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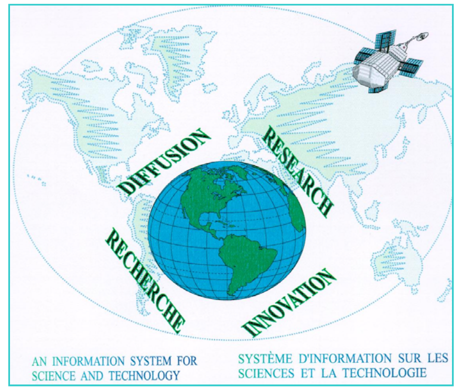
Innovation and the Use of Advanced Technologies in Canada's Mineral Sector: Metal Ore Mining



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Innovation and the Use of Advanced Technologies in Canada's Mineral Sector:

Metal Ore Mining

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Science, Innovation and Electronic Information Division

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Working Papers

The Working Papers publish research related to science and technology issues. All papers are subject to internal review. The views expressed in the articles are those of the authors and do not necessarily reflect the views of Statistics Canada nor, in this case, the views of Industry Canada, Natural Resources Canada or the National Research Council of Canada.

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Preface

The Information System for Science and Technology Project was created to develop useful indicators of science and technology activity in Canada based on a framework that ties them together into a coherent picture. To achieve the purpose, statistical indicators are being developed for five key entities:

- **Actors**: persons and institutions engaged in S&T activities. Measures include distinguishing R&D performers, identifying universities that license their technologies, and determining the field of study of graduates.
- **Activities**: the creation, transmission or use of S&T knowledge including research and development, innovation, and use of technologies.
- **Linkages**: the means by which S&T knowledge is transferred among actors. Measures include the flow of graduates to industries, the licensing of a university's technology to a company, co-authorship of scientific papers, and the source of ideas for innovation in industry.
- **Outcomes**: the medium-term consequences of activities. Outcomes of an innovation in a firm may be improved productivity, improved product quality and/or more highly skilled jobs. An outcome of a firm adopting a new technology may be a greater market share for that firm.
- **Impacts**: the longer-term consequences of activities, linkages and outcomes. Wireless telephony is the result of many activities, linkages and outcomes. It has wide-ranging economic and social impacts such as increased connectedness.

The development of these indicators and their further elaboration is being done at Statistics Canada, in collaboration with other government departments and agencies, and a network of contractors.

Prior to the start of this work, the ongoing measurements of S&T activities were limited to information and data on the investment of money and human resources in research and development (R&D). For governments, there were also measures of related scientific activity (RSA) such as surveys and routine testing. These measures presented a narrow picture of science and technology in Canada. More measures were needed to improve the picture.

It is in this context that the Survey of Innovation, 1999 was developed. It is hypothesized that innovation makes firms competitive. Thus one of the goals of this survey was to determine if there were significant differences between innovative and non-innovative firms in the manufacturing and selected natural resources sectors. The capacity to innovate resides in people and measures are being developed of the characteristics of people in those industries that lead science and technology activity. In these same industries, measures are being made of the creation and the loss of jobs as part of understanding the impact of technological change.

This working paper is part of a series that examines the results from the Survey of Innovation 1999. Previous working papers include an examination of national estimates of innovation in manufacturing and a second working paper, which included statistical tables of provincial estimates of innovation in manufacturing.

The framework briefly described above that guides the future elaboration of indicators was published in December, 1998 (**Science and Technology Activities and Impacts: A Framework for a**

Statistical Information System, Cat. No. 88-522). The framework has given rise to **A Five-Year Strategic Plan for the Development of an Information System for Science and Technology** (Cat. No. 88-523).

Working papers and research papers are available at no cost on the Statistics Canada Internet site at **http://www.statcan.ca/cgi-bin/downpub/research.cgi?subject=193**

Introduction

In 2001, Canada's mineral production included 26 metallic minerals, 31 non-metallic minerals and 4 fuels with a total production value of $83.8 billion based on shipments (Statistics Canada, 2001). Canada is one of the world's largest exporters of minerals and mineral products contributing $27.5 billion to the balance of trade in 2001 (Statistics Canada, 2002).

Innovation in Canada's mineral sector is vital if this industry sector is to be competitive in the global economy. As in other industries, competitive advantage can be gained through development of new products, adoption and use of new technologies, and improvements to organizational structure or improved management techniques.

