and direction of technological change.	• Which are the main knowledge domains relevant for the country • How is knowledge acquired from outside the company (through R&D services, cooperation with universities …)? • What are the main patterns of collaboration?
	Key technologies Mining is a business that depends on the use of technology. Technological progress is a prerequisite to produce minerals at reasonable costs.	• What are main technologies that are being developed / have been developed in the respective country? • What is the pace of technological change in the country? • Who files patents and for which product category?
Metrics for mining innovation system	In addition to the qualitative data, some quantitative measures are used to illustrate the R&I intensity of each region. As sources of data we use the Global Innovation Index as well as other data, if it is more specific on mining (e.g. business expenditure on R&D [BERD] by mining companies). Note that the GII is a measure of a country's overall innovation performance. The performance of mining innovation may differ from the innovation intensity in other industries.	• Global Innovation Index • Innovation and Technology Readiness indicators

1 It is worthwhile noting that qualified professional research staff are mobile and will migrate to international centres of research excellence wherever they are. The location of such centres of excellence changes with time - new ones are opened, others are closed down (such as U.S. Bureau of Mines). Although there is a formal structure in some countries, the relative importance of different institutions changes with time.

6. Operational analysis of research and innovation: Australia

6.1 The big picture of innovation in raw materials and mining in Australia

During its history, Australia´s economic development can be explained by the shifting interactions between resource abundance and institutional arrangements, and between international economic conditions and policy responses to them (e.g. changing trade and immigration policies). Economic and technological factors were particularly important in this development; through shifting economic and trade policies (e.g. protectionism vs an open economy) Australia has explored, discovered and made efficient use of its mineral resources. This has provided long periods of sustained economic growth (GDP growth). The first “golden age” took place during the decades of 1850-1880 marked by the discovery of alluvial gold in the Victorian fields, massive immigration and continued economic and population growth. The second “golden age” (1945-1973) was also fuelled by a mining boom based on a more diversified portfolio of commodities, tied to Japan´s rapid industrialisation and capitalising on previous discoveries of deposits of iron ore and coal. The third “golden age” (1991-2014) is also marked by a sustained period of economic growth based on exports of commodities, very favourable terms of trade and a service economy with low unemployment and inflation. (INTRAW, 2015)

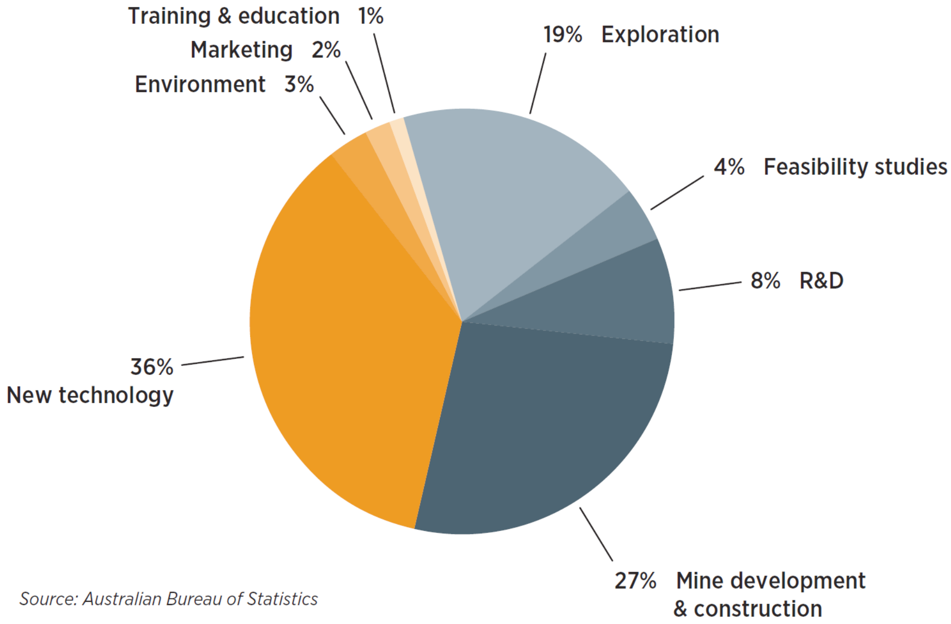
Australia is, with regard to raw materials (e.g. bauxite), one of the richest countries in the world. Furthermore, Australia is one of the leading suppliers in lead, iron, gold and lithium. Generally, the quality of all ores in Australia is as high as in South Africa, Brazil and Canada. Most raw materials are exported to foreign countries – especially to Asian countries such as China, Japan, South Korea and other big producing countries. (Hilpert & Mildner, 2013)

An exception to this is the processing of iron, which can be considered as one of Australia’s strengths. Almost 70 % of all extracted minerals are exported due to a high demand in export destinations and a relatively small demand of local industry. The mineral raw materials had a 8.8% share of the total Australian GPD in 2010 (Hilpert & Mildner, 2013, p. 35). In the end of 2014 the mining sector made up 10 % of the gross value added. Therefore, mining is the fourth biggest sector of the Australian industry. The biggest sector (“Business Services”) makes up nearly 25 % of the gross value added (Office of the Chief Economist, 2014). The mineral industry exports 50 to 60 % of the annual value of total exports. Iron ore, gold, copper, aluminium and nickel dominate mineral exports. The total export value nearly tripled from 2002 – 2003 to 2012 -2013 from $45.9 billion to $145.6 billion.

The majority of mining companies in Australia are Majors. Next to the big players such as BHP Billiton or Rio Tinto there are smaller Junior Mining companies and service suppliers, e.g. for safety or exploration. Some of the mining companies have their headquarters in foreign countries like the Swiss group Xstrata, but run their mines mainly in Australia. Australia’s wealth in minerals makes it very attractive for investors to fund mining projects. However, at present, Australia is losing its competitiveness and is seen as excessively expensive place to operate. The country is trying hard to regain this international competitiveness compared to other new high mineral potential locations.

Most inventions (i.e. filed patents) made in the mining sector are from mining equipment, technology and services (METS) with 4,934 in 2013. Classic miners made 863 inventions and public entities had 742 inventions in 2013. The distribution of innovation activities related to the types of expenditures are displayed in ***Figure 14***.

Figure 14: Innovation in mining in Australia. Types of expenditure July 1994 to June 1997.



Source: Scott-Kemmis, 2013, p. 15

Because Australia is rich in minerals, recycling is not distinctive and recycling companies are quite few in number (Scott-Kemmis, 2013).

Challenges for Australian mining companies:

Although Australia has an internationally competitive mining industry with well-developed companies that are specialized in developing mining equipment as well as technology and services, Australia has to deal with some challenges. These can be classified in four categories (Scott-Kemmis, 2013):

- **Mineral resources** including deeper deposits, mines far away from industry locations and harbours, more complex mining processes and lower mineral grade.
- **Human resources** such as an aging workforce, a need for skilled people (due to rising complexity of mining) and hazardous workplaces (even though removing from hazardous environments is priority already).
- **Environmental resources** including challenges like water scarcity, rising energy costs, fragile ecosystems that must be protected and dealing with waste products.
- **Social & corporate resources** dealing with accountability, community development, sovereign risks and scrunities.

In addition, Australia has to optimize the coordination of "innovation activities within the mining industry, its suppliers and the supporting research and education organizations". Major areas of improvement are seen in the creation of capabilities of METS for better internationalization, better integration of METS in the innovation complex and a more coordinated industry knowledge base (Scott-Kemmis, 2013). Australia is still following partly the criticism formulated on their national innovation systems (NIS) in the 1990s (Gregory, 1993) which includes a low level of science and technology expenditure, high level of government involvement in financing and undertaking research, low level of private sector research and development and an exceptionally high dependence on foreign technology. A big effort was spent in the last decade to overcome these criticisms and considering that mining is the sector creating the highest value-add per hour (Featherstone, 2012).

Drivers for mining research and innovation in Australia:

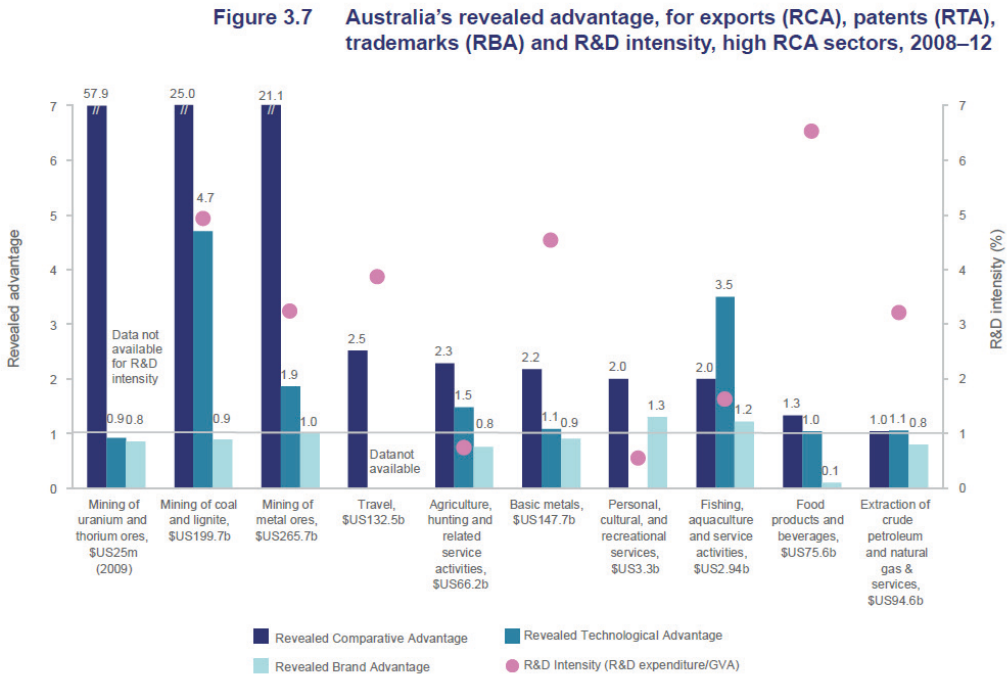
The environmental standards are one of the highest in the whole world so miners and METS have to meet them with sophisticated technology. The safety regulations are quite strict. So mining companies and METS are always forced to invent and improve technology to remain competitive to miners in other countries with low standards and regulations. The global demand for minerals will rise in the future, however, the fall of commodity prices in recent years has brought financial distress to many Australian miners (Scott-Kemmis, 2013, p. 38f).

External demand for raw materials has strongly driven Australia's innovation and economic performance in the last decade (Office of the Chief Economist, 2015). Due to the apparent end of the mineral boom, the focus changed from scale to productivity and cost saving. As measured by patents filed, Australians only have a very minor share of patents in the mining sector. Based on the countries for prosecution of patents filed by Australian inventors, the U.S. and Australia have been identified as major markets, followed by Canada, China, Japan and Europe (Francis, 2015).

Automation is the new trend in exploiting minerals that miners have to face in the coming years. Therefore, miners and METS need well skilled staff and direct cooperation to specialized suppliers to manage this next technology step. Generally, the links between miners, METS and other relevant R&I organizations are comparatively weak which does not promote innovation and the transfer of innovations to the industry (Scott-Kemmis, 2013). Survey estimates suggest that the METS sector generates revenues of around $90 billion annually with an export component worth $15 billion per annum and thus larger than the automotive industry. An overview on the revealed advantage for exports combined with information on patents, trademarks and R&D intensity is shown in ***Figure 15***.

Following the importance of Australian's mining industry for the overall economy, challenges and drivers are continuously monitored and integrated into policies, strategies and priorities of the mining sector. The high dependency of the Australian economy on raw material exports is a key challenge both, for the mining industry and other industries.

Figure 15: Australia's revealed advantage for exports (RCA), patents (RTA, trademarks (RBA) and R&D intensity, high RCA sectors, 2008-12.



Source: Office of the Chief Economist, 2014, p. 96

6.2 The mining innovation system in Australia

6.2.1 Raw materials strategy and priorities

The Australian mining strategy is defined by each State in a federal system (there are six states and two (mainland) territories). The current strategy and aim of the Australian (federal) Government is to make the *"mineral and energy exploration in Australia globally more competitive and economically attractive"*.[1] Currently the change of strategy is very important because of low commodity prices and an increasing uncertainty in global markets. In this context, the Australian Government created an Exploration Development Incentive to lure exploration investments, especially for SMEs. Australia tries to promote further progress in resource development. One part of Australia's deregulation ambition is to liberate the industry of red and green tape. The Productivity Commission, the Australian Government's independent research and advisory body, stresses that current regulation fails to assess the benefits of exploration (Pearson, 2014).

The politics of raw materials are highly influenced by the fact that Australia is a net exporter, i.e. it exports (especially iron) ore and concentrates rather than refined metal. Compared to the amount of ore produced, it has also a rather low domestic consumption. Because of its low rate of downstream consumption, the Australian raw material strategy is quite different to that of other countries. Each state has its own freedom to regulate mining activities but there is also a low coordination between all states and a general lack of a consistent strategy. Generally, the goal of each state is to be competitive with other countries in the world, including training of staff and an increase in productivity. The Australian Government interferes only if national interests are affected. Furthermore, the Government helps to prevent financial shortages in infrastructure projects (Hilpert & Mildner, 2013). Profits made by mining companies have been taxed since 2012, based the "Mineral Resource Rent Tax", which is settled from each federal state separately. However, this tax has been repealed as of 2014. To help smaller companies, financial profits under 50 million AUSD are not taxed. Furthermore, the Australian Government granted some energy subsidies for the transformation from bauxite to aluminium. The Australian Government further pursues international cooperation with other countries. It has established several *"Bilateral Minerals and Energy Cooperations"* (e.g. with China, Japan, India). These agreements are above all official consultations that aim to identify and facilitate commercial opportunities for Australian business (Austrialian Government, 2015).

State agencies are also responsible for mining regulations, health and safety– with some exceptions on a national level[2]. State governments are responsible *"for granting exploration and mining tenements and collecting mining royalty payments from the companies"*. The mining sector is more regulated than most other industries in Australia[3]. These regulations have a high influence on companies cost structures, productivity and capacities. Based on Australia's export orientation, it is in need of *"efficient, stable and risk-based regulatory systems"* (Minerals Council of Australia, 2014, p. 8f). However, the role of regulation as a barrier to global competitiveness should not be underestimated as Australia decreased its position from 5 in 2001 to 22 in 2014-2015 ranking within the Global Competitive Index from the World Economic Forum (Minerals Council of Australia, 2014). The biggest challenges in this context are project delays caused by long approval and cancellation times through federal regulations.

Among the strategic recommendations[4] that aim to increase efficiency and effectiveness of exploration approvals and processes and reduce costs associated with government processes are issues such as facilitating negotiations with lan-

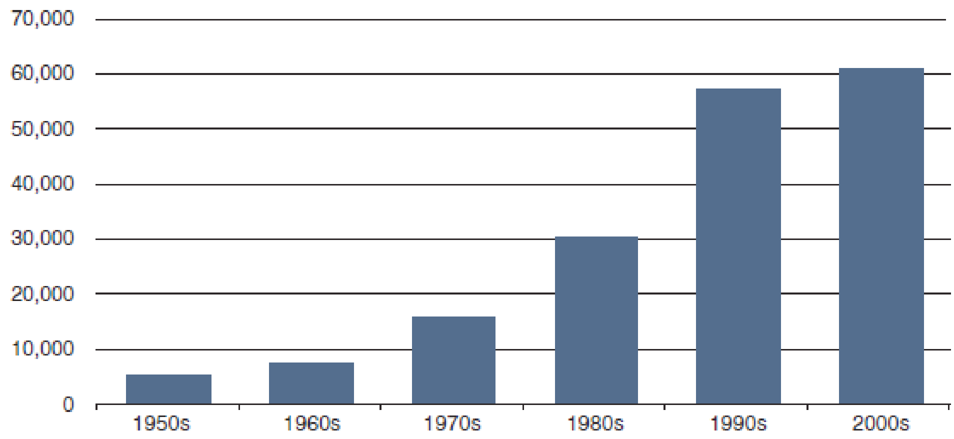
1 Report response to encourage resources and energy exploration. http://minister.industry.gov.au (Dec 2015)

2 Applying geoscience to Australia's most important challenges. http://www.ga.gov.au (Dec 2015)

3 Regulation & Infrastructure. http://www.minerals.org.au/policy_focus/regulation_infrastructure (Dec 2015)

4 The Australian Government's interim response to the productivity commission inquiry report into mineral energy resource exploration http://www.industry.gov.au (Dec 2015)

Figure 16: Commonwealth Government legislation (pages of new legislation).



Source: Minerals Council of Australia, 2014, p. 12 referring to Business Council of Australia, Deloite Access Economics.

downers and the elimination of contradictions and incompatibilities of regulations.

Very recently, on 7 December 2015, the Australian Government released its National Innovation and Science Agenda. While the agenda does not focus explicitly on mining, it acknowledges the need to improve the national innovation capability as the mining boom comes to end. The National Innovation and Science Agenda focuses on four key pillars: 1. Culture and capital, 2. Collaboration, 3. Talent and skills, and 4. Government as an exemplar. A total of $1.1 billion have been reserved to implement a broad range of measures over the coming four years.

6.2.2 Key actors and organizations

The landscape of organizations in Australia's mining sector covers all phases of the mining value chain. From a global perspective, the Commonwealth Scientific and Industrial Research Organisation (CSRIO) can be considered a key asset. Furthermore, the strong position of the mining equipment, technology and service sector, which plays an increasingly important role as a global exporter is another asset that is often overlooked when analysing the mining sector. A major challenge is still the collaboration between research organisations or universities with industry as well as a high amount of different legislative and administrative requirements, mainly due to a decentralised policy landscape in which the federal states play a strong role. The key players in the Australian mining sector are summarised in ***Table 4***.

The roles of these key players can be described as follows (Hilpert & Mildner, 2013, p. 35f):

- **The Department for Industry, Innovation and Science** is mainly responsible for resource policy at the federal level in Australia. The Office of the Chief Economist (formerly the Bureau of Resources and Energy Economics) provides economic

Table 4: Key players in innovation in Australia's mining and minerals sector.

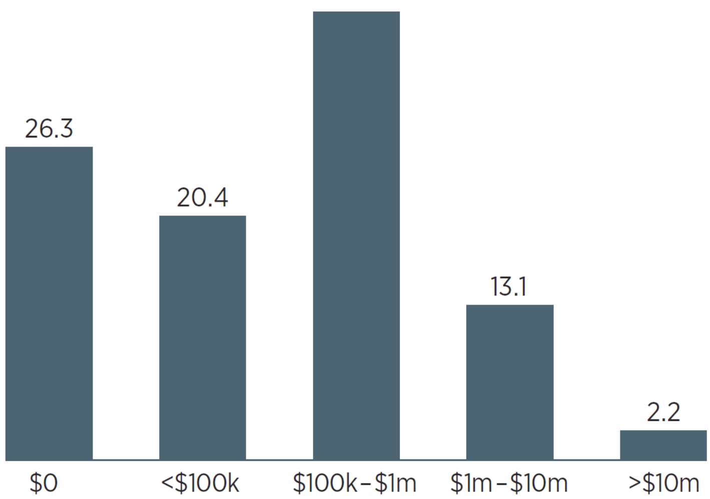
	KEY PLAYERS
Research and education system actors	Universities, Research organisations, Commonwealth Scientific and Industrial Research Organisation (CSIRO), State Geological Surveys, Geoscience Australia
Sector value chain actors	Minerals Council of Australia, major mining companies, mining equipment, technology and service sector (METS), AMIRA
Enabling agencies	Department of Industry, Innovation and Science (DIIS), AusTrade, Department of Foreign Affairs and Trade (DFAT), Council of Australian Governments

analysis of resources and energy for the Department.

- **Commonwealth Scientific and Industrial Research Organization (CSIRO)** is an independent research institution for companies and the Australian Government, carrying out research activities in different sectors of economic importance.
- **Minerals Council of Australia (MCA)** - represents the mining sector (companies). It also provides funds to the educational system to get high qualified workers and innovations and inventions in return. Major mining companies operating in Australia (Rio Tinto, BHP Billiton, Fortescue, etc) often act through the MCA.
- **Austmine** - the METS sector industry group
- **Australian Research Council** – government agency, primary funder of university research
- **AMIRA international** is an umbrella group for companies to collaborate and fund university and CSIRO projects
- **Geoscience Australia** – a federal agency that acquires data to improve understand of Australia's geology, geophysics, geochemistry and mineral potential (part of the Industry, Innovation and Science portfolio).
- **Minerals Research Institute of Western Australia** – statutory body established by State Government of Western Australia to promote research that stimulates investment in and the operation of the minerals industry in WA.
- **Chamber of Minerals and Energy in each state** are industry bodies that support industry and government with scientific information and advocate for industry interests.
- **Department of Foreign Affairs and Trade (DFAT)** is responsible for cooperation and diplomatic representation with other raw material supplying countries, including via foreign aid and capacity building.
- **Australian Trade Commission (Austrade)** deals with international trade affairs supports Australian companies as well as the exchange of education between federal institutions and private companies (part of the Foreign Affairs and Trade portfolio).

Companies in the mining sector pursue innovations in all phases (exploration, extraction, processing, and rehabilitation) of the mining process. Generally, the description of mining innovations in this context include not only innovations of miners but also university research groups, and service and consulting companies that do the preliminary work for mining enterprises. Exploration ("*an investment in knowledge about the location, type, quantity and quality of deposits*") (Office

Figure 17: Proportion of METS firms undertaking R&D expenditure in percent 2008-2009.



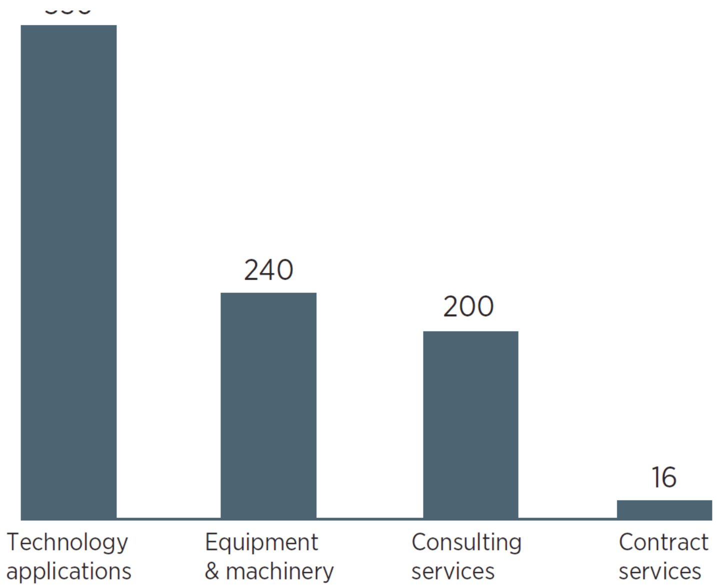
Source: Scott-Kemmis, 2013, p. 27 referring to 2009 ABARE-BRS Survey.

of the Chief Economist, 2015, p. 7) dropped sharply in the last few years. Due to low commodity prices and oversupply, many innovative companies investing in exploration have had to cut costs to stay profitable. In total, Australia's exploration expenditures fell about 6.7% to $ 6.6 billion from 2013 to 2014, including oil and coal (Office of the Chief Economist, 2015). A key danger is that cost-cutting aiming at short-term profitability often includes a reduction of innovation activities and thus might hurt long-term innovativeness.

A key group among the actors in the Australian mining sector are coming from the mining equipment, technology and service sector (METS). As shown in ***Figure 17***, almost 75 % of all METS companies invested in R&D, with 15 % spending more than 1 million dollar in R&D (Scott-Kemmis, 2013).

Overall the METS sector spent $986 million in R&D from 2008 – 2009. The technology application sector invested $530 million, equipment & machinery companies spend $240 million, consulting companies invested $ 200 million and the remaining $16 million was spent in contract services (see ***Figure 18***). Funds in R&D were invested both internally and externally. A major part of the external investment went to companies that specialise in R&D in mining.

Figure 18: R&D expenditure by METS sector in $m, 2008-09.