The Survey of Innovation 1999 surveyed manufacturing and was the first Statistics Canada innovation survey of selected natural resource industries in Canada[1]. It employed the framework and guidelines elaborated upon in the Oslo Manual (OECD/Eurostat, 1997) to collect innovation data. Questions were also included in the Survey of Innovation 1999 to explore the relationship between suppliers and selected natural resource industries. The Survey of Electronic Commerce and Technology 2000 included two questions on organizational and technological improvements, providing the first cross-economy data on these issues.

The goal of this paper is to examine innovation and advanced technology use in the mineral sector. The author will describe characteristics of and relationships between innovative firms from several industries in the mineral sector system focusing on metal ore mining. Data from the Survey of Innovation 1999 will be used to analyse the type of innovation and the innovative activities of firms in the mineral sector system. Sources of information for innovation, objectives of innovation, and firm success factors will also be examined, including an exploration of types of skills in demand in metal ore mining firms. Data from the Survey of Electronic Commerce and Technology 2000 will be used to explore how firms react to advanced technologies by describing the manner in which improved technologies were introduced to mining firms.

Building a system of innovation

There are several elements that influence how industries operate and, accordingly, should be incorporated into a system of innovation. These include infrastructure and macro-economic conditions, the characteristics of the production process and the firm's role in innovation activities (Freeman, 1987, Lundvall, 1992).

The cultural and institutional context and economic structure of a country forms the infrastructure under which firms operate. These underlying conditions influence all activities within a firm, including innovation. Lundvall (1992, 1998) proposed that innovation is rooted in knowledge and

[1] Statistics Canada has conducted several surveys of innovation since 1993 to better understand innovation in Canada. The 1993 Survey of Innovation and Advanced Technology surveyed manufacturing firms. The Survey of Innovation, 1996 surveyed the communications, financial services and technical business services industries. The 1999 Survey of Innovation, Advanced Technologies and Practices in the Construction and Related Industries was the first survey of advanced technologies and practices in the construction sector.

that learning is a prerequisite of knowledge. Furthermore, learning is predominantly interactive making it a “socially embedded process”. He hypothesizes that if research institutions define how things are done and how learning takes place, the economic structure affects ‘what is done’ and, as a result, what is learned. These institutions can have their origins far back in social history. Accordingly, if we want to understand innovation within an economy we must not only consider the macroeconomic conditions but also examine the institutional and cultural context of that economy so we can understand what is being done within the firm.

Innis’ (1956) “Staple Theory” provides a description of the institutional and cultural context of the Canadian economy and the cumulative effects of the exploitation of staple products such as lumber, wheat, fish (cod), furs and gold. These staple products form an important component in Canadian economic history. Migrants to Canada produced goods in demand in their home countries that would yield large profits. These goods were either used in the manufacture of luxuries or were goods that were not produced or were only minimally so in the home country. Harvesting or extraction of raw materials stimulated the manufacture of finished products in demand in the mother European countries and the colony. There was both a direct and indirect focussing of energy on the production of the staple commodity. Part of the population of the colony was involved directly in the production of the staple while others became indirectly involved through the direction of efforts to produce facilities that would promote production of the staple. The scale of production of agricultural products such as wheat and lumber and later of minerals such as gold, nickel and other metals grew with demand as improvements in production techniques (machinery and equipment), marketing and transportation infrastructure improved. These improvements affected both the harvesters/extractors and the manufacturers. Greater demand stimulated technological advances both to increase the supply of raw materials and to accommodate the influx of these raw materials to manufacturers.

Technological change in the production process is only one aspect of innovation; yet it has played a large role in firm innovation for metal ore mining in the history of the industry that continues today. Utterback and Abernathy (1975) and Abernathy and Clark (1985) have explored the influence of the production process on firm innovation. Characteristics of innovation correspond to the stage of development of the production process technology. Incremental technical change during the evolution of an industry is emphasized. The environment under which a firm operates and the competitive significance of the innovation, which includes the objective of the innovation and factors for firm success, will impact on the type of innovation a firm attempts.

How is innovation measured within the firm? Models of firm innovation explore interactions involving knowledge flows both within the firm and from external sources from the perspective of the firm (Kline and Rosenberg, 1986; Padmore et al. 1998). The Oslo Manual (1997) outlines guidelines for collecting and interpreting innovation data within a system of innovation. Technological changes are dealt with at the level of the individual firm or business enterprise, and involve a complex system with many interacting components. Application of the Oslo Manual allows for the production of internationally comparable, meaningful indicators of innovation. In the case of product innovation, the product must have been introduced to the market. An innovative firm is one that has offered a new or significantly improved product or introduced a new or significantly improved production/manufacturing process during the last three years. The term “product” includes both goods and services as innovation outputs. A process innovation must have been used within the production process.

In this firm-centric conceptual framework there are four domains, each of which plays a role in business innovation. The firm is referred to as an “innovation dynamo” as it is through the firm that innovations are introduced. Innovation in the firm will be affected by a series of “transfer factors” based around leaning. These are the human, social and cultural factors that affect the transmission of information to firms and the learning that occurs by them. Firms exist and carry out business under a series of established conditions and institutions that will affect the range of opportunities for innovation. These “framework conditions” include the basic education system, the communications infrastructure, financial institutions, the legislative and macroeconomic settings, market accessibility, industry structure and the competitive environment. The various institutions that provide the technological training and scientific knowledge to this system form the “science and engineering base”.

Understanding the ways new knowledge and information is generated and diffused is another important issue in the measurement of technological change. It can be embedded in new products, processes as described by Rothwell’s (1994) “system integration and networking” model of innovation that provides for the transmission of technological change through changes in technologies. New knowledge and information can also be in the form of organizational practices that become adopted by a given industry. It can be in the form of tacit knowledge embedded in people who have specialized expertise gained through education and experience or can be codified in manuals, forms of publications, computer software or product design. Diffusion of knowledge requires a user who can find, understand, absorb and then apply S&T knowledge in the form that it is transmitted (Statistics Canada, 1998a).

Foray and David (1995) have explored diffusion of knowledge and describe three basic activities in the S&T system: the generation, transmission and use of S&T knowledge. Statistics Canada’s Science, Innovation and Electronic Information Division developed a framework for the organization of data as a means of understanding the science and technology system (1998a). Recognizing that innovation is just one of the activities in the use of S&T knowledge[2], the approach considers interactions with society, economy and political system as a system of information flows. It promotes the examination of an industry within this system. “Actors” undertake product or process innovation with various objective and outcome indicators providing a statistical description of firm innovation.

This paper is divided into three sections. The first will present a model for a system of innovation for the mineral sector that encompasses many industry sectors and knowledge flows between sectors. The second section will explore the characteristics of innovative firms in the mineral sector system with emphasis on type of innovation and the innovative activities. Sources of information for innovation, innovation objectives and firm success factors will also be examined. The final section will present the manner in which improved technologies were introduced to mining firms.

[2] other S&T activities in the framework include: R&D, invention, and technology knowledge diffusion

An Innovation System for the Mineral Sector

Canada's mineral sector is an interactive system comprised of six main groups of actors operating within a macroeconomic, social and cultural context. The group of actors includes resource management, extractors of raw materials, manufacturers of products from raw materials, users of extracted raw materials, services to support the other actors in the system, and manufacturers of machinery, equipment and instruments used by the other actors in the system.

It can be argued that innovation in the Mineral Sector is taking place in a larger interactive system. No one part of this system should be viewed in isolation if the innovation process is to be understood. The North American Industrial Classification System or NAICS (Statistics Canada, 1998b) allows for the collection and dissemination of comparable industry data. The words "mining" and "mine" are found in the alphabetical index of NAICS under 17 entries encompassing industries from a wide range of sectors (2-digit NAICS). These include agriculture, forestry, fishing and hunting (NAICS 11); mining and oil and gas extraction (NAICS 21); construction (NAICS 23); some manufacturing industries (NAICS 33) wholesale trade (NAICS 41); real estate and rental and leasing (NAICS 53); professional, scientific and technical services (NAICS 54); and other services (except Public Administration) (NAICS 81) [3]. Only one of these industry sectors has the word "mining" in the title: mining and oil and gas extraction. There are even fewer entries listed for the word "mineral" which includes only 5 relevant[4] entries. Among these are some manufacturing industries (NAICS 32); wholesale trade (NAICS 41); and real estate and rental and leasing (NAICS 53)[5].