Source: Scott-Kemmis, 2013, p. 28 referring to 2009 ABARE-BRS Survey

Innovation areas in the METS sector are especially focused on increasing capabilities, improving their products and widening their product and service range and are gaining importance on an international level, following a similar model to the Scandinavian METS sector (Scott-Kemmis, 2013).

6.2.3 Knowledge base for research and innovation

The **Minerals Council of Australia** (MCA) is responsible for most mineral and processing companies in Australia. It works together with "*Australian universities to build up capacity in higher education through national collaborative programs in the core disciplines of mining engineering, metallurgy and minerals geoscience*". Therefore the minerals industry has invested over $ 40 million to guarantee an ongoing stream of qualified graduates. This is an important move, as outcomes of university research are not always translated into commercially viable innovation. Moreover, IP strategies of universities might hinder the commercialization of developed technologies due to unrealistic value expectations.[5]

There are several **Universities** offering mining research programs (mining engi-

5 Australia's innovation system. http://www.minerals.org.au (Dec 2015)

neering) include,

- University of Adelaide
- University of New South Wales
- Curtin University (WA School of Mines),
- University of Queensland,
- University of Western Australia,
- University of Tasmania,
- University of Ballarat,
- University of Wollongong.

There are about 20 universities offering geoscience programmes throughout Australia (Jeffrey & Camborne School of Mines, 2016)

A significant share of Australian Government support for research and innovation is targeted at universities through funding for research and research training. The fact that research and higher education communities are the main beneficiaries from governmental programs such as the **Excellence in Research for Australia** (ERA) is a key barrier to industry-oriented research. However, under the new innovation and science agenda, the role of the ERA is currently expanding to encompass research impact and engagement. A pilot assessment program is planned for 2017.

For several decades a number of universities have had research groups that actively engage with industry in industry-sponsored research, and which disseminate results directly to industry partners as research projects progress (examples includes CODES at the University of Tasmania, the Sustainable Minerals Institute at the University of Queensland, and EGRU at James Cook University).

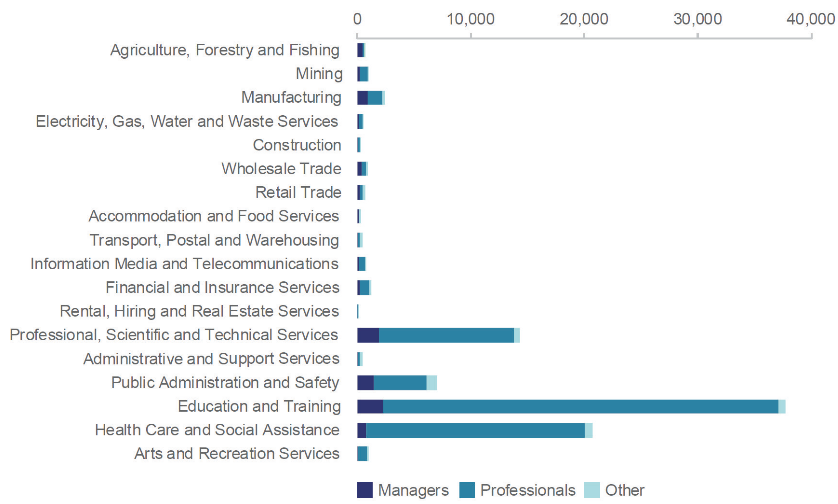
In addition, the **Australian Research Council** also facilitates collaborative research between universities and industry through its Linkage Programme. This programme supports, among other things, the initiation and development of long-term strategic research alliances between higher education organisations and industry.

Cooperative Research Centres (CRC) program – Funded by Government to establish centres that bring together university and industry partners to solve industry-led problems. Most important in this area are CRC Mining (www.crcmining.com.au), CRC for Optimising Research Extraction (www.crcore.org.au) and Deep Exploration Technologies CRC (www.detcrc.com.au)

Industry Growth Centres – new Government program to set strategic priorities for key sectors (http://www.business.gov.au/advice-and-support/IndustryGrowthCentres/Pages/default.aspx) includes METS Ignited Growth Centre (www.metsignited.org) and Oil, Gas and Energy Resources Industry Growth Centre

Related to the importance of the mining sector within Australian's economy, the level of education in the mining sector is relatively low compared to other sectors

Figure 19: PhDs in the workforce, by sector, by occupation, 2011.



Source: Office of the Chief Economist, 2014, p. 130 referring to 2011 Census of Population and Housing (see ***Figure 19***), however the professional scientific and technical services sector, which supports the industry, has high qualification levels.

Due to high investments into the scale of mining activities, productivity suffered in the period between 2001 and 2013 (Mitchell & Steen, 2014, p. 3). Thus, the current focus for developing the knowledge base is on regaining productivity while being confronted with a reduced demand for raw materials.

6.2.4 Key technologies

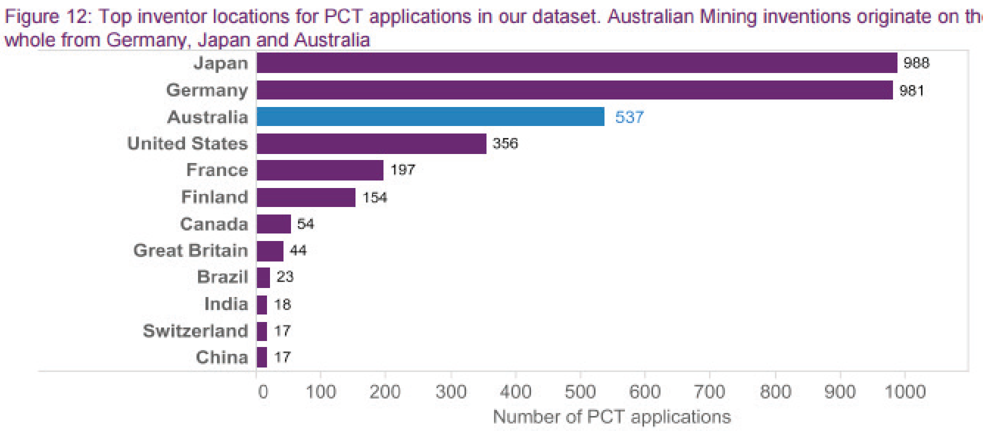
Overall, Australia's industry has been at the forefront of development in the following technology fields (Scott-Kemmis, 2013, p. 17f):

- Airborne geomagnetic survey sensors and analytical software
- Flotation separation technique of zinc from ore
- Recovery techniques to mine low grade gold deposits

A major part of patent applications comes from foreign applicants (see ***Figure 20***). Overall, only 1.2% of METS inventors are Australian (Francis, 2015).

For Australian applicants, the Australian Government & CSIRO, Rio Tinto Alcan International Ltd and the University of Queensland are the biggest representatives. Australian inventors tend to work in areas such as chemical investigation of materials or processes of separation as well as batteries or cells. For operating miners, the most important area for patent filing is the manufacturing of iron or steel and electromagnetic or optical prospecting, especially in the area of geophysics (Francis, 2015).

Figure 20: Top inventor locations for Patent Corporation Treaty (PCT) applications. Australian mining inventions originate from Germany, Japan and Australia.



Source: Francis, 2015, p. 20 referring to OECD, REGPAT July 2014

6.3 Metrics of Australia's mining innovation system

Within the Global Innovation Index, Australia is ranked highly for the innovation input sub-index, but underperforms relative to other countries on the innovation efficiency ratio (see ***Table 5***)

This can largely be explained by Australia's difficulty in translating research and innovation into industry-oriented results. While the quality of scientific research institutions is high - Australia is ranked in the top ten of participating countries - commercialising advanced technological products remains a challenge (***Table 6***).

A key performance metric of research and innovation is the business expenditure on R&D (BERD). After manufacturing, mining has the highest share of BERD in Australia (Office of the Chief Economist, 2015), however only a minor share of BERD is carried out outside of big corporations. Mining only represents a minor share of new business entries.

In the Australian mining industry, roughly 75% of patents relevant to mining are filed by METS companies, whereas the remaining 25% are shared between mining companies and public entities (Francis, 2015).

Table 5: Global Innovation Index[1].

	SCORE 0–100 OR VALUE (HARD DATA)	RANK
Global Innovation Index (out of 141)	55.2	17
Innovation Output Sub-Index	45.6	24
Innovation Input Sub-Index	64.8	10
Innovation Efficiency Ratio	0.7	72
Global Innovation Index 2014 (out of 143)	55.0	17

Source: Dutta, et al., 2015, p. 186

1 As mentioned in Chapter 5, note that the GII is a measure of a country's overall innovation performance. The performance on overall innovation may differ significantly from mining innovation.

Table 6: Australia's Innovation and Technology Readiness Indicators.

INDICATOR	VALUE	RANK / 144
Innovation		
Capacity for innovation	4.6	27
Quality of scientific research institutions	5.8	9
Company spending on R&D	3.6	39
University-industry collaboration in R&D	4.8	21
Gov't procurement of advanced tech products	3.4	73
Availability of scientists and engineers	4.7	27
PCT patents, applications/million pop.*	78.4	21
Technology Readiness		
Availability of latest technologies	6.0	24
Firm-level technology absorption	5.6	23
FDI and technology transfer	5.1	21
Individuals using Internet, %	83.0	18
Fixed broadband Internet subscriptions/100 pop.*	25.0	26
Int'l Internet bandwidth, kb/s per user*	67.1	39
Mobile broadband subscriptions/100 pop.*	110.5	4
Values are on a 1-to-7 scale unless otherwise annotated with an asterisk (*).		

Source: Schwab, 2015

To identify inventors as well as their origin, patent data is one of the most common information sources. Its strength is that it is available before major commercial activity and available in structured form. However, patent filing is often mainly carried out by major corporations or research organizations as it is relatively time consuming and expensive, especially from a SME perspective.

7. Operational analysis of research and innovation: Canada

7.1 The big picture of innovation in raw materials and mining in Canada

Canada is the 16th largest economy in the world (if measured by Gross Domestic Product purchasing power parity) and ranks 29th if Gross Domestic Product (GDP) is measured on a per capita level. Canada ranks 8th in the United Nation´s Human Development Index, its citizens enjoy high living standards and its mining industry has become a global leader in exploration, mine development and operation, financing, and site remediation (INTRAW, 2015). It is noteworthy that Canada is home to world-leading hubs at Vancouver and Toronto for exploration and investment, with Vancouver being the top destination for mining exploration, while Toronto is a global hub for mining financing.

The country is the world's largest producer of zinc, and a major producer of gold, nickel, aluminium, lead, uranium, diamonds and potash. In 2014, the mining industry contributed $57 billion to Canada's GDP (approx. 3.1% of total GDP), while employing roughly 375,000 people across Canada. Canada has one of the largest mining supply sectors globally, with more than 3,700 companies supplying engineering, geotechnical, environmental, financial and other services to mining operations. Canadian enterprises explore, build mines and / or process minerals all over the world with major impact in North America (important in the U.S.A.), Argentina and Chile, but also in Europe, Australia and Africa (ASSIMAGRA, 2016).

General challenges for Canadian mining companies

Despite the prominent role of mining, a study of the Mining Association of Canada (MAC) lists the following issues for the Canadian mining industry (Marshall, 2014).

- Global competitiveness: Discovering new deposits, developing and operating deeper mines, will become more costly, especially in remote and northern regions. Given recent market volatility and the general economic uncertainty, Canada should lower the barriers for new investments to stay competitive in the long run.
- Regulatory burdens: Mining projects have to undergo several federal reviews and approvals. Despite some changes in legislation in 2012, the new legislation has created more uncertainty in the permitting process.
- Investments in infrastructure: Due to Canada's vast geography, substantial investments are needed to develop remote and northern mining projects.
- Lack of human resources: Current forecasts suggest that more than 50,000 workers will retire by 2025. In contrast, the mining industry needs more than 100,000 new workers in the next decade.

The opinions on the future role of mining in the Canadian industry are twofold. One position is that mining, as a traditional industry will not be able to support the transition towards a knowledge economy. The other position is, that, due to its current importance for Canada's economy, mining will be essential and create spinoff benefits for other industries (Canadian Chamber of Commerce, 2013). In a similar vein to the considerations made by MAC , the Canadian Chamber of Commerce lists the following future success factors for mining (see e.g. Canadian Chamber of Commerce, 2013):

- Skilled Human resources capable of innovating (bringing knowledge to) the mining sector to sustained production of resources with minimal environmental impact and to sustain the national economy.
- Financial support from institutions and tax policies adapted to business requirements.

- Provide incentives for industry to innovate and develop new resources without dependency on public funding and public funded clean-up of abandoned mine sites.
- Lack of Infrastructure support, both tangible and intangible that enables resource access.
- Land access – future mining needs to demonstrate design and methods that minimize environmental and social impact. Until then Northern and Southern stakeholders will oppose mining.
- A strong supporting culture and history of mining.[1]

Drivers for research and innovation in Canada

With respect to research and innovation, the MAC report emphasizes the following shortcomings (Marshall, 2014):

- Research and academic institutions are primary beneficiaries of funds that do not necessarily respond to industry and market needs and priorities. Funding emphasizes academic publications and economic benefit to Canada. Some programs require industry partnership, but R&D spending does not necessarily take into account industry priorities.
- High fragmentation of the innovation value chain due to a lack of national scale coordination of government and industry R&D funding: Each provincial and regional jurisdiction operates and approves funding programs.
- Lack of efficient coordination and prioritization of Innovation activities in Canada's mining community.
- Insufficient integration of mineral industry service provider in innovation activities.

It is important to note, however, that the MAC report expresses the view of the industry. Canada has without doubt reinforced its R&I activities in recent years. The Canadian Mining Innovation Council (CMIC) was formed in 2008 with the aim of investing mining industry R&D dollars more strategically. It has the potential to coordinate activities in the mining community.

A study issued by the Council of Canadian Academies in 2013, which examined industrial R&D inputs (expenditures & personnel), outputs (patents & publications) and outcome (innovation and productivity), also gives a more optimistic view on innovation in the mining and the oil and gas extraction sector. As the overall importance of these industries grew over the past 15 years, so did industrial R&D intensity. Particularly the oil and gas industry has a high level of impact based on patent citations and rapid growth in both industrial R&D expenditures and economic output. Innovation activities have grown continuously, albeit admittedly from a very low level (Council of Canadian Academies, 2013). It is also worthwhile noting that R&D spending in mining, quarrying and oil and gas extraction had reached a peak in 2012 (approx. $1.6 billion). More recent numbers compiled by Statistics Canada indicate that R&D spending in 2015 is expected to reach about $1.5 billion (Statistics Canada, 2015).

Canada operates a number of national R&D programs, e.g. driven by the National Research Council of Canada (NRC), Innovation, Science and Economic Development Canada (Industry Canada), the Natural Sciences and Engineering Research Council of Canada (NSERC) and through National Centres of Excellence.

NSERC, which is the main federal government source of funding for academics, demands that more directed research should be undertaken and that the private sector should be active contributors to future govenment leveraged R&D efforts. The government has also recognised that the deliverers of innovation - the service and supply sector to the resource industry- are to be supported, too.

Canada has decided to continue investing into strategic strengths as well as in the continuous renewal of the mining industry. There is the expectation that firms that are the most successful now in

1 It is worthwhile noting that urban and aboriginal Canada commonly oppose mining, because of past and recent history of environmental degradation. Although strong industry organizations (CIM, MAC, PDAC, AMEBC) promote mining and socially responsible practices, the mining industry improve its image, and many First Nations communities influence mining practice through development partnership agreements with the mining industry.

achieving cost reductions through innovating will be well positioned when the global demand for resources picks up again (see e.g. Energy and Mines Minister's Conference, 2015, p. 13).

- Complexity and uncertainty: the high level of complexity throughout the mining value chain as well as a high level of uncertainty due to global markets and legislations are often considered as barriers to investment, especially in research and innovation. Many mine feasibility studies have insufficient data, and estimates of production are therefore highly uncertain. Incorrect estimates of head grades are the highest cost of failure.
- Capital intensity and long-term pay-outs: exploration requires high investments that pay-out only on very long time horizons. This long-term oriented business is often considered as a major barrier to innovation and risk-taking. Capital and operational costs are commonly underestimated and therefore a leading cause of mine failure.
- Commodity production: on a global level, differentiation in the commodity sector is more difficult to attain. Differentiation tends to be achieved in later stages of the value chain through specific refinement or within the products or services that are enabled by commodities. Historical base metal mines and oil sands required large supporting infrastructure and significant environmental impacts. In remote northern Canada gold and diamond mines are more likely to be permitted than large complex base metal mines. Proximity to winter roads and coastal seaports (deep water) are significant economic factors.
- High variety of production environments: Commodities highly differ in production environments. Solutions in raw materials have to be highly customized to fit to these environments. Significant investments in data collection, assessment and feasibility studies are critical to success.
- Terrain sensitivity: Resources commonly occur in areas of high environmental sensitivity. Examples are the oil sands in Alberta, the Ring of Fire chromium resources in northern Ontario in boreal wetlands or Windy Craggy zinc deposits in coastal mountains of British Columbia. Innovations are required to minimize the impact of the way Canada explores, defines and develops such resources.
- Exploration in remote areas: Establishing mines in the Far North is especially demanding and requires innovative, sustainable ways to operate mines. First, because there is little infrastructure (roads, energy etc.) available. Second, win-win situations have to found with the local indigenous communities. In general, the paucity of environmental data in remote areas and the cost of obtaining this info lead to less money being spent on mining related research and innovation by companies.

Given the challenges and barriers, that mining has to deal with at present; innovation is considered a key element for differentiation from low-cost raw material producers from emerging countries. This includes innovations across the mining value chain to render existing operations more efficient and to allow the exploration of deeper and lower grade ores.

7.2 The mining innovation system in Canada

7.2.1 Raw materials strategy and priorities

Since the 1990, Canada's mining industry has invested in automation technologies to lower production cost (Savine, 2015). The Canadian government has set up five strategic goals and priorities for research and innovation for the Pan-Canadian mining sector (Canadian Mining Innovation Council, 2008):

- Targeted areas for research and innovation: address critical needs through fundamental research breakthroughs in the areas of environment (including energy, water, and tailings and effluent management), exploration, deep mining, and process efficiency.

- Highly qualified people: enhance sustainable research performance and receptor capacity through high qualified people (i.e. build capacity in firms to capitalize on new ideas and technologies by employing more scientists and engineers).
- Collaboration: establish a collaboration culture, optimize research efficiency, and enhance innovation potential.
- Innovation systems and culture: create a collaborative environment (process, networks, and leadership) that connects enhanced research capability (people, infrastructure, equipment, and facilities) to the demand pull of industry customers for applied and breakthrough research and innovation.
- Brand, visibility and reputation: attract a new audience to mining research and innovation and to enroll decision-makers to support the importance of mining research and innovation.

Despite this Pan-Canadian strategy, several sources claim that in fact, the priorities are defined predominantly on province level (Hilpert & Mildner, 2013; Monitor Deloitte, Doblin, PDAC, 2015, p. 11). The thematic areas covered in the mining innovation strategy defined by the Canadian Mining Innovation Council (CMIC) in collaboration with industry are the following (Savine, 2015):

- Exploration: location of large, high-grade reserves while at the same time limiting disturbance to the ground or environment. This includes technology fields such as GPS surveying, 3D data maps, airborne technologies or down-hole seismic imaging.
- Extraction: Continuous mining methods that reduce cost through remote-operated equipment, automated loading and transportation systems, robotics and seismic mapping to make locations that are 2km or more beneath surface profitable.
- Smelting and Refining: improvement of pyrometallurgical operations, thermal treatment, and newer hydrometallurgical operations, as well as underlying electricity and chemistry usage or application.
- Five strategic themes for industry-focused programs have been defined by the Centre for Excellence in Mining Innovation (CEMI):
- Exploration: mineral exploration techniques in geology, geophysics and geochemistry.
- Deep Mining: risk mitigation in deep, high-stress, hot ore-bodies.
- Integrated mine engineering: mine design and enabling technologies to improve mine performance
- Underground mine construction: development techniques for more rapid access to ore
- Environmental & sustainability: enable more environmentally benign and socially beneficial impacts.

Especially for the funding of research and innovation activities, the Canadian Chamber's 2013 Mining Capital report states the following recommendations (Canadian Chamber of Commerce, 2013):

- Provision of funding beyond academic support that incorporates major industry players, service suppliers and cross-sectoral companies.
- Increase funding ratios and adapt funding flows to the requirements of different innovation projects.
- Facilitate and support coordination as well as collaboration between the different actors and organizations in the mining sector.

The Scientific Research and Experimental Development tax credit is a key tool of the federal government to support research and innovation activities in Canada (Canadian Chamber of Commerce, 2013). In the mining sector, a major part of research and innovation activities is visible in tax reduction through the purchase of innovative machinery and equipment. Thus, the tax reduction is a driving force for research and innovation activity carried out indirectly by the supplier industry.

7.2.2 Key actors and organizations

Canada has a very high variety of actors and organizations that carry out or support research and innovation activities, with more than 4000 sources of different and uncoordinated sources of funding. Overall, the mining supply sector in Canada is said to be the second biggest after the U.S. (Canadian Chamber of Commerce, 2013, p. 16). Around 40 different research and innovation organisations operate across Canada (Canadian Chamber of Commerce, 2013).

There is a need to recognise that the global consolidation of the mining industry has affected the financial commitment for mining innovation in Canada, too. As global mining conglomerates innovate, only a fraction of the money spent may end up in Canada. The government and more specifically the Department of Natural Resources (NRCan), which fund scientific activities (Hilpert & Mildner, 2013, p. 115; Lane, 2008, p. 17) should reconsider the size of research funds and the funding procedures to support larger, visionary Canadian mining innovation projects. Initiatives such as the Ultra-Deep Mining Network (UDMN), a $46 million business-driven initiative championed by Ontario's Centre of Excellence in Mining Innovation are successful examples of industry teaming up with academia to transfer R&D results into proven innovative technologies.

While there is a an obvious innovation track record, Canada aims to improve partnerships across the private and public sector to focus limited capacities and resources on the areas that offer opportunities to excel. The most important organisations in the mining-related business are:

- **Canadian Association of Mining Equipment and Services for Export (CAMESE)**: Trade association made up of Canadian member companies offering products and services to the mining industry.
- **Canadian Mining Innovation Council (CMIC**): A federally incorporated non-profit organization which was created to enable a more strategic investment of funding from the mining industry (Savine, 2015). It shall principally address the five major challenges of the mining innovation gap, the fragmentation of research, development and innovation organizations, the diversity of the industry, the tyranny of short termism and the innovation investment gap (Canada Mining Innovation Council, 2014)
- **Mining Association of Canada (MAC):** The national voice of the Canadian mining industry on a national and international level. MAC and PDAC (see further below) lobby the government particularly with respect to regulations, funding for juniors and set guidelines for corporate social responsibility.
- **Centre for Excellence in Mining Innovation (CEMI):** A funding agency that fosters innovation and implement excellence in the Canadian Mining Industry.
- **Geological Survey of Canada (GSC) and Provincial Geological Surveys**: delivery of geoscientific surveys
- **Canadian Mining Industry Research Organization (CAMIRO)**: Industry-based, not-for-profit, collaborative research broker for Canada's industrial mining sector for the past 35 years. Industry defined and funded project, 1 to 3 years in duration impact mining methods, mineral processing and exploration methods
- International Mining Innovation Institute (IMII): Industry-based funding agency for research and education in Saskatchewan
- **SOREDEM**: Industry-based mining research group of the Quebec Mining Association
- **COREM**: Not-for-profit industry supported mineral processing research and testing, it runs a unique pilot plant.
- **Canada Oil Sands Innovation Alliance (COSIA)**: Alliance of oil producers to advance environmental innovation
- **CanmetMINING**: Mining/Materials sector of NRCAN (Natural Resources Canada). Lead a green mining initiative. CanmetMINING also meets with the Chief Inspectors of Mines from every province and territory annually to discuss emerging issues, challenges and areas of R&D that

can help promote productivity, sustainability and health and safety in mining.
- **Canadian Institute of Mining and Metallurgy (CIM)**: Professional organization for mining in Canada
- **Prospectors and Developers Association of Canada (PDAC)**: Represents Junior Mining Industry to promote exploration and mine development in Canada, funded the Deloitte survey of innovation in Canada.
- **National Research Council of Canada (NRC):** Canada's premier research and technology organization that partners to provide innovation support and strategic research
- **Natural Sciences and Engineering Research Council of Canada (NSERC):** federal government agency to fund university scientific and engineering research in Canada
- **Natural Resources Canada (NRCan)**, is the ministry of the government of Canadaresponsible for natural resources, energy, minerals and metals, forests, earth sciences, mapping and remote sensing
- **University-based Exploration Research Centers:** Mineral Deposit Research Unit (MDRU) at the University of British Columbia, Mineral Exploration Research Centre (MERC) at Laurentian University, Subury, Ontario or CONSOREM group in Quebec.
- University-based Mining and Mineral Processing Centers: UBC Keevil School of Mining; Queens University Buchans School of Mining, University of Toronto Lassonde School of Mining, Laurentian University Goodman School of Mines, McGill University Materials Engineering, University of Alberta Canadian Centre for Clean Coal Carbon and Mineral Processing; Western University Surface Science Western, York University Lassonde School of Engineering

In 2011, 913 companies existed in Canada considering themselves as suppliers of the mining industry, delivering supplies, equipment and services to the global mining industry (Savine, 2015).