A systems approach to describing the Mineral Sector combines concepts from the "innovation policy terrain" described in the Oslo Manual and concepts from Statistics Canada's "Framework for a Statistical Information System" (Statistics Canada, 1998a). To reduce complexity and to limit the scope of this paper not all industry sectors are included. For instance, the Construction Sector that uses products that are outputs of extraction industries such as sand and gravel is not included in the analysis[6], but it is recognized that firms in the Construction Sector are users of outputs from the mining industries. Similarly, the Transportation Sector, Wholesale Trade and that part of the

[3] Industries listed include mine timbers, cutting (113311); mining molybdenum bearing ores (212299); mining lead-zinc bearing ores (212231); mining copper bearing ores (212233); mining gypsum (212395); mining appurtenance construction, general contractors (231390); mine loading and discharge station, construction (231390) mining machinery and equipment, manufacturing (333130); mining locomotives and parts, manufacturing (336510); mining machinery, wholesale (417220); mineral beneficiation machinery, wholesales (417220); mining machinery and equipment, wholesale agents and brokers (419170); mining property leasing (531190); mining machinery and equipment, rental (532410); mining engineering services (541330); mining machinery and equipment, repair (811310); mining associations (813910).

[4] Entries for mineral feed supplements, manufacturing (311119), mineral water, retail (445299) and mineral waters, purifying and bottling (312110) are not part of the scope of the subject of this paper.

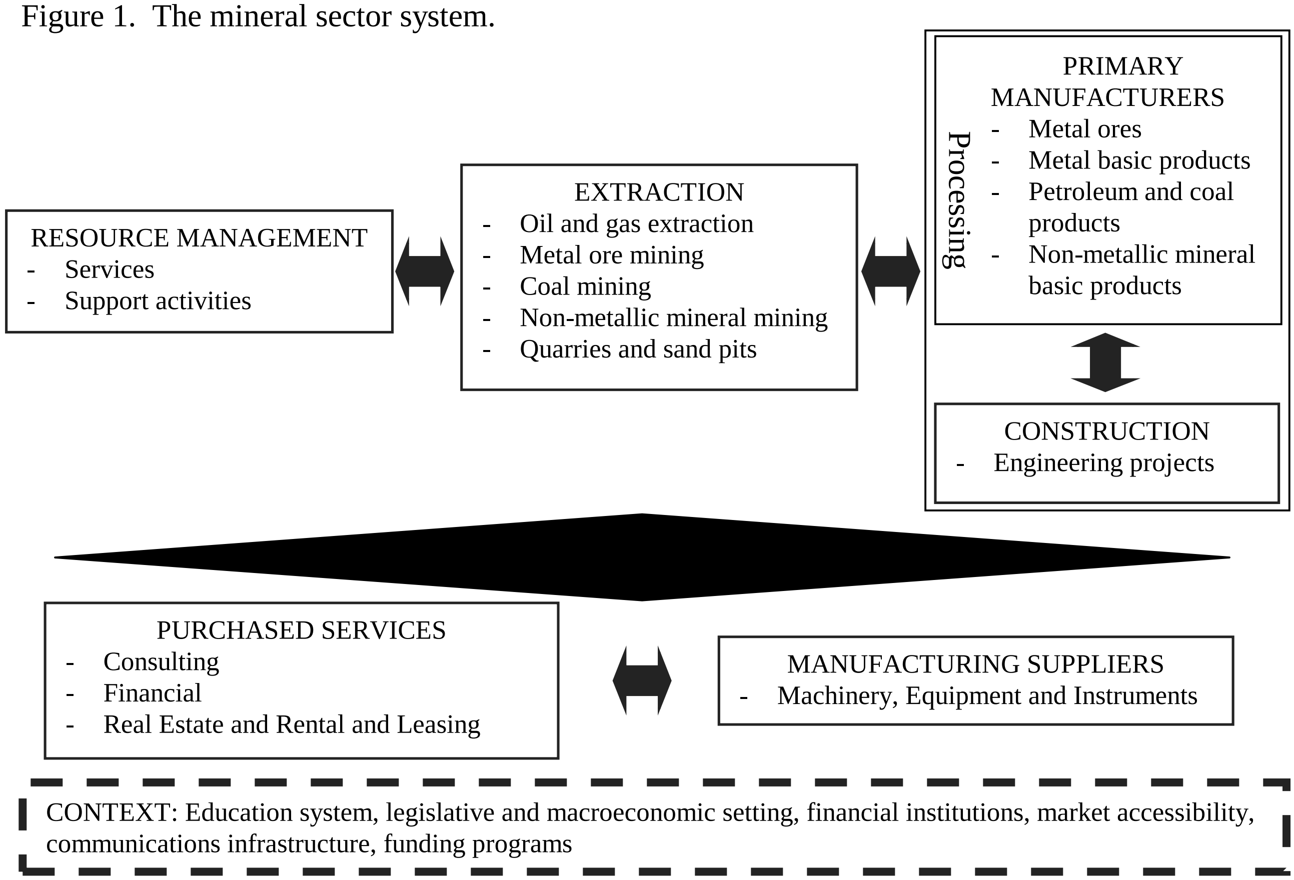
[5] Private sector industries listed include mineral wool, insulation, manufacturing (327990); mineral wool, limestone, slag and glass, manufacturing (327990); mineral wool insulation materials, wholesale (416390); mineral beneficiation machinery, wholesale (417220); mineral resource rights-of-way acquisition agent (531210);