Among the Canadian mining companies active in Research and Innovation, the following are mentioned among the top 100 R&D spenders in Canada in 2013 (Savine, 2015):
- No. 18: Syncrude Canada—$157.2 million
- No. 20: Vale Canada—$132 million
- No. 50: Novelis Inc.—$43 million
- No. 69: Molycorp Canada—$22.9 million
- No. 78: Teck Resources Limited—$19 million
- No. 83: Rio Tinto Iron & Titanium—$17 million
- No. 85: ArcelorMittal Dofasco—$19.9 million

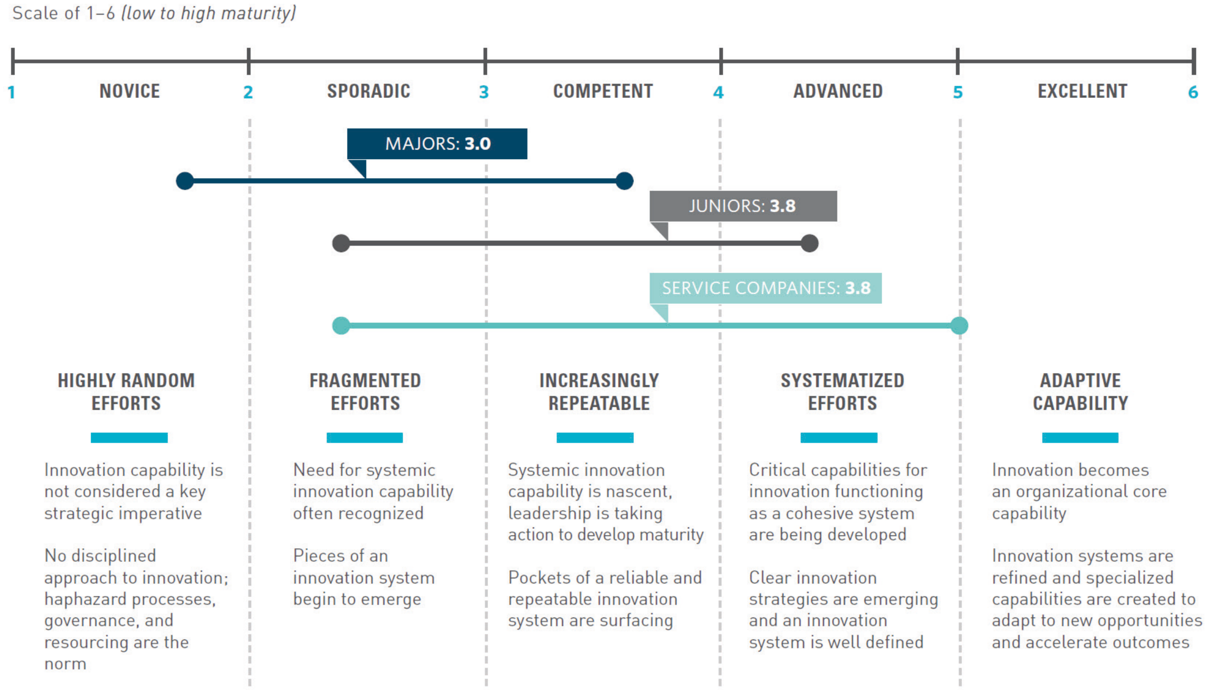
The mining supply and service sector is defined as a "hidden multi-billion industry" that is often not considered in the context of the analysis of the mining industry. The mining supply and service sector includes mining equipment, supplies and service companies, mining contract service companies as well as consulting services and other related companies (PWC, 2014). From an industry perspective, service and supply companies have taken a leadership role in Canada's mining research and innovation landscape whereas major companies are searching for research and innovation to a major part outside of their own organisation and junior companies often lack the funding and expertise for continuous innovation (see ***Figure 21***). Often, the lack of research and innovation activities in industrial companies is caused by reluctance to take risk and the lack of supportive structures such as innovation processes, incentives and strategies (Monitor Deloitte, Doblin, PDAC, 2015).

The role of small and medium sized companies and the need to support them in research and innovation activities is not a new phenomenon (Lane, 2008)

Politics related to raw materials:

Politics related to raw materials in Canada are highly influenced by the regions and thus often not centrally coordinated. From a historical perspective, it is interesting that Canada and the U.S. started out with the same laws respecting mining and mineral rights, but went

Figure 21: Innovation management maturity of industry players in the Canadian mining sector.



Source: Monitor Deloitte, Doblin, PDAC, 2015)

different ways with respect to regulatory and tax regimes. Firstly, in Canada minerals are reserved by the provinces, while in the U.S. minerals are either associated with surface ownership (primarily in the eastern US) or reserved by the federal government (primarily in the western US). Secondly, mineral rights in Canada are retained by the Crown or the provinces while in the U.S. mineral rights are privately owned. This poses, for instance, particular challenges for developing mining opportunities in proximity to First Nation jurisdictions. The following recommendations have been formulated for the Canadian mining policy (Dobra, 2014).

- Creation, strengthening or emulating private property rights.
- Reform of Canada's leasing system
- Reduction of uncertainty regarding environmental regulations
- Reduction of uncertainties and duplications in mining regulations
- Reduction of uncertainties in land rights

These policy recommendations indirectly influence innovation capabilities through their ability to restrict investments in mining. Furthermore, inter-university linkages are, based on a 2008 report from the CMIC, not encouraged by Canadian raw material policy (Lane, 2008). The Energy and Mines Minister's Conference, however states that "*the federal, provincial and territorial governments in Canada support an environment that favours innovation throughout the resource economy*" (Energy and Mines Minister's Conference, 2015).

In the allocation of significant funds for high quality scientific programs, Canada ranks below the U.S., Europe, Japan, China and Australia, whereas Australia and Canada are the countries with the strongest emphasis on the mining industry (Lane, 2008). Canada's geoscience (exploration) community demonstrates exceptional leadership in the planning and execution of publically-funded or ppefunded national and regional-scale geoscience R&D initiatives. Examples include: Lithoprobe; various ExTech programs; Discover Abitibi; Footprints etc.

7.2.3 Knowledge base for research and innovation

The knowledge base is one of the key success factors of the Canadian mining industry containing a relevant mix of knowledge and skills. This includes a variety of financial, organisational and technical knowledge. This knowledge base attracts major companies to settle in Canada for the coordination of their operations (Canadian Chamber of Commerce, 2013). Toronto is home to a large number of mining financings in the world and is a «centre for excellence» in mine/exploration finance. The Toronto Stock Exchange (TMX) and the TSX Venture are home to more resource sector companies than any exchange in the world.

The fact that provinces require companies to file data collected during mineral exploration for credit to keep mining claims in good standing has resulted in an extensive information database in Canada. This information combined with an extensive map database and regional data compilations provides an excellent knowledge base of Canada.

The priority of research personnel has shifted from mining to high-technology projects and instrumentation, weakening research and innovation activities in the core mining areas (Lane, 2008).

In terms of education, Canada is home of several prestigious universities offering mining related programmes (Jeffrey & Camborne School of Mines, 2016), most notably

- University of Alberta, School of Mining
- University of British Columbia
- Dalhousie University, Department of and Resource Engineering
- Haileybury School of Mines, Northern College Ontario
- Laval University, Department of Mining Engineering (Quebec)
- Goodman School of Mines, Laurentian University
- McGill University (Montreal), Department of Mining and Metallurgy
- Ecole Polytechnique Montreal
- Queens University, Department of Mining
- Lassonde Institute of Mining, University of Toronto
- Memorial University of Newfoundland, Earth Sciences

In addition, more than 25 community colleges across Canada offer mining-related programmes in mining and mineral engineering, metallurgical engineering and geological engineering.

7.2.4 Key technologies

Canada is a leading player in the global mining industry especially in the areas of exploration, mineral processing mineral extraction and environment. In mining technology however, the Canadian Mining Innovation Council stated in 2012 that Canada is no longer a leader (Canadian Chamber of Commerce, 2013), even though early on it pioneered the development of airborne electromagnetic survey tools; innovative mining technologies such as paste filling and vertical crater retreat mining etc.

Technologies mentioned in the context of Canada's advances in mining innovation are the reduction of emissions, upgrades of equipment and atmospheric emissions reduction. Furthermore, the areas of deep mining innovation to improve safety and productivity, exploration innovation to target deposits within Precambrian shield terrains, eco-innovations to reduce the levels of contamination from mine waste management facilities, transportation innovation that ensures efficient transportation of ore and waste rock and engineering innovation able re-design production processes are mentioned (Sudbury Community Foundation, 2014).

Especially the extensive science and technology network as well as the broad expertise in geoscience are mentioned among the strengths of Canada's mining industry. Furthermore, Canada's mining sector is said to be the global leader in green mining technologies (Energy and Mines Minister's Conference, 2015). CanmetMINING of the Natural Resources Canada is leading a Green Mining Initiative. Another example for technological excellence in Canada is the Ultra-Deep Mining Network (UDMN), a 46 million dollar initiative lead by Ontario's Centre for Excellence in Mining Innovation (CEMI) and mainly aiming at rock stress risk reduction, energy reduction, novel methods of material transport and productivity as well as improved human health. This work builds on historical rock stress studies at MIROC, CAMIRO, AMIRA and MIRARCO.

7.3 Metrics of Canada's mining innovation system

From an overall perspective, Canada scores well in the Global Innovation Index, especially in the innovation input sub-index (see ***Table 7***). However, there exists some potential for improvement in the Innovation Efficiency Ratio that aggregates both, the innovation in- and output sub index.

Whereas the availability of scientists and engineers as well as the quality of scientific research institutions is very high, the capacity for innovation does not score among the top 20. Technology transfer as well as company spending on R&D seem to be the major factors where Canada has a considerable potential for improvement (see ***Table 8***).

In 2013, Canadian mining companies invested $522 million in R&D (Marshall, 2014). It has to be considered that this investment was reduced significantly in the last years with a business expenditure on R&D (BERD) in the mining sector of $632 million in 2011 (Savine, 2015). The same applies for the gross expenditure on R&D (GERD) that has declined in recent years,

Table 7: Global Innovation Index.[1]

	SCORE 0–100 OR VALUE (HARD DATA)	RANK
Global Innovation Index (out of 141)	55.7	16
Innovation Output Sub-Index	46.4	22
Innovation Input Sub-Index	65.1	9
Innovation Efficiency Ratio	0.7	70
Global Innovation Index 2014 (out of 143)	56.1	12

Source: Dutta, et al., 2015, p. 186

1 As mentioned in Chapter 5, note that the GII is a measure of a country's overall innovation performance. The performance on overall innovation may differ significantly from mining innovation.

Table 8: Canada's Innovation and Technology Readiness Indicators.

INDICATOR	VALUE	RANK / 144
Innovation		
Capacity for innovation	4.6	26
Quality of scientific research institutions	5.5	15
Company spending on R&D	3.9	27
University-industry collaboration in R&D	4.9	19
Gov't procurement of advanced tech products	3.7	48
Availability of scientists and engineers	5.1	12
PCT patents, applications/million pop.*	84.8	19
Technology Readiness		
Availability of latest technologies	6.2	16
Firm-level technology absorption	5.4	30
FDI and technology transfer	4.6	71
Individuals using Internet, %	85.8	13
Fixed broadband Internet subscriptions/100 pop.*	33.3	12
Int'l Internet bandwidth, kb/s per user*	115.9	22
Mobile broadband subscriptions/100 pop.*	41.0	52
Values are on a 1-to-7 scale unless otherwise annotated with an asterisk (*).		

Source: Schwab, 2015, p. 147

especially related to average OECD expenditure (Savine, 2015).

Overall, R&D personnel employment in Canada is one of the highest in the OECD, which was primarily driven by business enterprises (Savine, 2015). In 2012, the mining industry employed 4700 people in R&D, more than e.g. the pharmaceutical sector (Marshall, 2014). In both, patent application and patent grants, Canada underperforms related to the OECD average from an overall perspective (Savine, 2015). The number of firm creation, especially in technical areas is relatively low in Canada (Savine, 2015)

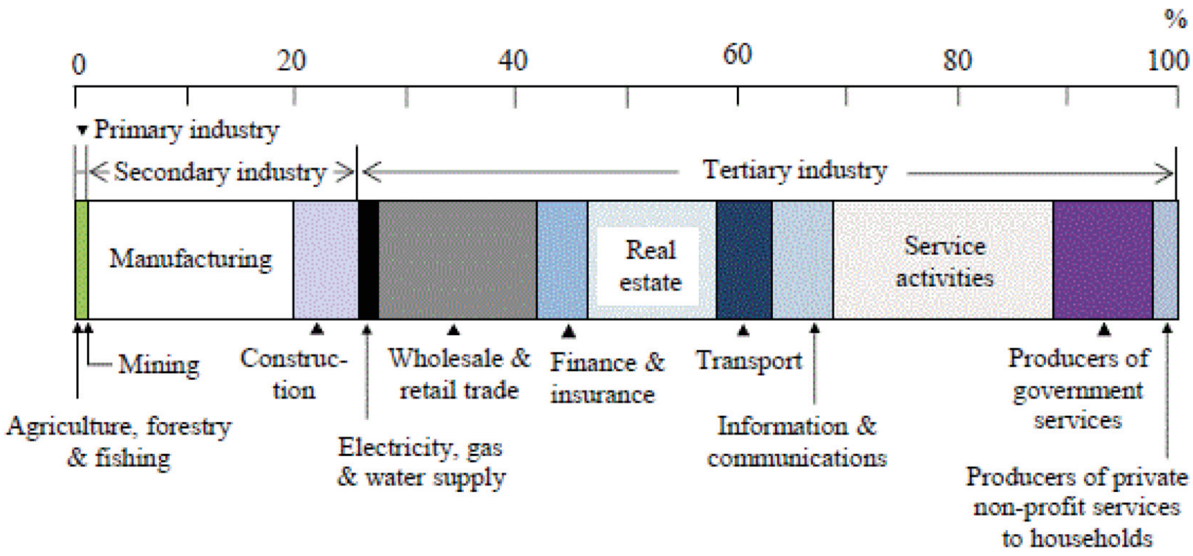
8. Operational analysis of research and innovation: Japan

8.1 The big picturee of innovation in raw materials and mining in Japan

Challenges for Japanese mining companies:

The domestic mining industry in Japan is small-scale and low-tonnage. Operating mines and employment in the mining industry have been in decline because of depleted ore reserves, high mining costs, the availability of cheaper imports and social problems, notably mine pollution. These days mining plays only a minor role in Japan (***Figure 22***). Its contribution to the GDP is marginal. In 2010, only a handful of mines were still operational.

Figure 22: Gross Domestic Product by Type of Economic Activity 2013.



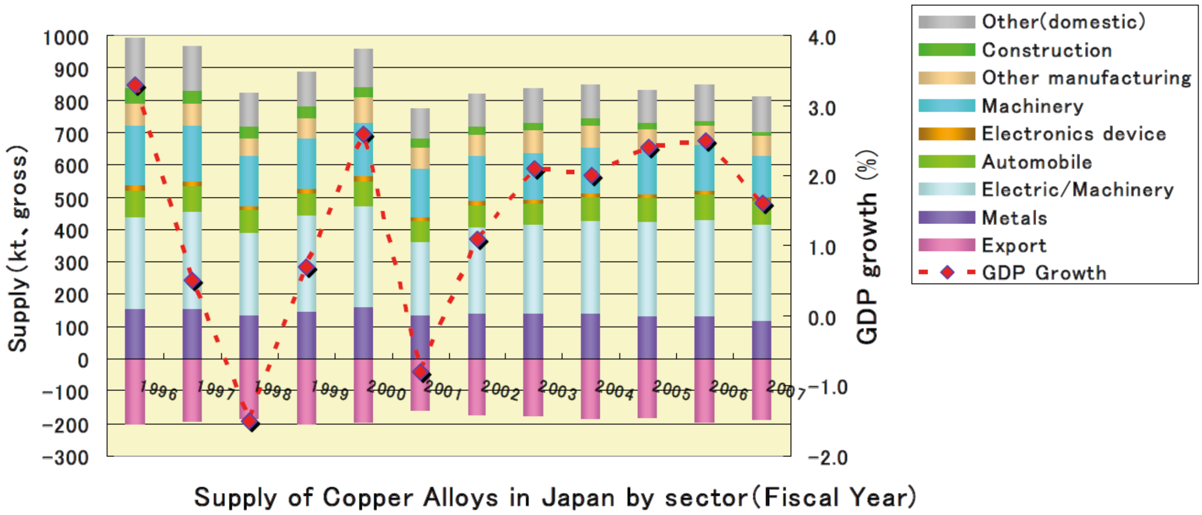
Source: Statistics Japan, 2015

The importance of raw materials for Japan can be explained by the country's history. As the Japanese economy rapidly grew after World War II, domestic raw materials production could not keep up with the demand of the manufacturing industries. In 1963 the Ministry of Economy, Trade and Industry (METI) established the Metal Mining Agency of Japan (MMAJ) to ensure a stable supply of non-ferrous metal and mineral resources. The MMAJ is the main organization that executes the government's mineral policies. Supply disruptions (e.g. the oil crises in the 1970s) increased the awareness of Japan's vulnerability as an importer of energy resources and non-fuel minerals and initiated a number of measures to ensure avoid shortage of raw materials (Koroshy, et al., 2010).

Japanese trading houses, smelters and mining companies therefore started investing all over the world and imported raw materials to Japan for refinement and smelting. They sold finished products to both the domestic manufacturing sectors and international customers. Some Japanese companies even sell their outputs directly from foreign mines to foreign buyers.

The mineral processing industry is large and includes the processing and production of chemicals, fabricated metal products, industrial mineral products, iron and steel, nonferrous metals, and petroleum products (INTRAW, 2015). Industries such as automotive, construction, machinery, electronics etc. demand significant amount of metals (e.g. copper, ***Figure 23***). Moreover, rare earth metals are needed

Figure 23: Demand of Copper Alloy by Sector.



Source: Kamijya, 2008

to manufacture consumer products including white goods, (electric) cars, computers and cell phones. Japan also sets a foot in other growing industries such as robotics and aerospace.

Japan always had mine-site smelters and refineries for the metal concentrates produced by domestic mines. Hence, the Japanese smelting industry has been "custom smelters" for the domestic market and for export needs (Kunitomo, n.d.). Approximately 20 smelters and refineries operate in Japan today.

In their quest to secure raw materials, the country has invested heavily in overseas mines during the past decades, including over 40 iron, nickel, copper, zinc and gold mines in Southeast Asia, Australia, North and South America, and Africa (***Figure 24***). Most of these investments had the objective of securing a significant and influential, but a minority, share of ownership in the target companies. In addition to involvement by mining companies, the main players include trading companies affiliated with their respective groups, for instance the Mitsubishi Corp.

Despite being located far away from the mining areas, Japan has built strong competences related to exploration; the

Figure 24: Japanese Involvement in Overseas Copper, Lead, Zinc Mines.

Mine	Major Products	Country	Production or Farm-in	Japanese Equity Interest	Japanese Companies
Huanzala	Pb, Zn	Peru	1968	100%	Mitsui Corp, Mitsui Mining
Endeavor (Elura)	Pb, Zn	Australia	1983	25%	Toho Zinc
Morenci	Cu	USA	1986	15%	Sumitomo Metal Mining, Sumitomo Corp.
Escondida	Cu	Chile	1994	10%	Mitsubishi Corp., Mitsubishi Materials, Nippon Mining, others
Tizapa	Pb, Zn	Mexico	1994	49%	Dowa Mining, Sumitomo Corp.
La Candelaria	Cu	Chile	1995	20%	Sumitomo Metal Mining, Sumitomo Corp.
McArthur River*	Cu	Australia	1995	30%	Nippon Mining
Northparkes	Cu	Australia	1995	20%	Sumitomo Metal Mining, Sumitomo Corp.
MacArthur River	Pb, Zn	Australia	1995	25%	Nippon Mining, Mitsui Corp, Marubeni
Huckleberry	Cu	Canada	1997	40%	Mitsubishi Materials, Furukawa, Dowa Mining, Marubeni
Collahuashi	Cu	Chile	1999	12%	Mitsui Corp, Nippon Mining, Mitsui Mining
Batu Hijau	Cu	Indonesia	1999	35%	Sumitomo Metal Mining, Mitsubishi Materials, others
Los Pelambres	Cu	Chile	2000	40%	Nippon Mining, Mitsubishi Materials, Marubeni, others
Antamina	Cu, Pb, Zn	Peru	2001	10%	Mitsubishi Corp.
Atakama Kozan*	Cu	Chile	2003	60%	Nittetsu Mining

Source: Kunitomo, n.d

development of a mine as well as the mining processes itself. These competences are an important asset in negotiations with mining companies abroad. However, Japan also seeks to be more independent from foreign imports by investing into the substitution, reuse and recycling of metals. These are other areas in which Japan, innovation-wise, has built an excellent reputation.

8.2 The mining innovation system in Japan

8.2.1 Raw materials strategy and priorities

The global situation for resource acquisition, in particular the immense resources needs of China and the other BRIC countries, and the emergence of more rapidly industrializing countries, made competition increasingly fierce for Japan's target resources. The combination between high demand and only few possibilities for the exploration and extraction of raw material in Japan required an explicit strategy of how to deal with raw materials (Hilpert & Mildner, 2013, p. 106f).

The following four key programs have existed as part of Japan's mining resources policy since the 1970s (Kikkawa, 2013).

- Promotion of domestic exploration to maintain the economic rationality of domestic mines, which are the most stable supply source of mining resources.
- Support for overseas resource development activities and technical cooperation for resource development by developing countries in order to secure stable overseas mining resources.
- Creation of a rare metals stockpiling system from the standpoint of national economic stability and security.
- Prevention of mine pollution from suspended or abandoned domestic mines.