[6] The Innovation, Advanced Technologies and Practices in the Construction and Related Industries Survey 1999 collected data on innovation, advanced technology and advanced practices being used in the construction and related industries. For a summary of survey findings see Anderson and Schaan (2001), Innovation, Advanced Technologies and Practices in the Construction and Related Industries: National Estimates Catalogue 88F0006XIE010004).

Construction Sector involved in the erection of mining facilities is not represented in the system presented in this paper but it is recognized that these are some of the other sectors that have a role.

Preliminary analytical work using data from the Survey of Innovation 1999 focussed on the innovative activities of the metal ore, non-metallic mineral mining and coal mining firms. The scope of industries examined was quickly expanded to include industries that had a role in the activities of these firms. The Mineral Sector System proposed in this paper builds on a systems approach that was originally developed during innovation analysis in the Forest Sector (Schaan and Anderson, 2002). The Mineral Sector System includes six main groups of actors: resource management, extractors of raw materials, manufacturers of products from raw materials, users of extracted raw materials, services to support the other actors in the system, and manufacturers of machinery, equipment and instruments used by the other actors in the system. Extraction industries served as a starting point in the development of the system. Groups of actors were identified by the industries they include (Annex 1) based on the main type of activity carried out by these industries. Aspects of the mineral sector system are presented in Figure 1. Between each group of actors are a series of transfer factors that influence the diffusion of S&T knowledge (depicted by the various arrows in Figure 1).

Figure 1. The mineral sector system.



Each group of actors operates within a macroeconomic, social and cultural context. The various groups of actors will be described in terms of their relationship to extraction industries.

Extraction

- Products (raw materials) are harvested or extracted from the Earth by industries such as mining and oil and gas extraction.

Primary Manufacturers

- Transform/refine raw materials into metal products, products composed of metal, or products containing mostly metal.
- Products are output for use by consumers or are input into other industries for further processing.

Construction

- Use extracted materials such as sand and gravel in their raw, unprocessed form in various engineering projects such as road construction.

Resource Management

- Includes a variety of surveying and mapping services, environmental services, engineering services, support services, and consulting industries.
- Services are directly related to deposits and to management of the resource so that reserves can meet demand and competitiveness is maintained.
- Has a large role in natural resource industries but is a less significant issue for manufacturing industries that have a factory production system.

Purchased Services

- Can provide services on a fee or commission basis to a variety of industries or can develop specialization in one sector.
- Includes private research and development labs, real estate and rental agencies, banks and investment counselling.

Manufacturing Suppliers

- Produce machinery, equipment and instruments.
- Can be used by any industry.

Context

- The underlying social and economic context in which all industries operate.
- Conditions and institutions determine the range of opportunities for innovation and can also affect the diffusion of S&T knowledge.
- Includes social context, public R&D facilities, communications infrastructure (roads, transportation networks etc.), operational regulations set by government, and industry protocols.