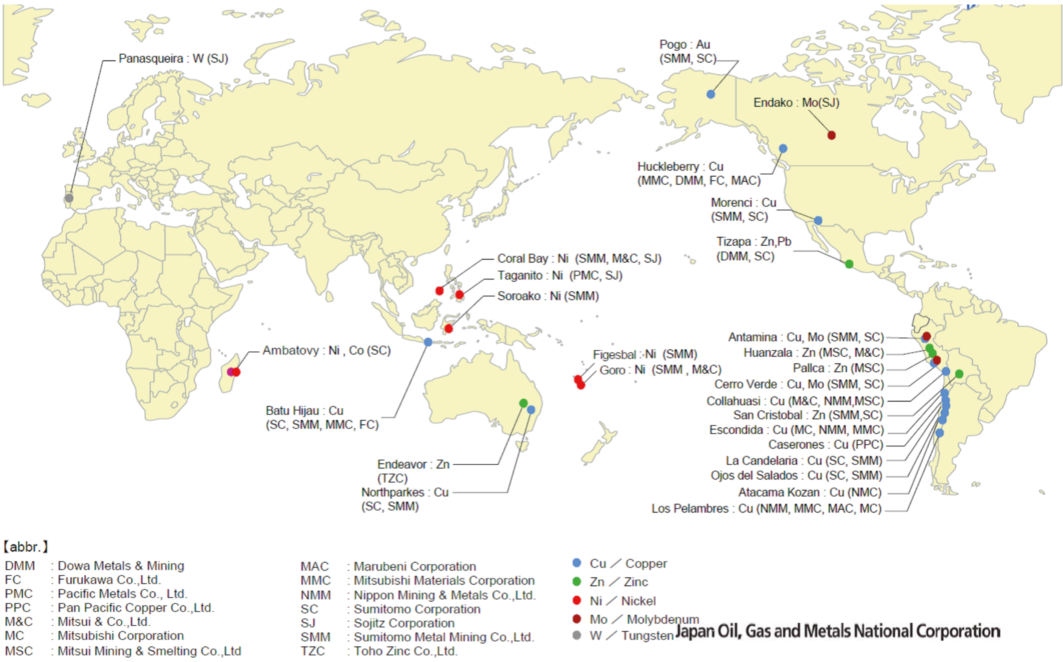
Japanese policy documents

Over time, Japan developed a truly comprehensive strategy to guide and coordinate policy on securing raw materials supplies. The strategy is set out in several policy documents. The most important are:

- **Strategic Energy Plan of 2007**, which was later revised in 2010 and 2014, which put forward recycling and stockpiling of rare metals, as well as seabed exploration (METI, 2014)[1]
- the **'Strategy for Ensuring Stable Supplies of Rare Metals'** of July 2009, compiled by the Ministry of Economy, Trade and Industry (METI): This strategy is built on four pillars:
  - The first pillar targets **diversifying supply sources through strategic resource diplomacy**. The government's main tasks in this respect are facilitating technology transfer, infrastructure development and energy cooperation through bilateral and multilateral trade agreements, which would serve the development objectives of resource-rich countries and at the same time assure access to raw materials for Japan. This strategy is closely linked to establishing joint exploration initiatives with resource-rich countries and their financing. In Japan such initiatives take form of public-private partnerships whereby public institutions, such as the Japan Oil, Gas and Metals National Corporation (JOGMEC), carry out overseas field surveys and provide financial assistance to high risk mine development projects (***Figure 25***).
  - The second pillar promotes **recycling of scrap and end-of-life products** and calls for improved utilization of existing recycling processes and promoting R&D in recycling technology. Several laws, among them the Law for Promotion of Effective Utilisation of Resources (1991), the Basic Law for Promoting the Creation of a Recycling-Oriented Society (2000) and the Home Appliances Recycling Law (2001), contributed to the successful establishment of the recycling-oriented society in Japan. Collecting these appliances made it in turn possible for companies to develop recycling processes for the recovery

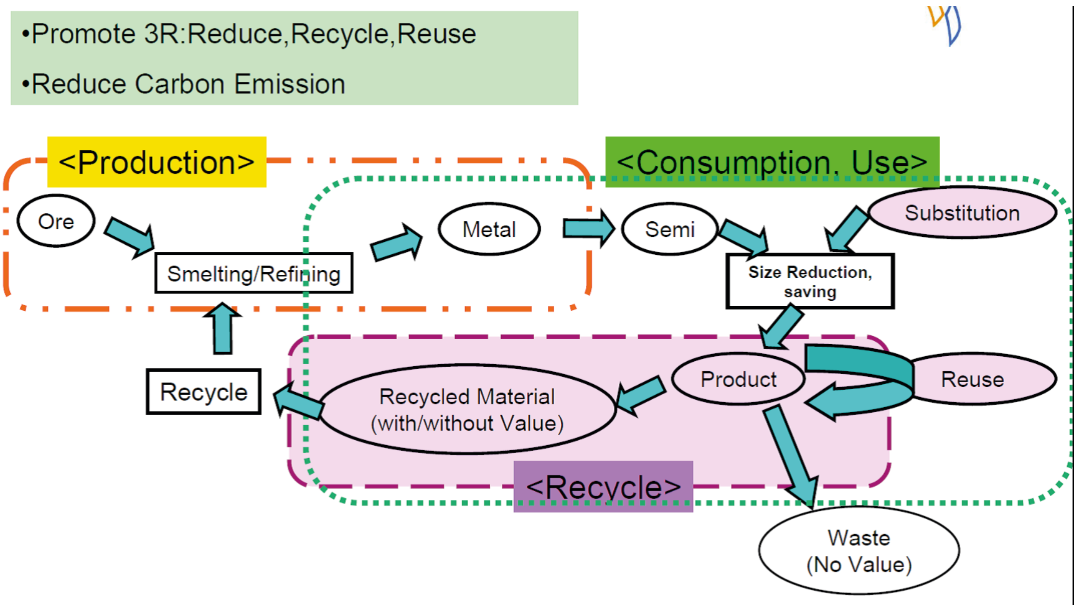
1 http://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/4th_strategic_energy_plan.pdf

Figure 25: Major Base Metal Mining Investment by Japanese Companies



Source: Kamijya, 2008

Figure 26: Sustainable Material Supply in Japan.



Source: Kamijya, 2008

of steel, copper, aluminum, and other materials. With the financial assistance of METI, these processes were later extended to recycling of rare earths, mainly dysprosium and neodymium. METI and other government agencies are promoting the "3Rs" policy (reduce, reuse, recycle) (***Figure 26***)."

• Thirdly, Japan also aims at promoting the **use and development of alternative materials** in order to maintain its competitiveness and to develop new industries, especially in the context of rare earths. To achieve this goal, its plan is to strengthen industry-university-government linkages as well as collaboration across up- and downstream sides of the supply chain (Advisory Committee on Energy and Natural Resources, 2009). Such efforts are carried out under the auspices of METI and the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and are financed through funding agencies: the New Energy and Industrial Technology Development Organization (NEDO); and the Japan Science and Technology Agency (JST) along with the Japan Society for the Promotion of Science (JSPS), respectively. While METI promotes applied research through the National Institute of Advanced Industrial Science and Technology (AIST) as well as industry related projects, MEXT fosters basic research at universities and strategic research by the National Institute for Materials Science (NIMS) and by the Riken research organization (NIMS, 2011).

- The fourth pillar describes the **stockpiling of strategic materials** in order to hedge against short-term supply risk, as a complement to the medium and long term strategies covered by the previous three pillars

- the **100 Actions to Launch Japan's New Growth Industry** of August 2010 presents the key policies of METI for the fiscal year 2011. It basically substantiates the Strategy for Ensuring Stable Supplies of Rare Metals, and indicates the budgets for the projects that follow the four pillars outlines above.
- The **Amended Mining Act of Japan**: The Mining Act, which provides for the basic rules for mining in Japan, has undergone no major revisions since the establishment in 1950.

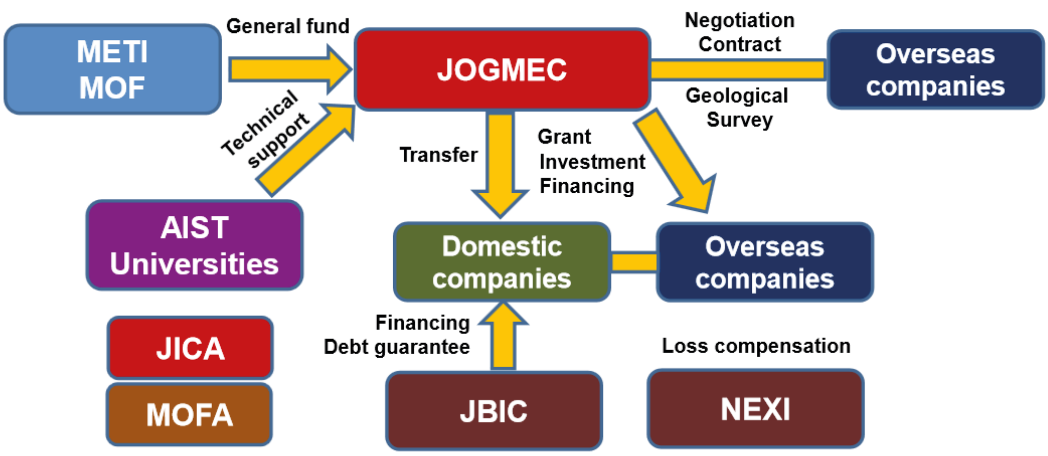
A key strength in the Japanese mining research and innovation system is the strong interlinkage between politics and economic actors (Hilpert & Mildner, 2013, p. 108). A huge effort is spent to reach common agreement that is than the basis for effective and fast realization of decisions taken. Furthermore, government actors observe technological developments and communicate those to universities and other research organizations for priority definition.

8.2.2 Key actors and organizations

Government: Japan promotes strategic collaboration between governmental bodies, agencies and independent administrative institutions in implementing their resources policy, including METI, JOGMEC, JICA, JBIC etc..

- The lead unit is the **METI (Ministry for Economy, Trade and Industry)**, where the information and decision strands converge. Due to its traditionally strong position, the METI may carry through a long strategic direction of commodity policy and contribute to a coherent implementation concern. The strength of the Japanese government and administrative system is the close institutional and personal links between politics, business and the manifold links between organizations.

Figure 27: Organisations involved in Securing Overseas Resources.



Source: Takagi, 2015

The implementation of the Strategy for Ensuring Stable Supplies of Rare Metals involves several independent administrative organisations. They complement each other by implementing seamless assistance to overseas mineral resources development companies throughout the life cycle of mining operations, from the grassroots exploration to detailed geological surveys, tax concessions, mining, metal smelting, slag recycling technology development, investment and financing, grant applications, debt guarantees, mine production technology and the training of personnel. Among them, JOGMEC is mainly responsible for the geological surveys, financing, debt guarantees, etc., JBIC for financing and debt guarantee, NEXI for trade insurance, and JICA for development of the surveys, staff training, organizational training classes, dispatch of experts, cooperation standard surveys and loans etc. It is due to the combined operations of the four agencies, which makes Japanese overseas exploration and development of mineral resources management system smoothly progress, and ultimately form «one-step» service for a seamless management system.

- The **JOGMEC** is the result of the merger of the governmental Japan National Oil Corporation (JNOC) and the Metal Mining Agency of Japan (MMAJ) in February 2004. More than 450 staff now devote themselves to JOGMEC's activities, funded by a budget that amounts to about $1.4 billion US dollars in fiscal year 2007. JOGMEC has three main functions.
  - First, in cooperation with other government agencies, JOGMEC supports Japanese companies that are active in exploration and the development for oil, natural gas, non-ferrous metals and minerals. It provides financial assistance, such as the provision of equity capital and liability guarantees to encourage E&P activities. JOGMEC also possesses cutting-edge technologies, such as bioleaching and recycling technologies in metals, which helps them to attract many resource developers and partners. As JOGMEC is a government-related organization, the rights to its acquired projects are transferred to mining and trading companies when positive results are obtained within a three-year exploration period.
  - Secondly, JOGMEC is responsible for strategic warehousing also of energy and mineral Resources and
  - Thirdly, it provides technical assistance to municipal governments or private companies that have responsibility for mine pollution control over suspended or abandoned mines all over Japan.
- **Japanese Bank for International Cooperation (JBIC)**: JBIC provides loans and guarantees to develop mines and mining infrastructure in resource-rich countries. In 2012, the Government of Japan increased the credit line for the Japan Bank for International Cooperation (JBIC)) to further enable the Japanese private sector to secure strategic natural resources, and expanded JBIC's mandate to provide financial assistance for certain types of natural resource development projects in developed countries.
- **Incorporated Administrative Agency, Nippon Export and Investment Insurance (NEXI)**: Created in2001, 145 employees, NEXI is a 100% government-owned organisation. NEXI mainly provides various types of insurance to cover political and commercial risks involved in the business or the overseas transactions, such as export, import, investment and financing, which private insurance cannot cover.
- **Japan International Cooperation Agency (JICA)**: JICA has two objectives in the mining sector: (1) to improve the investment environment in terms of both software and hardware aspects by, for example, strengthening the administrative capacity of developing countries' governments and developing peripheral infrastructure; and (2) to develop human resources. For the second objective, JICA has recently been working with Japanese universities to offer the training

program in Japan, popularly known as the «Kizuna Program.»[2] JICA has more than 1,800 employees.[3]

2 http://www.jica.go.jp/english/our_work/thematic_issues/energy/activity.html
3 http://www.daiwatv.jp/contents/epre/kouen/seminer/20269-001/download/20269-001.pdf

Research Institutes: Japanese research institutions actively pursue activities that reduce Japan vulnerability with regard to mineral access. They conduct research on technologies that can strengthen Japanese industry or create new opportunities for Japanese businesses.

Table 9: Key players and their activities in Japan's overseas mining activities.

	EXPLORATION	MINING
Enabling Agencies and Key Activities	METI & JOGMEC • Preliminary Survey by Remote Sensing • Technical Research on Separation and Extraction AIST • Geological Survey JBIC • Development funds (for infrastructure development)	• Import of natural resources JBIC • Development fund (Loan/liability guarantee to for the government in foreign countries, to mining companies to acquire equity) METI & NEXI • Trade insurance METI & JOGMEC • Problem resolution for site operation
Key Activities	• Geological survey • Equity Acquisition • Infrastructure Development • Technical assistance, Feasibility studies • Development of the legal systems • Support to environmental measures • Trade insurance	

- **The National Institute of Advanced Industrial Science and Technology (AIST)** is Japan's leading public research organization. It was formed in 2001 through a merger of 15 research institutes operating under the Ministry of International Trade and Industry (MITI, reorganized as METI in 2001) and the Weights and Measures Training Institute. In 2006 AIST established a Rare Metal Task Force to actively tackle the rare metal problem in Japan. The objective of the Task Force was to strengthen Japan's economic security by developing resource exploration technologies, technologies to reduce rare-metal consumption, substitutes and recycling technologies. It employs roughly 2,300 researchers.
- **Metal Economics Research Institute**

The Metal Economics Research Institute (MERI/J) is a non-profit research institute that is supported by Japanese non-ferrous metal industries. MERI/J was established in 1989 to promote economic research on a variety of topics related to non-ferrous metals markets.200 In 2010 MERI/J had 19 Full Members and 16 Associate Members, among which were JOGMEC, JBIC, trading companies such as Sumitomo Corp. and Mitsui & Co. and other members from the industry, including companies in the field of non-ferrous metal smelting, wire and cable, brass mill, and electric utilities.

Universities: Japan has interest in the downstream mining activities and as such there is a major research focus on downstream activities such as processing technology, material science and substitution (Jeffrey & Camborne School of Mines, 2016). The most important university chairs for research on mining and minerals are listed below.

- Akita University, Department of Earth Science and Technology
- Waseda Unviersity, Department of Resources and Environmental Engineering
- Kyoto University, Department of Civil and Earth Resources Engineering
- Kyoto University, Department Materials Science and Engineering
- Hokkaido University, Graduate School of Engineering
- University of Tokyo, Department of Materials Science and Metallurgy
- Kyushu University, Department of Earth Resources and Engineering

Industry:

At the time of writing only a few mines are operational and the mining sector is dominated by eight major mining houses: Dowa Metals & Country mineral Policy Mining, Furukawa Metals and Resources, Mitsubishi Materials, Mitsui Mining and Smelting, Nippon Mining & Metals, Nittetsu Mining, Sumitomo Metal Mining, and Toho Zinc.

Table 10: Key Industry Players in the Mining and Metals Industry.

TYPE OF ORGANISATIONS	MAIN PLAYERS
Mining Houses	• Dowa Metals & Country mineral Policy Mining, • Furukawa Metals and Resources, • Mitsubishi Materials, • Mitsui Mining and Smelting, • Nippon Mining & Metals, • Nittetsu Mining, • Sumitomo Metal Mining • Toho Zinc.
Trading houses	• Itochu Corp. • Sumitomo Corp. • Sojitz Corp. • Toyota Tsusho Corp. • Tokyo Boeki Steel & Materials Ltd. • Iwatani Corp. • Material Trading Company • Mitsubishi Corp. • Mitsui & Co., Ltd. • Marubeni Corp. • Hanwa Co., Ltd. • Okaya & Co., Ltd. • Alconix Corporation
Mining and non-ferrous metal companies:	• Mitsui Mining & Smelting Co.,Ltd. • Dowa Metals & Mining Co., Ltd. • Sumitomo Metal Mining Co., Ltd. • Furukawa Metals & Resources Co., Ltd. • JX Nippon Mining and Metals Co., Ltd. • Mitsubishi Materials Corp. • Nittetsu Mining Co., Ltd. • Toho Zinc Co., Ltd. • Pan Pacific Copper Co., Ltd. • Pacific Metals Co., Ltd. • Overseas Uranium Resources Development (OURD)

Iron ore and coal	• Nippon Steel & Sumitomo Metals Corp. • JFE Steel Corp. • Kobe Steel Ltd. • JFE Shoji Trade Corp. • Mitsui Matsushima Co., Ltd. • Tokyo Electric Power Co., Ltd. • Kansai Electric Power Co., Ltd. • Kyushu Electric Power Co., Ltd. • Tohoku Electric Power Co., Ltd. • Chubu Electric Power Co., Ltd. • Hokuriku Electric Power Co., Ltd. • Hokkaido Electric Power Co., Ltd.
Stakeholders for Rare Earths	• Shin-Etsu Chemical Co., Ltd.: The largest producer of chemicals. Produces also permanent magnets and has developed a technology to get REM • Hitachi Metals Ltd.: producer of metal products, including permanent magnets. • Hoya Corporation: market leader for optical products, e.g. lenses, lasers etc. Requires cerium for polishing high-precision optics. • Mitsubishi group: One of the biggest Keiretsu conglomerates. Has established a joint venture for the development of permanent magnets with less dysprosium together with Daido Steel and Molycorp (financed by Jogmec) • Panasonic Corporation: Uses Europium and Terbium for fluorescent materials in LCD panels. • TDK Corporation: Produces digital storage devices and holds more than 30% of the permanent magnet market • Toshiba Corporation: Has developed a technology to re-used mining waste metals, recycles electronic waste • Toyota Motor Corporation: part of the Toyota group, the biggest car manufacturer (also hybrid/electric cars). • Sojitz Corporation: One of the biggest trading houses, fosters diversification of Rare Earth Metals demand by being involved in mining projects in Australia and Vietnam • Santoku Corporation: one of the leading manufacturers of rare earth alloys for the magnetic market.

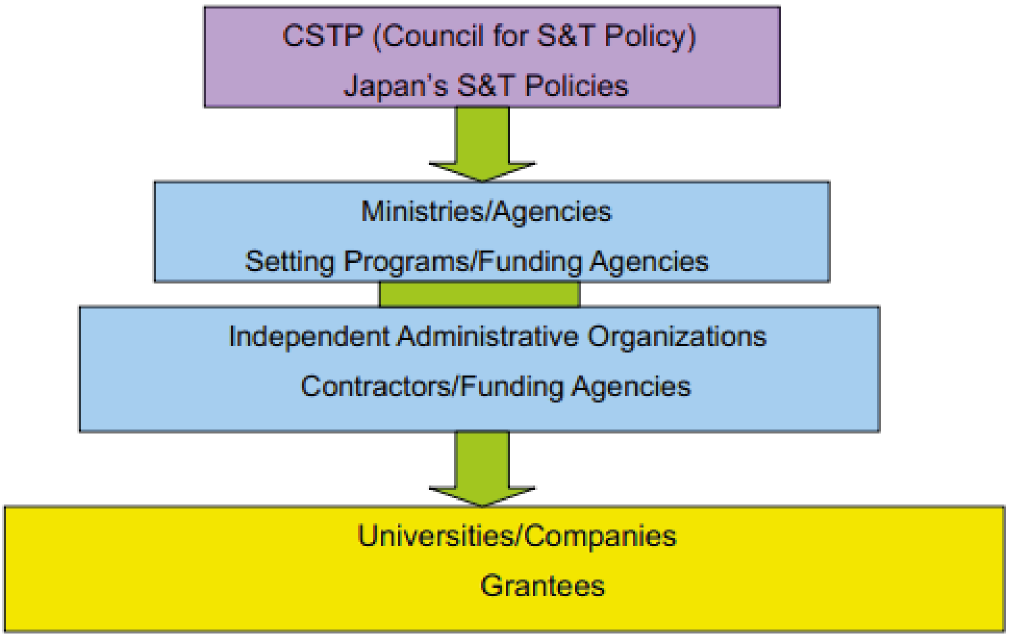
8.2.3 Knowledge base for research and innovation

R&D Policy Instruments for the Public Sector

The organizations involved in implementing competitive R&D funding act under the ministries/agencies. Each ministry/agency (e.g. METI) has one or more "independent administrative organizations" (e.g. JOGMEC), but the financial resources still come from the ministries/agencies and it is the ministries/agencies that set up competitive R&D programs. The council for S&T policy (CSTP) establishes Japan's science and technology policies in liaison with a number of stakeholders and asks the ministries and agencies to formulate research programs. These are then rated by the CSTP and ministries and the agencies eventually obtain budgets from the Ministry of Finance. Some of the grants are provided to the grantees directly by the ministries/agencies themselves, some are provided by the organizations under the ministries and agencies (***Figure 28***).

When a ministry/agency and an independent administrative organization under the ministry are jointly involved in one program, the typical mechanism is that the ministry/agency designs the programs and directly manages about half of the budget. They provide the other half to an organization under it so that the organization works as a contractor and takes care of all the administrative work

Figure 28: Structure of R&D funding mechanisms.



Source: National Science Foundation, 2006

incurred from the solicitation, reviewing, and transferring of funds to the grantees, in consultation with the ministry/agency.

The mining and minerals industry is targeted by several agencies. While JOGMEC plays the biggest role, there are other implementing organisations that participate in mining-related policy programs.

R&D Policy Instruments for the Private Sector

Regarding policy instruments relevant to the Private Sector, the following instruments are relevant: the R&D Tax credit; subsidies and research grants; and, SME policies (Woolgar, 2006).

- **R&D Tax Credit:** The Ministry of Finance introduced a proportional R&D Tax Credit in 2003 as an alternative to the existing R&D tax credit scheme. For R&D activities conducted jointly by academic, business and government circles, or R&D commissioned by the government in order to promote basic studies or innovative studies, a proportional tax credit of 12% plus 3% was introduced. The scope of qualified R&D expenses included such expenses as labour, non-personnel expenses, depreciation for machinery and buildings, and expenses of R&D activities conducted overseas.
- **Research Programs:** Various programs have been developed by Ministries to support private sector research activities. In 1999, a Japanese version of the US Small Business Innovation Research (SBIR) Program was established for supporting R&D activities by SMEs through contract research grants and subsidies. Other programs include the Advanced Technology Research Support program, operated by the National Institute of Information and Communications Technology. Funding expansion for environment and life science fields, and industrial R&D activities has increased through the science and technology basic plans, and corporate research appears to be expanding into areas related to energy saving electrical equipment, use of alternative power sources in automobiles or domestic use, as well as innovative food products that utilize bio properties
- **Small and Medium Sized Enterprises:** METI supports the development of SMEs based on measures in the following four areas: (1) support for

start-ups and SMEs entering new business, (2) development and use of human resources at SMEs, (3) diversification and facilitation of SME finance and support for revitalization of SMEs, through the use of research grants such as the Small Business Innovation Research Program.

8.2.4 Key technologies

JOGMEC is involved in a number of technology development project that touch on various subjects. (JOGMEC, 2012):

Development of exploratory techniques

1. Geophysical exploration: JOGMEC developed the TDEM data acquisition system by using the HT-SQUID (High Temperature Superconductive Quantum Interface Device). HT-SQUID is a very sensitive magnetometer that enables to improve the detectability of the deep underground structure.
2. Remote sensing technology: JOGMEC developed the data analysis technology to identify the host rock with rare metal and earth in Africa. Furthermore, It also developed an analysis technology for the identification of promising areas (e.g.porphyry copper and heavy rare earth deposit) assuming to utilize for next- generation satellite sensor (hyperspectral sensor) data. In addition,
3. Development of support device: JOGMEC completed the portable spectrum meter and produced the prototype for a new magnetic exploration technique (SQUID gradiometer), which is regarded as the next-generation geophysical exploration equipment

Mining and metallurgy technology development

With regard to the development of bio-leaching technology, which utilizes the power of microorganisms to extract copper from low-grade ores, JOGMEC commenced demonstration testing at a mine in Chile. Further, with regard to the development of energy-saving refining processes, JOGMEC has embarked on technological development to reduce the electric power used in the copper electrolysis process, which requires a large amount of power. JOGMEC also continues to perform studies and offer development support for rare metal recovery technologies.

Recycling Technology Development

The development of rare metal recovery technologies also applies to recycling raw materials such as waste small appliances and refining by-products. With regarded to waste small appliances, JOGMEC has conducted tests to identify the optimum leaching conditions for efficiently recovering the tantalum and cobalt contained in capacitors and lithium-ion batteries and acquired data ahead of demonstration plant testing. JOGMEC began considering processes to increase the quantity of antimony recovered from smelting by-products and have made progress in the development of antimony enrichment techniques and extraction agents.

Exploration of marine mineral resources and technological development

Japan possesses the world's sixth largest ocean area in terms of the size of its territorial waters, exclusive economic zone (EEZ) and continental shelf - an ocean area in which, in addition to oil and natural gas, the existence of energy and mining resources such as methane hydrate and sea-floor hydrothermal deposits has been confirmed. Various issues remain, however, with regard to the practical application and commercialization of these energy and mining resources. These include an understanding of the amounts of available resources and the status of their availability, the development of production techniques, and controls on the environmental impact from development. Future geophysical surveys in the ocean area around Japan will be accomplished Under the Ocean Energy and Mineral Resource Development Plan prepared in 2009, three-dimensional geophysical surveys covering 62,000 square kilometres will be implemented by FY2018.

- Cobalt-rich ferromanganese crust

survey
- Manganese nodule survey
- Sea-floor polymetallic sulphides

8.3 Metrics of Japans mining innovation system

The Global innovation Index ranks Japan in die mid-field of innovation, with other Asian rivals such as China, Korea and Singapore finishing ahead. In the Innovation and Technology Readiness Index, Japan scores higher value, especially with regard to company spending on R&D and patent applications.

Table 11: Global Innovation Index.[1]

	SCORE 0–100 OR VALUE (HARD DATA)	RANK
Global Innovation Index (out of 141)	54.0	19
Innovation Output Sub-Index	44.1	26
Innovation Input Sub-Index	63.8	12
Innovation Efficiency Ratio	0.7	78
Global Innovation Index 2014 (out of 143)	52.4	21

Source: Dutta, et al., 2015, p. 186

1 As mentioned in Chapter 5, note that the GII is a measure of a country's overall innovation performance. The performance on overall innovation may differ significantly from mining innovation.

Table 12: Japan's Innovation and Technology Readiness Indicators.

INDICATOR	VALUE	RANK / 144
Innovation		
Capacity for innovation	5.4	7
Quality of scientific research institutions	5.8	7
Company spending on R&D	5.8	2
University-industry collaboration in R&D	5.0	16
Gov't procurement of advanced tech products	4.1	21
Availability of scientists and engineers	5.4	3
PCT patents, applications/million pop.*	308.2	2
Technology Readiness		
Availability of latest technologies	6.2	14
Firm-level technology absorption	6.1	2
FDI and technology transfer	4.7	55
Individuals using Internet, %	86,3	12
Fixed broadband Internet subscriptions/100 pop.*	28.8	18
Int'l Internet bandwidth, kb/s per user*	39.2	64
Mobile broadband subscriptions/100 pop.*	120.5	3
Values are on a 1-to-7 scale unless otherwise annotated with an asterisk (*).		

Source: Schwab, 2015, p. 227

9. Operational analysis of research and innovation: South Africa

9.1 The big picture of innovation in raw materials and mining in South Africa

The South African mining industry is the fifth largest in the world, considering all mineral resources available and produced (ASSIMAGRA, 2016). South Africa used to have a legal framework in mining that favoured big mining companies and a monopolised structure. This has been changed after 1994 (post-apartheid era) by reverting mineral rights to the state, allowing new entrants into the market by new exploration and mining licences. Creating a stable operating environment is the main prerequisite for the South African mining industry, as foreign investors require stability in order to reduce the risk for long-term commitments. Therefore, the Parliament of South Africa passed the Mineral and Petroleum Resources Development Act (MPRDA), which came into effect on May 1, 2004, and now governs the acquisition, use and disposal of mineral rights. The old common-law principles are therefore no longer applicable. The MPRDA entrenches state power and control over the mineral and petroleum resources of the country.

A key feature of the new legislation has been the allowance of the repatriation of profits for all industries. Permitting times in South Africa have acted as an incentive. However, the situation is no longer so favourable due to inefficiencies at the Department of Mineral Resources (DMR), which have led to much longer lead times. There are efforts to speed up the authorisation process by streamlining the decision-making of three main responsible government authorities (DMR, Department of Environmental Affairs and Department of Water and Sanitation). In addition, amendments made to the MPRDA are being contested.

South Africa also managed to develop a skilled workforce (e.g. skilled engineers in shaft sinking, ventilation, rock engineering and scientists) that made deep level mining possible. After 1994 many skilled workers have moved abroad. This remains a challenge, alongside the increasing mechanisation of operations, also requiring more skilled workforce. (INTRAW, 2015, p. 58f)

The economic growth of South Africa is closely linked to the development of the mining industry. The key strengths of South African mining industry lies in the large access to natural resources (see e.g. Technology Innovation Agency, 2012). South Africa's mining sector depends on innovation, as mineral deposits are not especially rich. Deposits require both, large-scale investment as well as the application of technological knowledge to be profitably exploited (Kaplan, 2011, p. 7).

End of 2015, the mining "Operation Phakisa"[1] has been carried out (the results of which are not released yet), aiming at the identification of key constraints to investment, at clearing or overcoming some of the industry challenges and developing a shared vision and strategy for the development of South Africa's mining sector (Team Finland Mining Growth Program, 2015, p. 69).

Challenges for South African mining companies:

Generally, the state of research institutions, limited R&D funding as well as a shortage of skills are seen as major challenges or weaknesses of South Africa's mining sector. This is complemented by the reluctance of the industry to adopt innovation. While some of this is explained by general difficulties to innovate in mining (see section 3.3.1), the government's main focus has been to encourage activities downstream of mineral production, rather than to promote technology development further upstream. From an external perspective, a major threat seems to be the lack of R&D col-

1 In Sesotho Language, the term „Phakisa" can be translated into the meaning „Hurry Up"

laboration amongst industry role player that might lead to high import of specialised equipment and limited productivity improvement (see Technology Innovation Agency, 2012, p. 22f). A key challenge for South Africa's mining sector is, that it has some and at the same time most of the deepest mines of the world. This requires special solutions for cooling, ventilation, safety and transportation of labour as well as bulk material (Team Finland Mining Growth Program, 2015, p. 71)

In the focus of the industry are the challenges of increasing depths of mining, continuous mining as well as the application of real time information systems are named as technological challenges for South African mining sector (Technology Innovation Agency, 2012, p. 26). Furthermore, South Africa is confronted with increasing labour cost, large increases in the cost of electricity, power shortages as well as deep and narrow ore bodies. The mining methods are often not state of the art and rely to a major part on manual, unskilled labour. The decline in commodity prices combined with the increasing labour and energy costs, which apply especially for gold and platinum, require rapid modernisation and mechanisation in South Africa's mining industry (Team Finland Mining Growth Program, 2015, p. 8f).

With regard to mining technologies and systems, South Africa's mining industry is confronted with the following key challenges (Kaplan, 2011, p. 18f):

- **Skill shortages:** Within recent years, the migration of skilled workers has led to a decline in skills and competencies available for the mining sector, especially due to higher payment abroad.
- **Declining industry-research linkage:** There is little industry engagement with the research councils: While CSIR and MINTEK have some capacities, there is a significant decline of personnel and (publicly funded) mining research programs. The same is true for university-based research. Only very few specialist mining research units exist in South Africa.
- **Access to finance:** Limitation and high cost of export finance which might lead to a reduction of technology related investments. The same applies for venture capital to finance technology-based start-ups.

The current slowing growth of the world economy, especially in China, leads to a decline of the raw materials market and is challenging South Africa as well as the other regions.

9.2 The mining innovation system in South Africa

9.2.1 Raw materials strategy and priorities

Whereas South Africa's overall vision of the R&D strategy is to *"contribute to the knowledge economy in South Africa by attaining at least 1% of global R&D output by 2020"*, there are no mining sector specific objectives or actions mentioned within this strategic plan. (National Research Foundation, 2015).

Within the mining and minerals sector, the innovation strategy plan is principally based on the amendment of the broad-based socio-economic empowerment charter for the in South African mining and minerals industry (Department of Mineral Resouces, 2010). This charter aims at improved access to mineral resources, increased beneficiations from the exploitation, expansion of existing skills, promotion of employment as well as sustainable development and growth of the mining industry. Therefore, the innovation strategy plan for mining considers the following key aspects (Technology Innovation Agency, 2012):

- The current state of R&D in the sector
- Requirements and needs of relevant stakeholders
- Opportunities and challenges for the mining industry
- Emerging technological developments

Based on these aspects, the following objectives were defined, each underlined by a set of key performance metrics (Technology Innovation Agency, 2012, p. 32):

- **Efficient, safe and competitive production:** efficiency improvement through technological advances and

reduction of worker hazard.
- **Environmental and health management:** technology development for the reduction of impacts to the workforce, the environment and the community.
- **Minerals upgrading and value addition:** encouraging local manufacturing and production.
- **Lateral migration:** knowledge and capacity exploitation to increase value creation.
- **Establishment of an innovation culture:** enhancing leadership, skills and support infrastructure.

Under the terminology of beneficiation, one of the objectives of the government is a further value add to raw materials before export (Hilpert & Mildner, 2013, p. 144). On the other hand, recycling is pushed forward in the National Waste Management Strategy. For supporting these objectives, the following programmes have been set up (Technology Innovation Agency, 2012, p. 28):

- DST Technology Assistance Programme to the National Foundry Technology Network (NFTN)
- The Nuclear Energy Act (Act No 46 of 1999)
- National Industry Participation Programme (NIPP) of the Department of Trade and Industry
- Competitive Supplier Development Programme (CSDP) for State-owned Enterprises (SoEs) to develop the local supply industry
- Customized Sector Programmes
- Technology and Human Resources for Industry Programme (THRIP), managed by the National Research Foundation (NRF)
- The Support Programme for Innovation in Industry (SPII)

Main potential of improvement that can be identified based on the information available on these programmes is the collaboration between relevant actors in the mining value chain, especially between industry and research organisations, necessary to produce relevant and applicable results.

9.2.2 Key players and organizations

The classification of key role players and organizations along the mining value chain as well as according to different organizational categories is shown in ***Table 13***.

The key role players and organisations in the innovation system that are shown also in ***Table 13*** can be described in more detail as follows (see e.g. Hilpert & Mildner, 2013, p. 144; Technology Innovation Agency, 2012, p. 17):

- **Academy of Science of South Africa:** promote scientific thinking across disciplines and intellectual development to face relevant challenges in South Africa
- **Chamber of Mines of South Africa:** association of 75 mining companies representing about 90% of mine production value
- **Coaltech Research Association**
- **Council for Scientific and Industrial Research (CSIR):** foster industrial and scientific development, through directed and multi-disciplinary research, to benefit the public of South Africa
- **Department of Mineral Resources,**

Table 13: Key players in Innovation in South Africa's mining and minerals sector.

	EXPLORATION	MINING	MINERAL PROCESSING	MINERAL AND METAL BENEFICIATION	POST MINING LANDSCAPES
Research and education system actors	Council for Geoscience, Universities	Council for scientific and Industrial Research (CSIR), Mine Health and Safety Council (MHSC), Universities	Mintek, Universities	Mintek, CSIR, Nuclear Energy Corporation of South Africa (Necsa) and Universities	CSIR, CGS, MINTEK, Universities

Sector value chain actors	Consulting companies, geophysical service companies and mining companies	Mining consulting companies, equipment manufacturers, mining companies	Process consulting firms, equipment manufacturers, chemical suppliers	Capital Equipment manufacturers, waste management consultants, process control equipment manufacturers, Market research consultants, Logistics Management consultants, plant maintenance consultants.	Water, treatment, dust suppression companies, land use consultants, shaft sealing companies;
Enabling Agencies	National Research Foundation (NRF), TIA, Industrial Development Corporation (IDC), Provincial economic developing agencies, Department of Mineral Resources (DMR), Department of Science and Technology (DST), Department of Water and Environmental Affairs (DWEA), Dept. of rural development & land reform, the Department of Trade and Industry (dti) and Non-governmental Organisations (NGOs)				
Sector R&D Funding Agencies	Coaltech Research Association, South African Minerals to Metals Research Institute (SAMMRI), Mine Health and Safety Council (MHSC)				
Key Activities	Research and development, technology development and exploration services	Mine health and safety, energy and water efficiency, mine design, technology development, environment and mine of the future	R&D in process technology, process efficiency, water and energy efficiency, health and safety, and environment protection.	Advanced Manufacturing Technology Strategy (AMTS), Advanced metals initiative, project AuTek, PGM beneficiation, Minerals beneficiation strategy	Water, treatment, dust suppression, land use, shaft sealing.

(DMR): responsible for formulation, implementation and control of politics related to non-energetic raw materials.

- **Department of Science and Technology (DST):** responsible for scientific research and management of the science system.
- **Department of rural development & land reform (DRDLR):** former department of land affairs, dedicated to the social and economic development in rural South Africa.
- **Industrial Development Corporation (IDC):** source of commercially sustainable industrial development and innovation.
- **Mine Health and Safety Council (MHSC):** advise the Minister of Mineral Resources on occupational health and safety legislation and research outcomes.
- **Mintek:** South Africa's national mineral research organization and is one of the world's leading technology organizations specializing in mineral processing, extractive

metallurgy and related areas

- **National Advisory Council on Innovation:** advice to the Minister or Science and Technology and the government
- **National Research Foundation (NRF):** funding of research and innovation activities, facilities and human resource development
- **South African Minerals to Metals Research Institute (SAMMRI)**
- **Technology Innovation Agency (TIA):** stimulating and intensifying technological innovation in order to improve economic growth and the quality of life of all South Africans by developing and exploiting technological innovations.

Suppliers of Mining Equipment and Services are considered as key players in the mining industry. This includes the areas of exploration and surveying, mechanisation, drilling, blasting, construction, bulk material handling, energy/power, services, mine equipment & G.E.T., roof support, pumps, surface processing, analysis & testing, chemical producers, environment & waste water treatment as well consumables (Team Finland Mining Growth Program, 2015, p. 77).

Among the key mining companies that are active in South Africa are (Team Finland Mining Growth Program, 2015, p. 90f):

- Anglo American Platinum: major producer of PGM's, base metals and precious metals.
- Gold Fields: mid-tier and development in gold production.
- Norilsk Nickel: mid-tier producer of nickel.
- Rio Tinto: major global mining company, especially in heavy and mineral sands to produce iron and ilmenite.
- Royal Bafokeng Platinum: mid-tier producer of PGMs.
- Taung Gold Limited: gold exploration.

Especially the large mining houses drove innovation in the past, supported by the Chamber of Mines (Kaplan, 2011, p. 17).

Politics of raw materials:

It is said that South Africa lacks institutional and policy supports necessary to ensure future growth (Kaplan, 2011, p. 22). Mining is not explicitly mentioned in the Department of Science and Technology's 10-year plan (Department of Science and Technology, 2008) or in the overall vision of the R&D strategy (National Research Foundation, 2015).

9.2.3 Knowledge base for research and innovation

Mining in South Africa depends to a high degree on export, especially to producing countries like China and thus on economic cycles of importing economies. South African mineral deposits are not especially rich. Low ore grades and deep deposits are a challenge as they require investments into technology, but also the development of competencies for profitable mining (Kaplan, 2011, p. 16). It is especially the input supplier industries, which employ sophisticated technologies and provide products to the mining industry. Specialist services such as consulting and exploration are now supplied to global markets, however, most of the services are still provided to regional markets. While mining is a very important business for South African economy, contributing approx. 7% to GDP, technology-wise it is somewhat detached from other industries. Mining benefits from technology spill overs from other industries (e.g. IT, machining), but there is little spill over from mining and mining-related areas to other South African industries.

From an education perspective, South Africa disposes of some leading universities offering mining-specific degrees, most notably

- University of Witwatersrand, School of Mining Engineering (aka Wits)
- University of Pretoria, Department of Mining Engineering (aka Tuks)
- University of Johannesburg (Technikon), School of Mining, Metallurgy & Chemical Engineering (UJ)
- University of South Africa, Department of Mining Engineering (UNISA) (this is a distance learning university)

In addition to the mining schools, there are approximately 22 institutions providing tuition in geoscience, geology, earth science and similar programmes (Jeffrey

& Camborne School of Mines, 2016)

These education institutes perform mining R&D, even though, as mentioned earlier, the industry-research collaboration could be improved. Qualified personnel have often been attracted by other mining intensive regions such as Australia, Canada or the U.S. in the past, due to higher salaries of better working conditions. Throughout all sectors, the share of R&D personnel in relation to the overall personnel is relatively low e.g. measured by R&D Personnel per 1000 employees, South Africa: 2.43 vs. Canada: 13.35 (OECD, 2015, p. 104).

With regard to the workforce, South Africa has enacted several specific laws requiring mining companies to hire and/or educate Historically Disadvantaged South Africans (HSDA), e.g. the Broad-based Black Economic Empowerment Act 53 of 2003, and to seek a certain percentage of HSDA ownership of the mining industry. Due to these policies and the strong position of workers and unions (especially the National Union of Mineworkers (NUM)), South African mines have had to deal with frequent worker strikes. Quite recently, the South African Chamber of Mines recently reported that the mining industry, which employs approx. 500,000 people, cut 47,000 jobs between 2012 and early 2015 (Seccombe, 2016). These employment cuts are mainly due to low commodity prices and increasing mining costs (especially for electricity, but also for job-related costs (e.g. health care)).

9.2.4 Key technologies

South Africa mining industry is said to have an advanced technological position. Firstly, this position is underpinned by means of its intellectual property apparent in existing patents and the development work carried out in South Africa by subsidiaries of transnational mining corporations. Secondly, it is evident through the large and increasing export of mining equipment with high local value add and a dominant position in South Africa's capital export (Kaplan, 2011, p. 8). An example for a key technology developed in South Africa is the cyanide-based extraction technology (Kaplan, 2011, p. 17).

Furthermore, the country has produced sizable know-how in mining explosives, drilling equipment and abrasives, metallurgical processes and plants, and delivering knowledge-based services. Some South African companies can be considered to be at the frontier of innovation. Some of these companies include:

- AECI and Sasol - leading suppliers of mining explosives,
- Boart Longyear - a world leader in drilling and abrasives,
- SRK and Bateman - among the leading consulting mining engineering companies in the world.
- LTA plays a major role in specialist contract mining in Africa

To reach the objectives of reducing people, capital and energy intensity while increasing mining intensity, in addition to improving mining technologies, especially the fields of information and energy technology are seen as critical to assure the future success of mining in South Africa (see e.g. Lane & Beier, 2014)

9.3 Metrics of South Africa's mining innovation system

Considering the Global Innovation Index 2015 (see ***Table 14***), South Africa worsened its position from 53 in 2014 to 60. Whereas South Africa scores fine in the innovation input sub-index, potential for improvement exists in the innovation efficiency index, that aggregates the input as well as the output of innovation activities.

Despite the fact that university-industry collaboration is mentioned as one of the challenges of South Africa's mining industry, the overall South African score is among the best ranks of all innovation indicators considered (see ***Table 15***). Based on these indicators, the major potential for improvement exists in government procurement of advanced technology products as well as in the availability of scientist and engineer, both consistent with qualitative descriptions of the mining industry.

In 2012/13 the Gross Expenditure on Research and Development (GERD) was 0.76% of the Gross Domestic Product (GDP), considerably below that of other emerging economies (DST & HSRC, 2015).

Table 14: Global Innovation Index.[1]

	SCORE 0–100 OR VALUE (HARD DATA)	RANK
Global Innovation Index (out of 141)	37.4	60
Innovation Output Sub-Index	29.7	61
Innovation Input Sub-Index	45.2	54
Innovation Efficiency Ratio	0.7	94
Global Innovation Index 2014 (out of 143)	38.2	53

Source: Dutta, et al., 2015, p. 186

1 As mentioned in Chapter 5, note that the GII is a measure of a country's overall innovation performance. The performance on overall innovation may differ significantly from mining innovation.

Table 15: South Africa Innovation and Technology Readiness Indicators.

INDICATOR	VALUE	RANK / 144
Innovation		
Capacity for innovation	4.3	35
Quality of scientific research institutions	4.7	34
Company spending on R&D	3.4	48
University-industry collaboration in R&D	4.5	31
Gov't procurement of advanced tech products	3.0	112
Availability of scientists and engineers	3.5	102
PCT patents, applications/million pop.*	6.5	45
Technology Readiness		
Availability of latest technologies	5.5	39
Firm-level technology absorption	5.4	29
FDI and technology transfer	4.8	50
Individuals using Internet, %	48.9	69
Fixed broadband Internet subscriptions/100 pop.*	3.1	89
Int'l Internet bandwidth, kb/s per user*	3.7	126
Mobile broadband subscriptions/100 pop.*	25.2	74
Values are on a 1-to-7 scale unless otherwise annotated with an asterisk (*).		

Source: Schwab, 2015, p. 341

Almost half of the expenditure comes from the private sector. Government funding represented 45.4% while the business sector funded 38.3% of R&D activities in 2012/2013 (DST & HSRC, 2015). ***Table 16*** shows some key indicators of the overall situation of R&D expenditure and personnel in South Africa.

Mining and quarrying remained the third-largest contributor to BERD, following a continuous growth of R&D expenditure in the period between 2008/09 to 2012/13 of 168,5% and business expenditure in R&D of R1.554 billion in 2012/13 (DST & HSRC, 2015, p. 19). However, this amount does not include mining related R&D expenditure in other sectors.

Table 16: Key R&D indicators, South Africa, 2010/2011 to 2012/2013.