Innovation in the Mineral Sector: Metal Ore Mining

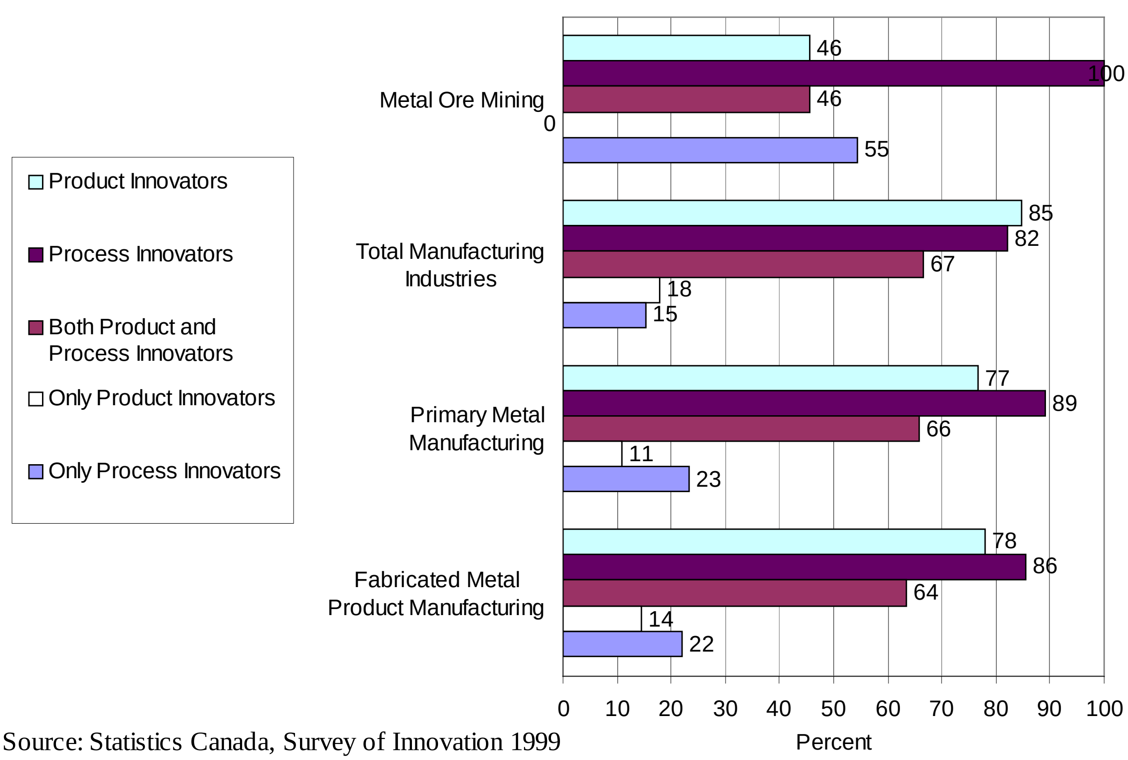
Methodology

The target population for the Survey of Innovation 1999 was all firms operating in Canada in the manufacturing sector or in selected natural resource industries that had completed existing production surveys[7]. Five selected natural resource industries, including 83 metal ore and 922 non-metallic mineral mining firms in the sample, for a total sample size of 674 firms in the selected natural resource industries. All thirty-one manufacturing industries were sampled for a total survey sample size of 5944 manufacturing firms. The survey results provide innovation data for only some of the industries in the various groups of actors identified in Figure 1 including the extraction industries and manufacturing. Innovative firms in metal ore mining and manufacturing will be the focus of the next section of the paper with data from the Survey of Innovation used to describe the innovation system in the Mineral Sector.

Innovative activities in mineral sector industries

Understanding why a firm might innovate can help predict the type of innovation it undertakes: product or process. Primary manufacturing and extraction industries in the mineral sector distinguish themselves by the type of innovations they produce (Figure 2).

Figure 2. Percent of innovative firms by type of innovation for innovative metal ore mining, innovative manufacturing, and innovative primary manufacturing industries in the mineral sector.



Source: Statistics Canada, Survey of Innovation 1999

[7] For details on survey methodology see Schaan and Nemes (2002), Survey of Innovation 1999, Methodological Framework: Decisions Taken and Lessons Learned. Statistics Canada Catalogue no. 88F0006XIE2002012.

Overall, innovative manufacturing industries show a stronger affinity toward product over process innovation. For industries in the mineral sector, most notably in metal ore mining, however, the tendency is reversed. Data for both innovative metal ore mining and the innovative primary manufacturing industries indicates that these industries favour process innovation over product innovation. In addition, the difference between the percentage of product innovators and the percentage of process innovators is greatest within the metal ore mining industry when compared to primary manufacturing industries. Moreover, all innovative metal ore mining firms are process innovators but less than one half (46%) are product innovators. Metal ore mining is the only industry included in the Survey of Innovation 1999 for which all innovative firms were process innovators.