KEY INDICATOR			
	2010/11	2011/12	2012/13
Gross domestic expenditure on R&D, GERD (R million)	20 254	22 209	23 871
Gross domestic product (GDP) at current prices (R million)	2 664 269	2 917 539	3 138 980
GERD as a percentage of GDP (%)	0.76	0.76	0.76
Civil GERD as a percentage of GDP (%)	0.71	0.72	0.72
Basic research (R million)	4 848	5 440	6 031
Total R&D personnel (FTE*)	29 486.4	30 978.4	35 050.3
Total researchers (FTE*)	18 719.6	20 115.1	21 382.4
Total researchers (FTE*) per 1 000 in total employment	1.4	1.5	1.5
Total R&D personnel (FTE*) per 1 000 in total employment	2.2	2.3	2.4
Total researchers (headcount)	37 901	40 653	42 828
Female researchers (headcount) as a percentage of total researchers (%)#	41.7	42.3	43.7
Total employment (in million)	13 118	13 497	14 558
* FTE = Full-time equivalent; # Following OECD practice, doctoral students and post-doctoral fellows are included in researchers			

Source: DST & HSRC, 2015, p. 3

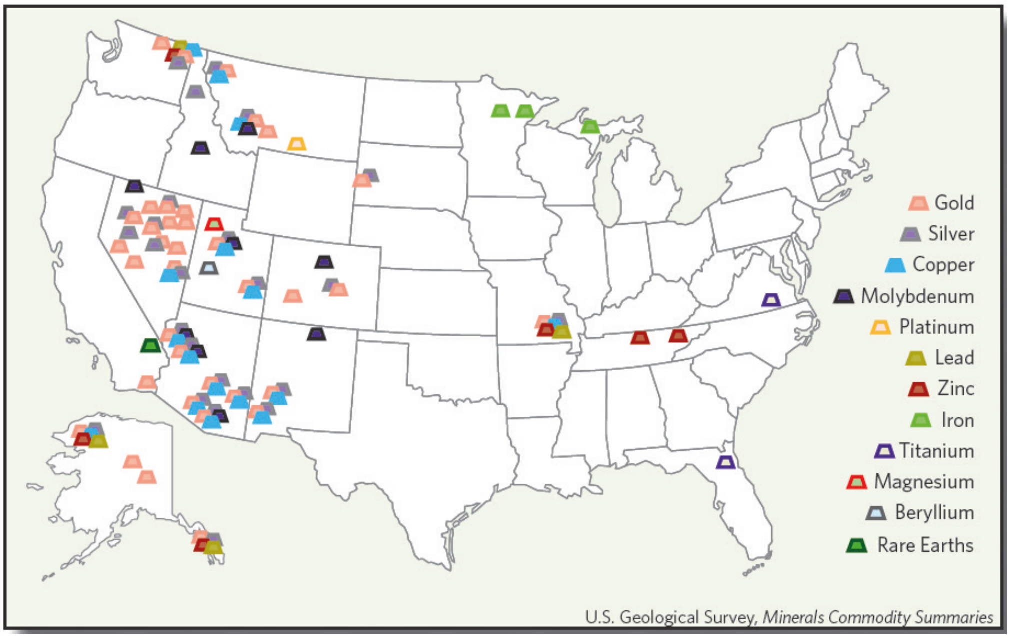
10. Operational analysis of research and innovation: United States

10.1 The big picture of innocation in raw materials and mining in the United States

The U.S. has a territory favourably endowed with raw materials (energy and non-energy minerals) which has steadily provided the material base for the domestic industry, underpinning economy grow. Since early in the 20th century the types and quantities of raw materials demanded and processed by the U.S. manufacturing industries and consumers have evolved. With the exception of petroleum (not included in the figure), overall material resource use of raw non-energy minerals, especially construction materials, have had a great importance in the economic development of the country. The continued long-term growth in material use reflects ongoing growth of an affluent population with resource-intensive consumption patterns, punctuated periodically with decreases during major economic downturns and wars, which tend to have a negative impact on the demand of some materials, while boosting others. These punctuating events include WWI, the Great Depression of the 1930s, WWII and the post-war expansion, the two oil crises in the 1970s, recessions in the 1980s and early 1990s and the Great Recession in 2007 (INTRAW, 2015, p. 12).

Metals and minerals are needed as inputs for manufacturing. The U.S. is the largest manufacturing nation, with many

Figure 29: Major metal producing areas.



of the companies ranking in the top ten in their respective industries (***Table 17:***). Manufacturing industries use a diverse array of metals. The average car alone contains more than a ton of iron and steel, 240 pounds of aluminum, 42 pounds of copper, 41 pounds of silicon, 22 pounds of zinc, and more than 30 other minerals, including titanium, platinum and gold. Significant amounts of minerals are also used in high-tech products such as computers, mobile phones etc. For instance, computer circuitry will use minerals such as gold, aluminum, lithium, chromium, silver, nickel, gallium, lead, zinc, copper, steel, tungsten, titanium, cobalt, germanium, tin and tantalum. (SNL Metals and Mining, 2014).

Table 17: Examples of U.S. manufacturing industries making use of minerals.

	INDUSTRY	US COMPANIES (EXAMPLES)
Mature Manufacturing	Automobiles and Parts	Ford, General Motors, Johnson Controls
	Aerospace and Defense	Boeing, United Technologies
	Industrial Engineering	Caterpillar, Illinois Work Tools
	General industrials	General Electric, 3M, Honeywell International
New Manufacturing	Electricity	Southern, Nextera Energy, Dominion Resources
	Electronic and Electrical Equipment	Emerson Electric, TE Connectivity
	Technology Hardware and Equipment	Apple, Qualcomm, Intel, Cisco Systems

Source: SNL Metals and Mining, 2014

The U.S. is a net exporter of four major metallic minerals (gold, iron ore, molybdenum and zinc) and a net importer of four others (copper, platinum, palladium and silver). However, domestic production tends to be highly concentrated as most of the production for many metallic minerals lies in the hands of the top five mines. The U.S. dependence on these mines exposes domestic production to risks of disruption (SNL Metals and Mining, 2014).

Mining is not only an important industry due to its employment and the contribution to GDP. From a U.S. perspective, mining and the fabrication of metals and manufacturing should mutually benefit from each other. The proximity of mining companies, smelters and manufacturers is seen as an advantage. Alcoa, the country's biggest mining company, is itself vertically integrated and thus benefits, for instance, from better procurement.

As a developed economy, the consumption of mineral commodities in the United States is high and has increased with population growth. In Canada and Australia, the positive correlation observed between growth in population, GDP, and mineral demand are being met with increased mineral production and increased employment in the mining industry (Lowry, et al., 2006) (Natural Resources Canada, 2012) . In the U.S., high metal prices due to demand on the world market for various products have encouraged some U.S. mining companies to increase production at existing mines and to restart production at others. (Committee on Emerging Workforce Trends in the U.S. Energy and Mining Industries, 2013).

The public perception of mining in the U.S., however, is that of a mature and environmentally damaging industry that requires intensive regulation and control to prevent problems such as pollution, noise, environmental degradation, and health issues. A favourable image and community support is essential for mining companies today, commonly phrased as "social license".

Factors affecting the mining industry and policy making in the U.S. can be summarized as follows:

- Growing consumption of minerals and metals due to a general increase of population (approx.. 318 million people) and high standard of living
- Importance to the national economy (job created by mining, adjacent industries) support of manufacturing)
- (Lack of) domestic production of minerals and metals to support manufacturing
- Importance for defense
- Geopolitical tensions that may impact foreign supply (for example, more than 90% of Rare Earth Elements are imported from China)

Today, the overall strategy of the U.S. government currently consists mainly of two streams of activities

- To create a solid understanding for the need of critical materials (for industry) and strategic materials (for defense), in terms of their importance, the current and future

needs and supply, etc.
- To stabilize supply through a range of measures, e.g. by diversification of supply, by stockpiling, by fostering technology development, by boosting domestic production.

10.2 The mining innovation system in the United States

10.2.1 Raw materials strategy and priorities

In contrast to other countries with a strong manufacturing sector, which strive for securing minerals supply, the U.S. pursue a less explicit and 'top-down' strategy. To date, despite a short-lived attempt to do so, there is no comprehensive legislation on mineral resources or a single document that summarizes the U.S.' views and minerals policies. This doesn't mean though that the U.S. do not pursue any strategy at all, however, major policy initiatives are rare.

One of the priorities of the U.S. is the provision of 'critical' materials (if required by industry) or 'strategic' materials (if required for defense purposes). While there have been evaluations of strategic materials in the 1970s, the influential report on "Minerals, Critical Minerals, and the U.S. Economy[1]" by the National Academies in 2008 was an important precursor to the formulation of the Department of Energy's (DOE) 'Critical Materials Strategy'. Further efforts to elaborate on rare earth minerals include the reports *'Elements of Security: Mitigating the Risks of U.S. Dependence on Critical Mineral'* by the Center for a New American Security (Parthemore, 2011) and 'Energy Critical Elements: Securing Materials for Emerging Technologies' (American Physical Society and the Materials Research Society, 2011).

In the Department of Energy's Critical Materials Strategy, a material's criticality is defined based on the material's supply risk and its importance to clean energy (DOE, 2011) (Hilpert & Mildner, 2013, p. 172) (***Figure 30***). The most critical (rare earth) elements possess such unique magnetic, catalytic, and luminescent properties that they represent key resources for the clean energy economy. They enable the production of, for instance, wind turbines, solar panels, electric vehicles, and energy-efficient lighting.

For such critical materials, the strategy is threefold: The first objective is to diversify supply and make use of new sources of critical materials. The first rare earth mine in the U.S., the Mountain Pass Mine in California operated from 1952 to 2002. It reopened in 2012 but the production

1 http://www.nma.org/pdf/101606_nrc_study.pdf National Research Council. Minerals, Critical Minerals, and the U.S. Economy. Washington, DC: The National Academies Press, 2008

Figure 30: Strategic and Critical Minerals.

1970s-80s Strategic Minerals (W.C.J. van Rensburg)	2008 Critical Minerals (National Research Council)	2010 DOD Recommended Materials for National Defense Stockpile (Report to Congress)
Aluminium	Platinum Group Metals	Beryllium Metal
Chromium	Rare Earth Elements	Chromium Metal
Cobalt	Indium	Cobalt
Manganese	Manganese	Columbium (Niobium)
Nickel	Niobium	Ferro Chromium
Platinum Group Metals		Ferro Manganese
Titanium		Germanium
		Iridium
		Platinum
		Tantalum
		Tin
		Tungsten
		Zinc

Source: Koroshy, et al., 2010

was suspended in 2015 as prices for rare earth metals declined significantly. The second objective is to develop substitutes that can replace critical materials. The third priority is the improvement of reuse and recycling by developing appropriate technologies.

With respect to other, less critical minerals, no official strategies and priorities have been published recently. In the early 2000s, several organisations had expressed their opinion on R&D needs for mining. A serious attempt to set directions for R&D was the „Mining Industry Roadmap for Crosscutting Technologies" which was created by more than 30 experts from industry, government and academia in 2002[2]. This document, howver, was never updated. In 2002, the National Academies' Committee on Technologies for Mining Industry issued a fairly comprehensive report (Committee on Technologies for the Mining Industry, 2002) on the R&D needs for future mining technologies (***Figure 31***). It pinpointed in a detailed manner the research needs in the areas of exploration, mining, in-situ-mining and mineral processing. This publicaton also described in detail the capacities of the National Laboratories with respect to exploration, mining etc.

2 http://www1.eere.energy.gov/manufacturing/resources/mining/pdfs/ccroadmap.pdf

Figure 31: Opportunities for R&D in US Mining.

Look-Ahead Technologies
- seismic methods and alternatives, such as electromagnetics and ground-penetrating radar
- combinations of sensing methods to provide wider ranges of application and better resolution
- processing algorithms that take advantage of current parallel-processing technologies to provide real-time visualization ahead of the mine face
- visualization of data extended to suit the particular needs of the mining application
- ore-grade analyzers to quantify metal and mineral contents
- down-hole analysis with analyzers for ore and waste interfaces

Cutting and Fragmentation
- cutter designs that optimize fragment size to minimize dust, move materials, and minimize processing
- hardrock cutting methods and tools with lower thrust requirements
- improved blasting methods for better control of fragment sizes and more precise rock movement
- improved explosive tailoring and timing
- blasting technology for the preparation of in-situ rubble beds

Ground Control
- procedures for ground-control design and effective monitoring and prediction systems for operational ground control
- field characterization to determine properties of intact rock and the collective properties of the rock mass
- integration of the automatically monitored data (such as data from a seismic and/or other geophysical data acquisition network) into the design of mine structures
- approaches to facilitate real-time analysis and interrogation of data with 3-D models
- modeling methods that address stochastic features and coupled systems

Materials Handling
- a truly continuous haulage system that advances with the cutter-loader
- automated roof bolting that can be integrated with the cutting and hauling functions
- advanced technology for the integration of location sensors, obstacle-detection sensors, travel-protection devices, automatic controls, and communication tools
- technologies for monitoring the operational status of autonomous operations
- methods of achieving downstream processing while ore is being transported
- alternative energy sources, such as new-generation battery technology, compressed air, and novel fuel-cell technology

Mining Systems
- innovative mine development schemes to reduce lead times and enhance recovery rates
- mining technology—equipment and mining systems—for problematical deposits (e.g., technology for mining thin coal seams, particularly thin-seam longwall mining, and equipment and methods for mining thick coal seams)
- adaptation of longwall and continuous coal mining technology to the mining of other laminar metallic and nonmetallic deposits
- continuous hardrock mining with new cutting concepts incorporated into a continuous mining system
- in-situ gasification of energy resources to address technical problems and environmental issues
- exploration of chemical and biological mining of coal to determine basic mechanisms and develop mining-system concepts
- secondary recovery methods for mining

Improved Machine Performance
- development of sensors, software, and communications for mining situations
- new alternatives for man-machine interfaces
- semiautonomous control methods, such as "fly-by-wire" systems
- more autonomous vehicles that can perform complex tasks without human intervention or oversight

Source: Committee on Technologies for the Mining Industry, 2002

In the same year, the USGS issued an information circular that listed the following measures as ways to cope with the risks of a scarcity of resources (see USGS, 2002, p. 14f):

- New materials research: creation of specialty materials with new performance features.
- Technological advancements: advancements in process technologies along the mining value chain.
- Substitution: replacing a commodity with a less scarce commodity.
- Exploration: discovery of additional sources and deposits.
- Mining lower grade material: mining in deposits that were previously not profitable or feasible.
- Processing efficiencies: increase of the amount of material that reaches the market.
- Recycling: reduction of the amount of "virgin" material that needs to be extracted.
- Reuse: recovery or reapplication of components or products to avoid early stages of the value chain.
- Remanufacturing: rebuilt of products based on previously used parts (see effect of reuse)

Another attempt worth mentioning is a report issued by the Earth Resources Engineering (ERE) Section of the National Association of Engineers (NAE) in 2010 (and edited in 2012).In a response to a 2008 report of the NAE on grand challenges for engineering (National Academy of Engineering, 2010), the ERE section developed some grand challenges specific to ERE (NAE Section 11, 2010)

It highlights four particular earth engineering challenges that have a relevance for minerals mining as well:

- Make the Earth Transparent, e.g. better imaging techniques to assess the earth's potential resources
- Understand, Engineer and Control Subsurface Coupled Processes, i.e. hydrological, thermal, mechanical, chemical and biological processes, which usually are complex and interactive
- Minimize the Environmental Footprint, e.g. less toxic reagents for the separation process, reduction of energy consumption, in-situ-leaching etc.
- Protect People, e.g. by introducing appropriate equipment and procedures.

US policy documents

Critical Materials Strategy 2011: In December 2010, The U.S. Department of Energy (DOE) published the 'Critical Materials Strategy', which focused on the minerals needs for energy systems. An updated version appeared in 2011 in response to important developments during the year. The strategy rests on three pillars:

- Diversified global supply chains: To manage supply risk, multiple sources of materials are required. This means taking steps to facilitate extraction, processing and manufacturing here in the U.S., as well as encouraging other nations to expedite alternative supplies. In all cases, extraction, separation and processing should be done in an environmentally sound manner.
- Substitute development: Research leading to material and technology substitutes will improve flexibility and help meet the material needs of the clean energy economy.
- Recycling, reuse and more resource efficiency could significantly lower world demand for newly extracted materials. Research into recycling processes coupled with well-designed policies will help make recycling economically viable over time.

Report on Stockpile Requirements: The Department of Defense regularly reports to Congress on Critical Materials. Under the National Defense Stockpile (NDS) Program, which aims at reducing the risk on dependence on foreign suppliers, more than 160 minerals and processed materials are monitored. The latest report was published in 2015 (Department of Defense, 2015).

Apart from official policy documents, there are a number of laws that should to be taken into consideration to better understand the U.S. policies on materials and minerals. These laws include:

- Strategic and Critical Materials Stock Piling Act of 1946 – the first action to appropriate money to the accumulation of strategic and critical material (oil, rubber, fibers etc.) needed in wartime
- Mining and Minerals Policy Act of 1970, which recognized the national interest in the Mining and Minerals industry,
- National Materials and Minerals Policy, Research, and Development Act of 1980, which directed the president to assess material demand
- Deep Seabed Hard Mineral Resources Act of 1980, an act to establish a procedure for the development of hard mineral resources in the deep seabed

Currently, the American Mineral Security Act of 2015 is being discussed, but it hasn't passed yet. Among other things, it would require that the USGS establish a list of minerals critical to America and it would direct the Department of the Interior and Energy to address issues associated with their discovery, production, use, and reuse, and to improve the permitting system.

There are many federal laws (e.g. National Environmental Policy Act, Clean Water Act, ...) as well as state laws that are applicable to a typical mining operation. While these laws do not directly address the need for minerals research and innovation, they do serve as a catalyst for innovation as companies strive to meet their requirements.

10.2.2 Key actors and organizations

GOVERNMENT (FEDERAL AGENCIES)

The U.S. has a decentralised approach to materials and mining policies. The major agencies involved in minerals and materials (DOI, DOE, DOD) sponsor R&D projects according to their missions, but there is no coordinated approach to materials development. The federal government is hesitant to "pick winners", and leaves many decisions to the private sector. There is also the concern that it would create too much bureaucracy.

The key actors and organization that currently contribute to research and innovation in the U.S. are listed below:

- **Department of the Interior (DOI):** As part of its mandate to manage and protect large portions of the federal land system, the U.S. Department of the Interior is involved in mining issues. The Bureau of Land Management and the Office of Surface Mining Reclamation and Enforcement provide regulatory control for existing mining operations. The Office of Surface Mining is active in the transfer of information and technologies applicable to regulating the coal mining industry to local, tribal, and state governments.
  - **United States Geological Survey (USGS):** Under the Geological Survey Organic Act of 1879 and the Economy Act of 1932, the United States Geological Survey, USGS, provides research on mineral deposits and assesses national mineral resources; it also provides statistics and information on the worldwide supply of, demand for, and flow of minerals and materials essential to the U.S. economy, the national security, and protection of the environment. The basic level of support is the development of geologic maps, which help identify potential areas with mineral resources. USGS also publishes the annual Mineral Commodity Summaries and Minerals Yearbook, which also provides mining information for most of the countries of the world.
  - The **Bureau of Ocean Energy Management (BOEM)**, is responsible for a number of activities that manage offshore natural resources (among them minerals)
  - On a side note, the **Bureau of Mines**, which employed 1,200 people in 12 locations, including several research centers, was closed in 1996. About 600 employees were reassigned to other federal agencies, among them the USGS, DOE, the US Bureau of Land Management (BLM) .
- **Department of Energy (DOE):** Currently, most of the federal engineering and technology development that is focused on or

could be useful to the mining industry is being conducted by DOE.

- **The National Research Laboratories:** Engineering development on many fronts is being conducted in 17 DOE national laboratories. Among them, the **Critical Materials Institute (CMI)**[3] based in Ames stands out. The CMI collaborates with other partners from other national laboratories, universities and industry on the research priorities addressed by the Critical Materials Strategy (diversifying supplies, developing substitute materials, efficient use of materials). (***Figure 32***)
- **Department of Defense (DOD):** The Department of Defense has an interest in the supply of rare earths, because lower tiers of the supply chain use these materials (for instance, in permanent magnets). The **Defense Logistics Agency (DLA) Strategic Materials**[4] is the leading U.S. agency for the analysis, planning, procurement and management of materials critical to national security
- **Office of Science and Technology Policy (OSTP):** The OSTP is not a

3 https://cmi.ameslab.gov/

4 http://www.dla.mil/HQ/Acquisition/StrategicMaterials.aspx

Figure 32: Estimates of Mining R&D Capabilities of National Laboratories.

	Albany Research Center	Ames Laboratory	Argonne National Laboratory	Brookhaven National Laboratory	Idaho National Engineering & Environmental Laboratory	Kansas City Plant	Lawrence Berkeley National Laboratory	Lawrence Livermore National Laboratory	Los Alamos National Laboratory	National Energy Technology Laboratory	National Renewable Energy Laboratory	Oak Ridge National Laboratory	Pacific Northwest National Laboratory	Sandia National Laboratories	Savannah River Technology Center	Y-12 Plant
Exploration and Resource Characterization																
Exploration optimization strategies	C				C		S	S	C			C	C	S		
Remote sensing for geophysical systems			S		SC	C	S	S	S	S	C	C	S	S	S	
Subsurface imaging and characterization/ Geologic basin modeling			SC	S	SC	SC	S	S	S	SC		C	S	S	S	
Explosive design and engineering									S					S		
Satellite imaging/data interpolation	C		C		SC	C	C	C	S			SC	S	S		
Rock mechanics					C		S	S	C			C		S		
Advanced drilling technologies					C		SC	SC	S	C				S		C
Geochemical sensors and analytical devices		C	SC	C	S		S	S	S	SC	C	SC	SC	S	SC	C
Sensors and analytic devices for imaging physical material properties	C	C	S	S	S	C	S	S	S	C	C	C	S	S	S	SC
Mining Operation																
Gas, aerosol, noise sensors			SC	SC	SC		SC	SC	SC		S	C	S	S		C
Robotics/automation for autonomous equipment					S	C	SC	SC	SC			S	SC	S	S	C
Fuel cells/power supplies		C	S	C	C		S	SC	S	S	SC	C	SC	SC	SC	C
Alternative fuels/propulsion systems			S	C	SC		S	SC	C		S	C	C	S	SC	SC
Information and data systems in support of autonomous technologies			S		SC	S	SC	SC	S		C	SC	C	S	SC	SC
Mine climate simulation									S				C	C		
Advanced materials (e.g. strength, durability, hardness)	S	S	S	C	S		S	S	S	C		S	S	S	SC	C
Minerals Processing																
Separations technologies for solids processing	SC		S		SC		C	C		S	C		SC	SC	SC	
Dewatering and water-reuse technologies	SC		SC		SC		C	C		S		S	S	SC		C
Biological processes for in-situ metal extraction				S	S		SC	C		SC	C	SC	SC			
Geochemistry for minerals processing	SC				S		SC	S	C	C		SC	C	S		
Real-time analytic techniques and models		SC	C	C	S	C	SC	C	S	S	SC	SC	S	S	S	SC
Alternative technologies for processing by-products and alternative uses for products	SC		SC	SC	SC		C			S		C	SC	SC		
Sensors for process-stream characterizations and control		SC	SC		S		SC	SC	S	C	SC	SC	S	S	S	SC

S – strength; SC – significant capability; C – capability.

Source: Committee on Technologies for the Mining Industry, 2002 federal agency, but part of the Executive Office of the President, advises the President on science and technology policy. The OSTP developed the Materials Genome Initiative to help researchers develop advanced materials more efficiently and quickly.

- **Environmental Protection Agency (EPA):** The EPA is an independent agency that performs studies and reports to Congress regarding, among other things, management methods and potential hazards of mining wastes (e.g. waste water). When Congress writes an environmental low, the EPA implements it by writing regulations

ASSOCIATIONS:

- **National Mining Association (NMA):** The NMA, formed in 1995, represents the mining industry in Washington. While there are other mining associations, including the Industrial Minerals Association–North America and the National Stone, Sand & Gravel Association, the NMA is the most influential.
- **Society for Mining, Metallury & Exploration (SME):** The SME published the book 'Mineral Processing and Extractive Metallurgy: 100 Years of Innovation' in 2014.

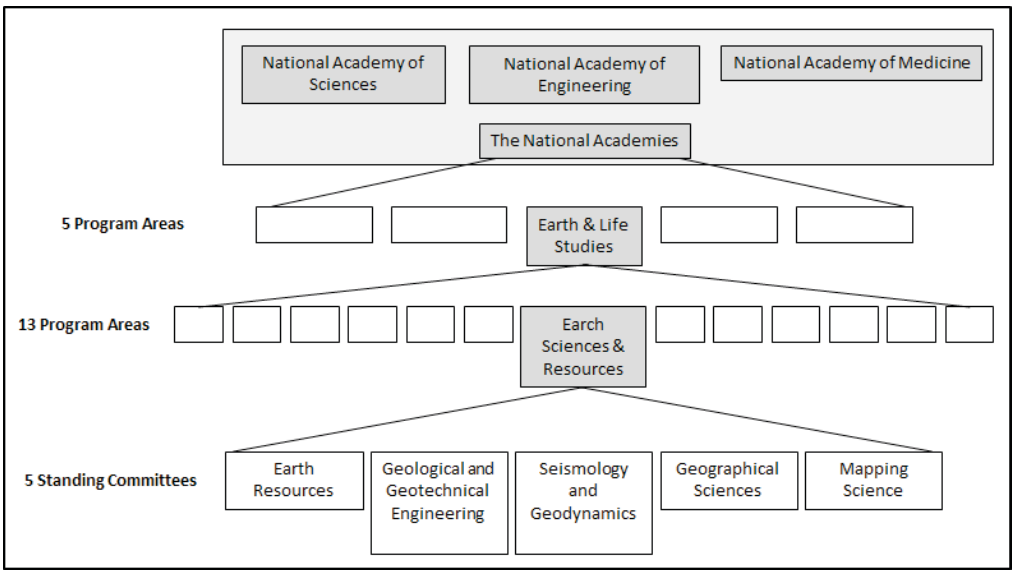
RESEARCH INSTITUTES:

- **See description of** National Research Laboratories above.

THINK TANKS:

- **National Academy of Science (NAS):** The NAS is a congressionally-chartered non-profit organization, including 2,200 members, mostly distinguished scholars engaged in scientific and engineering research. The Academy has a mandate that requires it to advise the federal government on scientific and technical matters. The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs. The **National Research Council (NRC)** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. It became the principal operating agency

Figure 33: The Organisational Structure of the National Academies.



of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. In 2015, the National Research Council was absorbed into the National Academies and NRC Divisions are now known as program units within the National Academies. One program unit is dedicated to Earth & Life Studies, which in turn has a program area on Earth Sciences & Resources with several committees that meet on regular bases to exchange recent findings in their areas of expertise (***Figure 33***).
- **Center for Strategic and International Studies (CSIS)** has published some work on mining, especially on rare earth elements.

INDUSTRY:

- **MINING COMPANIES:** The U.S. mining industry consists predominantly of big firms. The biggest mining and metals companies, in terms of revenues (even though not all of their revenue stems from mining alone and not all of their mines are in the U.S.) are
  - Freeport-McMoRan
  - Alcoa
  - Nucor
  - Newmont Mining
  - Southern Copper

10.2.3 Knowledge base for research and innovation

Because of high capital requirements, small profit margins and long lead times for the development of new properties, the mining industry historically has been very conservative in initiating and adopting new technologies. Still, the industry has made significant advances in productivity, environmental control, and worker health and safety.

R&D POLICY INSTRUMENTS IN THE PUBLIC SECTOR

There are no particular research & innovation programs especially designed for the mining sectors. The US Bureau of mines (USBM) used to be a focal point for federal research in mineral technology and it offered a modest funding base for mining schools. As the USGS took over some the tasks, it still does some basic research and offers some (smaller) grants. Since the demise of the USMB, the National Institutes of Health (NIH) (which consists of approx. 20 separate Institutes and Centers) have been the leading funder of mining research - mostly focused on health and safety aspects of operations and impacts.

Generally-speaking, however, R&D funds provided by the federal government are fairly small. Bigger initiatives are initiated (and sometimes carried out) by the agencies and their subordinate organisations (e.g. National Laboratories), other centres of excellence and universities, in response to particular necessities (e.g. stable supply of rare earths).

Several states have small research programs in mining-related technologies, but they are not significant. Mining schools actually struggle to find funding to support their programs and to continue to provide the personnel and talent needed by industry and government.

UNIVERSITIES:

As of December 2015, there were fifteen universities offering mining engineering degrees (there are nearly 800 colleges and universities that offer geoscience related programs) (Jeffrey & Camborne School of Mines, 2016).

- University of Alaska Fairbanks, College of Engineering and Mines
- The University of Arizona, Department of Mining and Geological Engineering
- Colorado School of Mines, Department of Mining
- Southern Illinois University Carbondale, Department of Mining Engineering
- University of Kentucky, Department of Mining Engineering
- Michigan Technological University, Department of Geological, Mining Engineering and Sciences
- University of Missouri S&T, Department of Mining and Nuclear Engineering
- Montana Tech of the University of Montana, Department of Mining Engineering
- Mackay School of Mines, University

of Nevada, Reno, School of Earth Sciences and Engineering
- New Mexico Institute of Mining and Technology, Department of Mineral Engineering
- The Pennsylvania State University, College of Earth and Mineral Sciences
- South Dakota School of Mines and Technology
- The University of Utah, College of Mines and Earth Sciences
- Virginia Polytechnic Institute and State University, College of Engineering
- West Virginia University

This list only contains universities offering mining engineering degrees. There are many more offering degrees in mining-related subjects. It is worth mentioning that there has been a steady decline of accredited mining and engineering programs. The Society for Mining, Metallurgy and Exploration claims that twelve universities have closed their mining engineering programs since 1985.

INDUSTRY DRIVEN R&D

Bigger mining companies can make use of in-house, corporate R&D units or they find individual researcher for one-off, small-scale projects (e.g. Ph.D. students). Smaller and mid-sized firm, which are limited in terms of resources, typically do not pursue R&D activities, but they may support M.S. students and they may join bigger consortia that work collectively on particular problems. It is common that industry pools resources for a group of researchers to work on specific problems, and usually those companies have exclusive access to the resulting technology and knowledge for a set period of time before researchers can publish their work. These initiatives, however, are driven mainly in response to concrete problems that need to be solved (***Figure 34***).

10.2.4 Key technologies

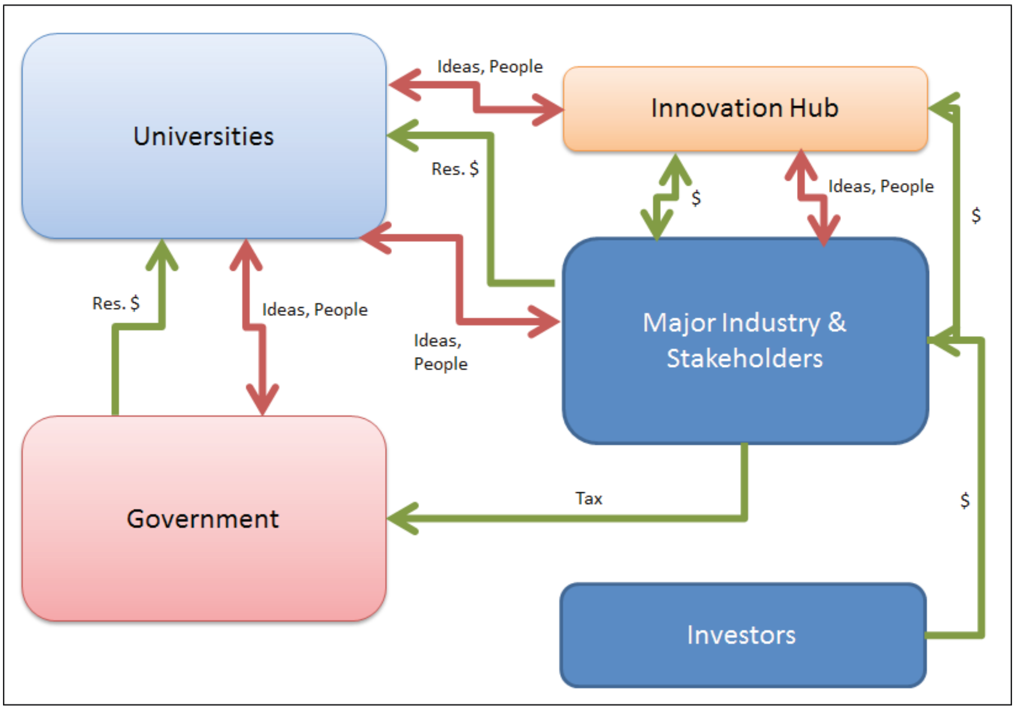
Technological development in the U.S. is mainly responsible to increasing work productivity in individual mines and driving down costs imposed by external factors. Among the most important technological recent innovations was the solvent extraction/electrowinning process (NRC, 2013, p. 90).

10.3 Metrics of the United States mining innovation system

The U.S. is a leading innovator in many ways, being among the top 10 countries for overall innovation, innovation input and innovation output in the Global Innovation Index (***Table 18***).

The same goes for the Innovation and

Figure 34: Main mechanisms to access and enlarge the mining knowledge base in the U.S.



Technology Readiness Indicators. The U.S. attains excellent scores related to capacity for innovation, quality of research institutions, company spending on R&D and university-industry collaboration in R&D (***Table 19***).

Table 18: United States of America Global Innovation Index.[1]

	SCORE 0–100 OR VALUE (HARD DATA)	RANK
Global Innovation Index (out of 141)	60.1	5
Innovation Output Sub-Index	52.9	9
Innovation Input Sub-Index	67.3	5
Innovation Efficiency Ratio	0.8	33
Global Innovation Index 2014 (out of 143)	60.1	6

Source: Dutta, et al., 2015, p. 186

1 As mentioned in Chapter 5, note that the GII is a measure of a country's overall innovation performance. The performance on overall innovation may differ significantly from mining innovation.

Table 19: U.S. Innovation and Technology Readiness Indicators.

INDICATOR	VALUE	RANK / 144
Innovation		
Capacity for innovation	5.9	2
Quality of scientific research institutions	6.1	4
Company spending on R&D	5.5	4
University-industry collaboration in R&D	5.8	2
Gov't procurement of advanced tech products	4.4	8
Availability of scientists and engineers	5.3	5
PCT patents, applications/million pop.*	149.8	11
Technology Readiness		
Availability of latest technologies	6.5	2
Firm-level technology absorption	6.1	3
FDI and technology transfer	4.9	41
Individuals using Internet, %	84.2	16
Fixed broadband Internet subscriptions/100 pop.*	28.5	19
Int'l Internet bandwidth, kb/s per user*	64.1	42
Mobile broadband subscriptions/100 pop.*	92.8	10
Values are on a 1-to-7 scale unless otherwise annotated with an asterisk (*).		

Source: Schwab, 2015, p. 379

11. Comparison/evaluation of regions

11.1 Quantitative performance benchmark

The quantitative performance benchmark aims at providing a basis for comparing the regions with each other, indicating relations between performance indicators and successful practices. The quantitative performance benchmark is based on data that is available for INTRAW's reference regions. In some cases, data from different years will be applied for the comparison, because of limited data availability. Furthermore, the basis of the statistical analysis may vary between the regions, so despite using numbers for the evaluation they are meant as to serve a rough indicators for the performance in each region. A frequently used approach to quantitative performance measurement is to consider input and output indicators of R&D. Input is usually measured in terms of personnel and expenditures whereas R&D output is measure via patents.

11.1.1 Relevance of mining in the regions

The importance of mining in the regions varies considerably. An indicator supporting the analysis of the mining sector relevance is the contribution of the mining sector to the overall GDP of a region (see ***Table 20***). The higher the contribution of mining to the countries' GDP, the more important the mining industry (e.g. in terms of employment).

Unsurprisingly, mining plays the biggest role in countries with big mineral endowments, such as Australia, South Africa and Canada whereas it plays a minor role in the U.S. and only a marginal role in Japan.

This view, however, does not take into account the contribution of the domestic mining related equipment and service industry, nor does it reflect the strategic importance of mining to the country. The U.S. require mineral commodities for production further downstream in the value chain. Sheet metal, for instance, is important for the U.S. car industry, but much less so for Australia.

11.1.2 Input: expenditure and personnel

For the comparison between different regions, the overall gross expenditure on R&D is put into relation to the gross domestic product. For comparison, the 28 members of the European Commission reported an average research intensity of 1.97% in 2012/13 (DST & HSRC, 2015, p. 43). This comparison allows to a draw conclusions on the overall importance of research and innovation activities in the regions from an input perspective (see ***Table 21***).

Among the regions considered, Japan spends the most on Research and Development, followed by the U.S., Australia, Canada and South Africa are all but below the OECD average concerning their gross expenditure on R&D related to the GDP.

Table 20: Relevance of mining related to the overall GDP in the regions.

REGION	CONTRIBUTION TO GDP
Australia	8.5 %AUS
Canada	4.0 %CAN
Japan	<0.1 %JPN
South Africa	4.9 %RSA
United States	1.4 %USA
RSA: 2013[1]; USA: 2012 (National Mining Association, 2014, p. E2); JPN: n.a. (Hilpert & Mildner, 2013, p. 105); CAN: 2014[2]; AUS: 2013-14[3]	

1 http://www.statssa.gov.za/ (Jan 2016)
2 http://www.nrcan.gc.ca/publications/key-facts/16013 (Jan 2016)
3 http://www.abs.gov.au (Jan 2016)

Table 21: Overall research intensity in the regions.

REGION	RESEARCH INTENSITY (PERCENT & RANK/5)	
Australia	2.11 %***	3
Canada	1.61 %**	4
Japan	3.58 % **	1
South Africa	0.73 %*	5
United States	2.74 %***	2
OECD Total	2.37 %**	-
*2012; **2014; ***2013[1]		

1 https://stats.oecd.org (Jan 2016)

Table 22: Innovation input sub-index of the regions.

REGION	INNOVATION INPUT SUB-INDEX (VALUE & RANK/144 (5))	
Australia	64.8	10 (3)
Canada	65.1	09 (2)
Japan	63.8	12 (4)
South Africa	45.2	54 (5)
United States	67.3	05 (1)

Source: Dutta, et al., 2015

Table 23: BERD in mining and quarrying related to overall BERD in the regions.

REGION	MINING BERD RELATED TO OVERALL BERD (RANK/4)
Australia	22.4 %* (1)
Canada	6.4 %*** (2)
Japan	<0.1 %*** (4)
South Africa	n.a.
United States	0.9 %** (3)
*2011; **2012; ***2013[1]	

1 https://stats.oecd.org (Jan 2016)

The innovation input sub-index (Dutta, et al., 2015, p. 9) represents the areas of institutions, human capital and research, infrastructure, market sophistication and business sophistication and therefore evaluates the innovation input from a more holistic perspective than the measure of the research intensity (see ***Table 22***). Taking into consideration this holistic perspective, the ranking slightly differs from the research intensity.

Considering the overall research intensity, an important factor is the share of research expenditure that is spent in the mining industry. This can be shown by the consideration of the business expenditure on R&D coming from the mining industry in relation to the overall business expenditure on R&D in the regions (see ***Table 23***).

Despite the overall high research intensity in Japan, only a minor part of R&D expenditure is allocated to the mining sector. Related to the overall business expenditure in R&D, companies in the mining sector in Australia are those who spent most. The regions with the highest R&D expenditure allocate only a minor part of business R&D expenditure to the mining sector. Based on the numbers available, the same applies for R&D personnel based on business enterprise R&D personnel related to the overall business enterprise R&D personnel in the regions (see ***Table 24***).

From the input perspective, the quantitative performance measures confirm

Table 24: Business enterprise R&D personnel in mining and quarrying related to overall business enterprise R&D personnel in the regions.

REGION	BERD PERSONNEL IN MINING AND QUARRING RELATED TO OVERALL BUSINESS ENTERPRISE R&D PERSONNEL	TOTAL R&D PERSONNEL PER THOUSAND EMPLOYMENT**** (2 COLUMNS DUE TO 2 SOURCES)	
Australia	7.3 %*	n.a.	n.a.
Canada	1.3 % **	12.54	4.49[CAN]
Japan	<0.1 % ***	13.35	5.20[JPN]
South Africa	n.a.	2.43	0.41[RSA]
United States	n.a.	n.a.	4.01[USA]
*2011; **2012; ***2013[1];****2013 (OECD, 2015, p. 104) and from other sources: USA, CAN; RSA: 2012; JPN 2013[2]			

1 https://stats.oecd.org (Jan 2016)
2 http://data.worldbank.org (Jan 2016)

that mining is not among the R&D intensive sectors (OECD, 2015, p. 28). Furthermore, the relevance of mining in the regions as well as the overall ambition to implement advances through research and innovation activities is reflected in the performance indicators.

11.1.3 Output: analysis of patent application and usage[1]

Patents are a key indicator for the output of research and innovation activities. An advantage of patent analysis is the availability of data on origins, involved actors and usage of patents. The amount of patents filed is considered a key indicator to analyse the amount and intensity of research and innovation activities. The citation and usage of patents is applied to measure the relation between research and innovation activities and the application of achieved results. However, SME tend to file less patents for cost reasons. Patents also do not reflect research and innovation activities that are not valid for patenting processes or those research results developed for the application within business enterprises. ***Table 25*** provides an overview on the amount of patents filed in each region.

The overall amount of patents filed differs between the regions. Referring to the usage of patents shown by the citation of mining technology patents (see ***Table 27***), especially patents from South Africa are cited more often in the mining industry than in other industries whereas mining patents from other regions are cited less frequently than patents from other sectors. The number of patents by itself, being only a part of the overall output is evaluated from a broader perspective by the innovation output sub-index (Dutta, et al., 2015, p. 9). This index is composed of knowledge and technology outputs including knowledge creation, impact and diffusion as well as creative outputs that include intangible assets, creative goods

1 To add to the limitations of the usage of patents as indicators, we also find that differences in patent applications due to differences in both culture and patent law. For example, theh U.S. is strong in patenting because it is a litigious country and innovators have a culture of using patents to protect their work.

Table 25: Total patent applications in the regions (in 2013).

REGION	TOTAL PATENT APPLICATIONS FILED UNDER THE PCT
Australia	1814
Canada	3157
Japan	41207
South Africa	275
United States	60067
2013, inventor(s)'s country(ies) of residence, priority date, total patents[1]	

1 https://stats.oecd.org (Jan 2016)

Table 26: Innovation output sub-index of the regions.

REGION	INNOVATION OUTPUT SUB-INDEX (VALUE & RANK/144 (5))	
Australia	45.6	17 (2)
Canada	46.4	22 (3)
Japan	44.1	26 (4)
South Africa	29.7	61 (5)
United States	52.9	09 (1)

Source: Dutta, et al., 2015

Table 27: Average mining patent counts and citation in regions.[1]

REGION	MINING PATENT COUNTS RELATED TO OVERALL PATENT COUNTS	ALL PATENTS AVERAGE CITATIONS PER PATENT	MINING TECHNOLOGY PATENTS AVERAGE CITATION PER PATENT	OTHER PATENTS AVERAGE CITATION PER PATENT
Australia	1.9 %	5.39	4.15	5.41
Canada	1.3 %	6.69	4.70	6.72
Japan	n.a.	n.a.	n.a.	n.a.
South Africa	4.3 %	5.52	7.06	5.44
United States	0.5 %	8.52	6.99	8.53

Source: Kaplan, 2011, p. 10

1 A patent belongs to the "Mining Technologies" cluster if it belongs to one of the following 3-digit USPC classes: 299 - Mining or In Situ Disintegration of Hard Material, 051 - Abrasive Tool Making Process, Material, and Composition, 023 - Chemistry: Physical Processes, 037 – Excavating, 075 - Specialized Metallurgical Processes, 172 - Earth Working

and services as well as online creativity. Note that these numbers don't specifically reflect mining specific aspects.

Taking into account both, the amount of patents filed as well as the innovation output sub-index, the U.S. is ranked at the top position. Japan's total number of patents is high, however, its composite innovation output is much lower and relatively speaking, it is ranked behind the U.S., Australia and Canada. Australia's innovation output scores much better in the evaluation scheme that goes beyond simple patent counting or patent citation analysis.

Especially in South Africa, the share of expenses for research and innovation activities varies related to the amount of patents in the mining industry whereas a relatively high quality standard has to be considered in regions such as the U.S. (see ***Table 27***).

11.2 Qualitative performance benchmark

The qualitative performance benchmark is carried out based on the qualitative description of the regions followed by an evaluation of each of the aspects described for each region in the previous chapter. The innovation system in the mining industry is evaluated on a basic evaluation scheme in three levels

Table 28: High-level innovation-system maturity model for the qualitative analysis of the regions.

MATURITY LEVEL	DESCRIPTION
3	Structures, resources and capabilities exist, are strongly interlinked and are able to support research and innovation activities in a commendable manner.
2	Structures, resources and capabilities exist with a potential for improvement in interlinkage or guidance to sufficiently support research and innovation activities.
1	Basic structures, resources and capabilities exist but have a considerable potential for improvement to support research and innovation activities.

(see ***Table 28***). The evaluation is done by measuring maturity levels (low, medium, high), which will be adapted to each of the categories described as being important for the mining innovation system. It is based on the information collected in existing publications and complemented by the expertise of the INTRAW consortium.

Note that the evaluation scheme, is – intentionally - strongly simplified. If country A has a higher score than country B, it does not necessarily imply that country A performs better, simply because each country faces different challenges and follows a different path to respond to these challenges. For instance, Japan has a well-defined, comprehensive raw materials strategy while the U.S. have a strategy for Rare Earth materials only.

The maturity levels described in Table 28 as well as the more detailed description for each of the categories depends strongly on the regions and thus may consider different aspects that are described in the qualitative evaluation of the maturity. The categories describe the mining innovation system from different perspectives:

- **Raw material strategy and priorities:** Does a strategy on research and innovation for mining exist, is it formulated based on relevant stakeholder requirements and able to be put into practice based on clear priorities to guide research and innovation activities?
- **Key actors and organizations:** Are the mining value chain as well as the different phases of research and innovation represented by actors and organizations? Are these actors and organizations collaborating to carry out research and innovation activities in a value-adding manner for the industry?
- **Knowledge base:** Is the personnel to carry out research and innovation activities available in academia and industry?
- **Key technologies:** Is there a basis and targeted research and innovation activities existing in key technology fields able to support the regional mining industry?

The evaluation of these four categories is shown and described in more detail in ***Table 29*** to ***Table 32***. The link to the maturity level is indicative and therefore might cover more than one level to consider the different aspects of each category concerned.

11.2.1 Raw material strategy and priorities

The raw material strategy and underlying priorities guide policy support and the creation and funding of organisations and actors. Furthermore, these are defining the key areas in which funded research and innovation takes place and are able to trigger collaboration between different actors along the mining value-chain. The maturity-levels are described in more detail as follows:

- **Maturity-level 1:** existence of a clearly formulated raw material strategy. Indication of research and innovation priorities in a well-defined time horizon.
- **Maturity-level 2:** linkage of the raw material strategy and priorities to specific programs and thereby to the actors and organisations carrying out research and innovation activities.
- **Maturity-level 3:** clear linkage between raw material strategy and priorities formulation, relevant organisations and actors and practical applications, products and services in the mining industry.

The evaluation of the raw material strategy and priorities in each of the regions analysed are shown in ***Table 29***.

11.2.2 Key actors and organizations

Actors and organizations are at the heart of research and innovation activities. This includes academia represented by university or research organisations as well as all kinds of industrial organisations such as major mining companies or small service or equipment suppliers.

- **Maturity-level 1:** existence of a variety of actors and organisations covering all areas of research and innovation from basic research to applied development.
- **Maturity-level 2:** structures to enable the targeted collaboration between different actors and organizations are

Table 29: *Evaluation of raw material strategy and priorities in the regions.*

REGION	DESCRIPTION	MATURITY -LEVEL		
		1	2	3
Australia	The raw material strategy of Australia is defined principally on the level of federal states and, only on a very high level by the central government. Priorities defined by the central government were not found in the reports analysed. This lack of central thematic coordination together with an increasing amount of federal regulations were partly seen as major barriers to the mining sector. It is only hardly transparent which current and future core competencies are especially supported through the raw material strategy and priorities.			
Canada	Originally, Canada's mining strategy has been defined on a very decentralised level which has been complemented by various approaches to define strategic objectives by the CMIC. However, the decentralised approach combined with a lack of central coordination is among the key critics of the Canadian raw material strategy. Canada has succeeded to set up policies enabling the creation of knowledge-based clusters on core mining industries. This success was especially driven by the thematic areas of exploration and finance which are clearly defined as most relevant current and future core competencies of Canada's mining sector.			
Japan	The raw materials strategy of Japan is well-defined to secure access to natural resources. The government determines which metals are critical to the economy and analyses how to ensure sufficient supplies. Japan has put in place a unique and well-proven way to execute the strategy by promoting the exploration and development of new mines, assisting in the development of exploration technologies and by assisting in corporate exploration investment and financing in Japan and aborad. There is a close institutional and personal link between politics and business to reach the objectives set in the strategy.			
South Africa	South Africa has defined strategy and priorities, underlined by key performance metrics. The linkage to research and innovation programmes is described on a general level, but does not go into detail on the practical application that are envisioned in the context of the programmes. The strategy and priorities are also defined on a relatively general level and are not providing detailed information on current and future core competencies of South Africa's mining sector.			
United States	The U.S. pursues a less explicit raw materials strategy, with the exception of the DOE's policies that aim to secure the provision of critical and strategic materials. There have been attempts to set directions for mining R&D in the past, mainly driven by industry and academia. Various think-tanks express their views on what should be done with respect to strengthening the minerals sector.			

established.

- **Maturity-level 3:** all organisations and actors in the value chain are carrying out research and innovation activities in a coordinated and targeted way.

The evaluation of the maturity-level of key actors and organizations in each region is shown in ***Table 30***.

Table 30: Evaluation of key actors and organizations in the regions.

REGION	DESCRIPTION	MATURITY -LEVEL		
		1	2	3
Australia	In research and innovation, a high variety of actors and organizations is active in the Australian mining sector. CSIRO is seen as one of the success factors of Australian mining industry whereas it is often stated that the role of the mining equipment, technology and service sector is often not considered in research and innovation activities, policies or analyses. The collaboration between actors and organisations is still seen as one of the major challenges, especially concerning the collaboration between universities and industry. Overall coordination of mining research and innovation activities is relatively decentralised rendering collaboration and coordinated research and innovation activities difficult. There is no explicit organization existing for the coordination of Pan-Australian mining research and innovation activities integrating all different types of organizations and actors.			
Canada	Actors and organisations in mining research and innovation cover the entire innovation value chain. Canadian companies are leading compared to other regions on a global level, especially in the area of endowment of metals and minerals. A challenge is the spreading of different actors and funding organizations involved and the decentralised coordination of research and innovation activities. A special organisation, the CMIC was created to enable more strategic investment in research and innovation activities. A key barrier for central coordination of research and innovation activities is the decentralised definition of mining policies. Comparable to Australia, the mining supply and service sector is often not considered for the planning and funding of research and innovation activities.			
Japan	The implementation of the Strategy for Ensuring Stable Supplies of Rare Metals involves several independent administrative organisations, such as JOGMEC (geological surveys, financing, debt guarantees), JBIC (financing and debt guarantee), NEXI (trade insurance) and JICA (staff training, organizational training classes). They seamlessly complement each other and can therefore grant access to overseas mineral resources. According to the government's strategy, research programmes are defined. Universities and research labs (e.g. AIST) carry out the research in close cooperation with the governmental bodies.			
South Africa	Role players in South Africa's mining sector cover the entire innovation value chain. Especially the organisations MINTEK and CSIR are considered as key players enabling world leading research and innovation activities. A key barrier for research and innovation activities is a lack of institutional and policy support necessary for the close collaboration between actors and organizations in the mining innovation value chain.			
United States	The U.S. has a decentralised approach to materials and mining policies. The major agencies involved in minerals and materials (DOI, DOE, DOD) sponsor R&D projects (carried out by universities, National Laboratories etc.) according to their missions, but there is no coordinated approach to materials development. The National Institutes of Health (NIH)) have been the leading funder of mining research - mostly focused on health and safety aspects of operations and impact. Bigger initiatives are initiated (and sometimes carried out) by the agencies and their subordinate organisations (e.g. National Laboratories), other centres of excellence and universities, in response to particular necessities (e.g. stable supply of rare earths).			

11.2.3 Knowledge base

The knowledge base represents the foundation for research and innovation activities. In the long run, it is the most important category and is composed of research and innovation personnel, supportive structures as well as IP protection and IP exploitation mechanisms.[2]

2 While the knowledge base of each individual country can be examined country by country, it is necessary to recall the global mobility of mining industry professionals and the rapidity of knowledge transfer around the world. A simple example - mining geostatistics started in South Africa, a theoretical basis was developed in France, and R&D is now active also in Australia, USA, and elsewhere, led by key individuals of different nationalities.

- **Maturity-level 1:** existence of industry driven programs to ensure continuous availability of appropriately educated personnel for research and innovation activities.
- **Maturity-level 2:** support structures for transforming knowledge into research and innovation results, including appropriate funding mechanisms for different organizations.
- **Maturity-level 3:** structures for the continuous protection and exploitation of intellectual property is available and is used by the different

Table 31: Evaluation of the knowledge base in the regions.

REGION	DESCRIPTION	MATURITY -LEVEL		
		1	2	3
Australia	The education of qualified graduates is in the hand of the MCA in close collaboration with Australian universities, and thus to a high level driven by industry needs. A key challenge lies in the collaboration between universities and industry in patent application and exploitation. Thus it is stated that the investment in university research is only rarely translated into commercially viable innovation.			
Canada	The knowledge base in Canada's mining sector is considered as one of the key success factors. Mining personnel contains a relevant mix of knowledge and skills, attracting not only Canadian companies but also mining companies from abroad. There are no special mechanisms mentioned for patent management in mining research and innovation.			
Japan	Japan has interest in the downstream mining activities and as such there is a major research focus on downstream activities such as processing technology, material science and substitution. Based on the raw materials strategy, research programs are formulated and grants are given to universities and private companies, mainly on the subjects of material substitution, mineral exploration, excavation, refining and safety research. Apart from research grants, R&D Tax credits and SME-targeted measures are the main policy instruments to create incentives for research and innovation related to mining and materials.			
South Africa	South Africa has a well established system to assure the graduation of high qualified personnel responding to industrial requirements. A key challenge is the migration of qualified personnel due to better salaries or working conditions in other mining intensive regions. Overall, the share of personnel related to research and innovation is relatively low compared to other regions. Patenting is a key asset of South Africa's mining industry which is reflected by a high citation rate of South Africa's mining patents.			
United States	There are 15 universities offering mining engineering programs, however, there has been a steady decline of accredited mining and engineering programs over the past 15 years. Much of the research and innovation is industry-driven. It is common that industry pools resources for a group of researchers to work on specific problems. R&D funds provided by the federal government are rather small.			

actors of the innovation value-chain.

The evaluation of the knowledge base within the different regions is shown in ***Table 31***.

11.2.4 Key technologies

Key technologies is a category that is relatively difficult to evaluate on a regional level due to a high flow of most recent technologies on a global level. Despite this difficulty, it is important to analyse the capability to develop and exploit key technologies. Thus the maturity of each region shall be evaluated based on the following factors:

- **Maturity-level 1:** existence of the capability to develop relevant technologies for the application in the mining sector.
- **Maturity-level 2:** linkage of relevant actors and organisations to exploit technological know-how into advanced products and services.
- **Maturity-level 3:** structures for the continuous protection and exploitation of intellectual property is available and is used by the different actors of the innovation value-chain.

The evaluation of key technologies in the regions is shown in ***Table 32***.

Table 32: Evaluation of key technologies in the regions.

REGION	DESCRIPTION	MATURITY -LEVEL		
		1	2	3
Australia	Australia is at the forefront of technological development in specific technological fields. A key challenge is that a major part of Australian patent applications are filed by foreign organizations or applicants. Furthermore, technologies developed by universities are only seldom exploited based on filed patents due to barriers in industry university collaboration. CSRIO however is recognised as a leading player in technology development on a global level			
Canada	Despite being a leading player in the global mining industry, it is stated that Canada is not a leader in mining technology. This is contradictory with the extensive science and technology network combined with broad expertise in areas such as geoscience as well as a leading role in green mining technologies. The number of patents filed in the mining sector exceeds those in regions such as Australia or South Africa but is far below Japan and the U.S..			
Japan	Despite having abandoned most of the domestic mining activities, Japan never stopped developing mining technologies and technologies for mineral processing. JOGMEC uses this knowledge (e.g. notably for exploration) in a strategic way to transfer knowledge and technology to countries that are abundantly endowed with mineral resources and which are likely to collaborate with Japanese companies at some point in the future. Apart from that, Japan is a leading country with regard to mineral processing and recycling.			
South Africa	South Africa's mining sector has produced sizeable know-how, especially in the area of mining explosives, drilling equipment and abrasives, metallurgical processes and plants. Patents filed in the mining sector seem to have a high relevance compared with other South African sectors or with other global mining regions. A key challenge is the lack of policy support for future technological developments in the mining sector.			
United States	Technological development in the U.S. is mainly responsible for increasing work productivity in individual mines and driving down costs imposed by external factors. There is no indication of particular know-how or particular technologies that are very specific to the U.S.			

References and bibliography

Energy and Mines Minister's Conference, 2015. *Innovating for a Strong Canadian Energy and Mining Sector*, Halifax: Energy and Mines Minister's Conference.

American Physical Society and the Materials Research Society, 2011. *Energy Critical Elements: Securing Materials for Emerging Technologies.* s.l.:s.n.

Arnold, E. & Bell, M., 2001. Some new ideas about research for development. In: *Partnership at the Leading Edge: A Danish Vision for Knowledge, Research and Development*. s.l.:s.n., pp. 279-316.

ASSIMAGRA, 2016. *INTRAW report - Transactional Analysis on Industry & Trade*, s.l.: s.n.

Austrialian Government, D. o. I. I. a. S., 2015. *Bilateral minerals and energy cooperation.* [Online] Available at: http://www.industry.gov.au/resource/Enhancing/bmec/Pages/default.aspx [Zugriff am February 2016].

Bartos, P., 2007. Is mining a high-tech industry? Investigations into innovation and productivity advance. *Resources Policy*, pp. 149-158.

Canada Mining Innovation Council, 2014. *CMIC Annual Report 2014*, s.l.: CMIC.

Canadian Chamber of Commerce, 2013. *Mining Capital: How Canada has transformed its Resource Endowment into a Global Competitive Advantage,* Ottawa, Toronto, Montreal, Calgary: Canadian Chamber of Commerce.

Canadian Mining Innovation Council, 2008. *The Pan-Canadian Research and Innovation Strategy*, s.l.: s.n.

Committee on Emerging Workforce Trends in the U.S. Energy and Mining Industries, 2013. *Emerging Workforce Trends in the U.S. Energy and Mining Industries: A Call to Action*. Washinton, D.C.: National Academy Press.

Committee on Technologies for the Mining Industry, 2002. *Evolutionary and Revolutionary Technologies for Mining*. Washington, D.C.: National Academy Press.

Commonwealth of Australia, 2013. *Research and Experimental development, businesses 8104.0*, Canberra: Australian Bureau of Statistics.

Council of Canadian Academies, 2013. *The state of industrial R&D in Canada / The Expert Panel on the State of Industrial R&D in Canada*, Ottawa: Council of Canadian Academies.

David, P. & Foray, D., 1995. Interactions in knowledge systems: Foundations, policy implications and empirical methods. *STI Review*, pp. 14-61.

Department of Defense, 2015. *Strategic and Critical Materials: 2015 Report on Stockpile Requirements* , s.l.: s.n.

Department of Mineral Resouces, 2010. *Amendment of the broad-based socio-economic empowerment charter for the South African mining and minerals indUSry*, s.l.: DMR, Republic of South Africa.

Department of Science and Technology, 2008. *Innovation Towards a Knowledge Economy. A Ten Year Plan for South Africa*, Pretoria: Department of Science and Technology.

Dobra, J. L., 2014. *Divergent Mineral Rights Regimes: A Natural Experiment in Canada and the United States Yields Lessons*, Vancouver: Fraser Institute.

DOE, 2011. *Critical Materials Strategy*, Washington: DOE.

DST & HSRC, 2015. *National survey of research and experimental development, main analysis report 2012/2013*, Pretoria: DST & HSRC.

Dutta, S., Lanvin, B. & Wunsch-Vincent, S., 2015. *The Global Innovaiton Index 2015: Effective Innovation Policies for Development*, Geneva: Cornell University, INSEAD, and the World Intellectual Property Organization (WIPO).

Dutta, S., Lanvin, B. & Wunsch-Vincent, S., 2015. *The Global Innovation Index 2015: Effective Innovation Policies for Development*, Geneva: Cornell University, INSEAD, and the World Intellectual Property Organization (WIPO).

Edquist, C., 2001. *The Systems of Innovation Approach and Innovation Policy: An account of the state of the art*. [Online] Available at: http://www.druid.dk/uploads/tx_picturedb/ds2001-178 [Zugriff am January 2016].

Ericsson, M., 2012. *Mining industry corporate actors analysis*. [Online] Available at: http://www.eisourcebook.org/cms/Mining%20industry%20corporate%20actors%20analysis.pdf [Zugriff am February 2016].

European Commission, 2014. *European Commission*. [Online] Available at: http://bookshop.europa.eu/de/regional-innovation-scoreboard-2014 [Zugriff am January 2016].

EY, 2014. *Productivity in mining: Now comes the hard part*. [Online] Available at: http://www.ey.com/Publication/vwLUAssets/EY-productivity-in-mining-now-comes-the-hard-part/$FILE/EY-productivity-in-mining-now-comes-the-hard-part.pdf

Featherstone, T., 2012. *Better ways to get the digging done. BRW.*, 29 March.

Filippou, D. & King, M. G., 2011. R&D prospects in the mining and metals industry. *Resources Policy*, pp. 276 - 284.

Francis, E., 2015. *The Australian Mining Industry: More than Just Shovels and Being the Lucky Country*, s.l.: Australian Government, IP Australia.

Freeman, C., 1974. *The Economics of Industrial Innovation*. Harmondsworth: Penguin Books.

Freeman, R., 1994. The economics of technical change. *Cambridge Journa*l, pp. 463-514.

Gregory, R. G., 1993. The Australian Innovation System. In: R. R. Nelson, Hrsg. *National Innovation System: A comparative Analysis.* Oxford: Oxford University Press.

Hilpert, H. G. & Mildner, S.-A., 2013. *Nationale Alleingänge oder internationale Kooperation? Analyse und Vergleich der Rohstoffstrategien der G20 Staaten.* Berlin: Stiftung Wissenschaft und Politik.

Hilpert, H. G. & Mildner, S.-A., 2013. *Nationale Alleingänge oder internationale Kooperation? Analyse und Vergleich der Rohstoffstrategien der G20 Staaten*, Berlin: Stiftung Wissenschaft und Politik (SWP) und Bundesantstalt für Geowissenschaften und Rohstoffe.

Hollanders, H. & Janz, N., 2013. Scoreboards and indicator reports. In: F. Gault, Hrsg. *andbook of innovation indicators and measurement*. s.l.:s.n., pp. 279 - 297.

Hollitt, M., 2012. *XXVI International Mineral Processing Congress (IMPC 2012)*. [Online] Available at: https://www.ausimm.com.au/content/docs/branch/2014/nwq_2014_10_presentation_IMPC.pdf [Accessed January 2016].

INTRAW, 2015. *Contextual Analysis of the Reference Countries: Australia*, s.l.: INTRAW.

INTRAW, 2015. *Contextual Analysis of the Reference Countries: Canada*, s.l.: INTRAW.

INTRAW, 2015. *Contextual Analysis of the Reference Countries: Japan*. s.l.:s.n.

INTRAW, 2015. *Contextual Analysis of the Reference Countries: South Africa*, s.l.: INTRAW.

INTRAW, 2015. *Contextual Analysis of the Reference Countries: United States of America*, s.l.: INTRAW.

Jeffrey, K. & Camborne School of Mines, 2016. *INTRAW Report - Transactional Analysis of Education and Outreach*, s.l.: s.n.

Jeffrey, K., kein Datum *The mining life cycle and the mining life cycle*. s.l.:s.n.

JOGMEC, 2012. *JOGMEC Corporate Profile*. [Online] Available at: http://www.jogmec.go.jp/content/300196198.pdf

Kamijya, N., 2008. *JAPAN's Sustainable Metals Supply and the Role of JOGMEC*. [Online] Available at: http://www.cochilco.cl/archivos/presentaciones/20090112150136_Presentaci%C3%B3n%20JOGMEC.pdf [Accessed January 2016].

Kaplan, D., 2011. *South African mining equipment and related services: growth, constraints and policy*, Cape Town: MMCP Discussion Paper No. 5.

Kikkawa, T., 2013. WHY HAS JAPAN REVISED THE MINING ACT? - HISTORICALAND CONTEMPORARY BACKGROUND. *Hitotsubashi journal of commerce and management*, 10, pp. 33 - 42.

Kline, S. J. & Rosenberg, J., 1986. An overview of innovation. In: R. Landau & N. Rosenberg, eds. *The Positive Sum Strategy: Harnessing Technology for Economic Growth*. Washington, D.C.: National Academy Press, pp. 275 - 305.

Koroshy, J., Korteweg, R. & de Ridder, M., 2010. *Strategy & Change report 'Rare Earth Elements and Strategic Mineral Policy»*. The Hague: World Foresight Forum.

Kunitomo, H., n.d. JOGMEC: *Japan's Metal Mining Policy and the role of JOGMEC*. [Online] Available at: htt://mric.jogmec.go.jp/...05/JOGMEC_Kunitomo2.pdf [Accessed January 2016].

Kuo, C. S., 2012. The Mineral Industry of Japan. In: *The 2010 Minerals Yearbook*. s.l.:s.n.

Lane, A. & Beier, J., 2014. The Future of Mining in South Africa, Johannesburg: Deloite & Touche.

Lane, T., 2008. *Innovation, Reserach and Development Needs in Mineral Exploration*, s.l.: Canadian Mining Innovation Council CMIC.

Lowry, D., Molloy, S. & Tan, Y., 2006. *The Labour Force Outlook in the Minerals Resources Sector: 2005 to 2015*. Adelaide: Flinders University.

Mahdjoubi, D., 1997. *The Linear Model of Technological Innovation: Background and Taxonomy*. [Online] Available at: https://www.ischool.utexas.edu/~darius/04-Linear%20Model.pdf [Zugriff am January 2016].

Malerba, F., 2005. Sectoral Systems: How and why innovation differs across sectors.. In: *The Oxford Handbook of Innovation*. New York: Oxford University Press, pp. 380-406.

Marshall, B., 2014. *Facts & Figures of the Canadian Mining Industry 2014*, Ottawa: The Mining Association of Canada.

McKinsey Global Institute, 2013. *Disruptive technologies: Advances that will transform life, business, and the global economy*, s.l.: McKinsey & Company.

Minerals Council of Australia, 2014. *Minerals industry priorities for regulatory reform*, Kingston: s.n.

Mitchell, P. & Steen, J., 2014. *Productivity in mining,* s.l.: Ernst & Young Global Mining & Metals Center.

Monitor Deloitte, Doblin, PDAC, 2015. *Innovation state of play. Mining edition 2015*, s.l.: Monitor Deloitte, Doblin, PDAC.

NAE Section 11, 2010. *Grand Challenges in Earth Resources Engineering*. [Online] Available at: https://www.nae.edu/106328.aspx [Accessed January 2016].

National Academy of Engineering, 2010. *Grand Challenges for Engineering.* [Online] Available at: www.engineeringchallenges.org/cms/8996/9221.aspx

[Zugriff am 2016 January].

National Mining Association, 2014. *The Economic Contributions of U.S. Mining* (2012), Washington: National Mining Association.

National Research Foundation, 2015. *NRF Strategic Plan 2015-2020*, Pretoria: National Research Foundation.

National Science Foundation, 2006. *Report Memorandum #06-03*. [Online] Available at: http://www.nsf.gov/od/oise/tokyo/reports/trm/rm06-03.pdf [Accessed January 2016].

Natural Resources Canada, 2012. *Natural Resources Canada Employment Information Bulletin: Minerals and Metals Secto*r. [Online] Available at: http://www.nrcan.gc.ca/mining-materials/publications/8792#T1 [Zugriff am January 2016].

Nelson, R., 1993. *National innovation systems: a comparative analysis*.. Oxford: Oxford University Press.

NRC, 2013. *Emerging Workforce Trends in the U.S. Energy and Mining Industries*, Washington: The National Academies Press.

OECD / EUROSTAT, 2005. *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, 3rd Edition, The Measurement of Scientific and Technological Activities. 3rd Hrsg. Paris: OECD Publishing.

OECD, 1997. *OECD*. [Online] Available at: http://www.oecd.org/science/inno/2101733.pdf [Accessed January 2016].

OECD, 2015. *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities.* Paris: OECD Publishing.

OECD, 2015. *OECD Science, Technology and Industry Scoreboard 2015. Innovation for growth and society*, Paris: OECD Publishing.

Office of the Chief Economist, 2014. *Australian Industry Report 2014. Highlights*, s.l.: Australian Government, department of industry.

Office of the Chief Economist, 2014. *Australian Innovation System Report*, Canberra: Australian Government, Department of Industry.

Office of the Chief Economist, 2015. *Australian Innovation System Report,* Canberra: Australian Government, Department of Industry, Innovation and Science.

Office of the Chief Economist, 2015. *Australian Innovation System Report*, Canberra: Australian Government, Department of Industry, Innovaiton and Science.

Office of the Chief Economist, 2015. *Resources and Energy: Major Projects*, Canberra: Australian Government, Department of Industry.

Oliverira, M. B. d., 2014. 2014. *Scientiae Studia*, 12, pp. 129-146.

Parthemore, C., 2011. *Elements of Security: Mitigating the Risks of U.S. Dependence on Critical Minerals*. s.l.:s.n.

Pearson, B., 2014. *Minerals Council of Australia*. [Online] Available at: http://www.minerals.org.au/news/productivity_commission_supports_untangling_exploration_red_tape [Zugriff am February 2016].

Peterson, D., Latourette, T. & Bartis, J., 2001. *Technology Forces at Work in Mining: Industry Views of Critical Technologies.* s.l.:RAND.

PWC, 2014. *Pan-Ontario mining supply and services sector economic impact study, Ontario: Canadian Association for Mining Equipment and Services for Export*.

Savine, K., 2015. *Canada's Innovation Performance: a scorecard*, Canada: deepcenter.

Schwab, K., 2015. *The Global Competitiveness Report 2014-2015,* Full Data Edition, Geneva: World Economic Forum.

Scott-Kemmis, D., 2011. *Australian Mining Technology Services and Equipment Suppliers. A Pilot Study for the United States Studies Centre*, Sydney: University of Sydney.

Scott-Kemmis, D., 2013. *How about those METS*, Kingston: The minerals council of Australia.

Seccombe, A., 2016. *SA's mining sector has bled 47,000 jobs in three years*. Business Day.

SNL Metals and Mining, 2014. *U.S. Mines to Market*, s.l.: s.n.

Som, O. & Kirner, E., 2015. *Low-tech Innovation: Competitiveness of the German Manufacturing Sector.* Berlin: Springer.

Statistics Canada, 2015. *Industrial Research and Development: Intentions*, Ottawa: Statistics Canada.

Statistics Japan, 2015. *Statistics Bureau Homepage - Statistical Handbook of Japan 2015*. [Online] Available at: http://www.stat.go.jp/english/data/handbook/c0117.htm [Accessed January 2016].

Sudbury Community Foundation, 2014. *Greater Sudbury's Annual Check-up 2014, Mining Innovation Edition*, Sudbury: Sudbury Community Foundation.

Takagi, T., 2015. *Governmental strategy for the securement of mineral resources in Japan.* [Online] Available at: http://www.worldforum-sustainability.org/wp-content/uploads/2015/10/Takagi_Governmental-strategy-for-the-securement-of-mineral-resources.pdf [Accessed January 2016].

Team Finland Mining Growth Program, 2015. *Team Finland Mining Growth Program South Africa*, *Module 4.2 Market Studies,* s.l.: Team Finland.

Technology Innovation Agency, 2012. *The Mining Sector Innovation Strategies Implementation Plan 2012/13–2016/17*, Pretoria: Technology Innovation Agency.

The Business of Mining, 2010. *Vertical integration in mining: the trader's value chain*. [Online] Available at: http://www.mining.com/vertical-integration-in-mining-the-trader%E2%80%99s-value-chain/ [Zugriff am January 2016].

Twigge-Molecey, C., 2011. *Challenges to Innovation in the Consulting Engineering Business.* [Online] Available at: http://www.ibram.org.br/sites/1300/1382/00003448.pdf

USGS, 2002. *Materials in the Economy. Material Flows, Scarcity, and the Environment,* Denver: U.S. Geological Survey.

VCI, 2014. *Innovation - State of Play*, s.l.: s.n.

Woolgar, L., 2006. *Monitoring and analysis of policies and public financing instruments conducive to higher levels of R&D investments.* [Online] [Accessed January 2016].

World Bank and International Finance Corporation, 2002. *Treasure or Trouble? Mining in developing countries*, Washington, D.C.: International Finance Corporation.

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