As raw materials output by metal ore mining firms become further processed within the various primary manufacturing industries, the difference between percentage of product and process innovators narrows (Figure 2). Take, for example, the outputs from smelting and refining in primary metal manufacturing that can then be processed into products such as sheet metal, strips, rods, bars and wires or castings and other basic metal products. Here the difference between the percentage of product and process innovators is 12%. Metal products can become processed further by fabricated metal product manufacturing industries into assembled products such as metal windows, doors and hardware. Here, the difference between percentage of product and process innovators has narrowed to 8%.

The affinity toward process innovation in the extraction and primary manufacturing industries is also demonstrated in the percentage of product only or process-only innovators. There are no metal ore mining firms that undertake only product innovation. However, more than half (55%) of innovative metal ore mining firms are process only innovators. A similar relationship exists in the primary manufacturing industries. However, the gap between the percentage of product only and process only innovators is much narrower. For manufacturing overall, this tendency is reversed. The percentage of product only innovators is greater than the percentage of process only innovators.

Natural resource industries produce raw materials with long life cycles, some, for example gold, have virtually a infinite life cycles. Only 3.1% of innovative metal ore mining firms indicated that replacing products being phased out was an important objective of innovation compared with over one-third of innovative manufacturing firms (37%, Table 2). The innovation indicator is influenced by the length of a product's life cycle (Oslo Manual, page 21).

Less than one-third of all metal ore mining firms indicated that developing new products or processes was important to firm success compared to over half for the primary manufacturing firms in the mineral sector and close to two-thirds for manufacturing overall (Table 1). When firms did develop new products or processes, just over one half (53%) of these innovative metal ore mining firms indicated that developing new products and processes was a firm success factor. This compared to almost three-quarters (72%) for total manufacturing and about 60% for the primary manufacturing firms in the mineral sector. So, although it is an important success factor, it seems that innovation is not as important to firm success for metal ore mining firms as it is for manufacturing industries overall or the primary manufacturing industries.

On the other hand, the satisfaction of existing clients is the factor to which the highest percentage of innovative manufacturing and primary manufacturing industries attribute firm success, indicated by over 97% of these firms. Client satisfaction is the third most frequently indicated success factor of innovative metal ore mining firms chosen by less than two-thirds (62%) of the firms. Less than one quarter (21%) of all metal ore mining firms introduced new products during the period 1997-1999 compared to over two-thirds (68%) for manufacturing firms overall. Amongst innovative firms, less than one-half of the metal ore mining firms are product innovators compared to 85% of manufacturing firms overall and over three-quarters of firms in the primary manufacturing industries (Figure 2). Innovative metal ore mining firms do not feel that they need new products in spite of the opinion that satisfying clients is important to firm success. Why then would we expect that they would develop new products?

Industries that produce products with shorter life cycles have a more frequent need for innovation than industries that produce products with longer life cycles. In consideration of the nature of the products produced by the metal ore mining industry there would not be a strong need for these mining firms to be innovative on the three-year cycle of the Oslo Manual. They should show a stronger affinity to process innovation than to product innovation. Are there other drivers of innovation in metal ore mining?

The macroeconomic and cultural context of the Canadian metal ore mining industry and other harvesting/extraction industries was set in our early economic history where markets for raw materials were developed and inter-dependencies with manufacturers forged. Just over one-third of innovative metal ore mining firms see seeking new markets as a firm success factor compared to upwards of three quarters of innovative manufacturing firms (Table 1). An even smaller percentage

Table 1. Selected firms success factors of metal ore mining, manufacturing and primary manufacturing industries in the mineral sector.

Firm Success Factor	Percent of firms indicating factor is important[8]							
	Metal Ore Mining		Manufacturing		Primary Metal Manufacturing		Fabricated Metal Product Manufacturing	
	All	Innovators	All	Innovators	All	Innovators	All	Innovators
Satisfying existing clients	48.8	61.9	96.1	97.0	98.5	98.1	96.1	97.8
Developing new products (goods or services) and processes	29.9	53.3	64.3	72.2	52.7	60.0	53.6	61.2
Seeking new markets	25.4	37.4	73.4	77.0	70.1	74.6	66.7	71.8
Developing niche or specialized markets	18.6	26.0	68.0	72.0	71.5	76.6	61.9	65.4

Source: Survey of Innovation 1999

of metal ore mining firms feel that developing niche or specialized markets is a firm success factor compared to a range of two-thirds to three quarters for innovative manufacturing firms (Table 1). A

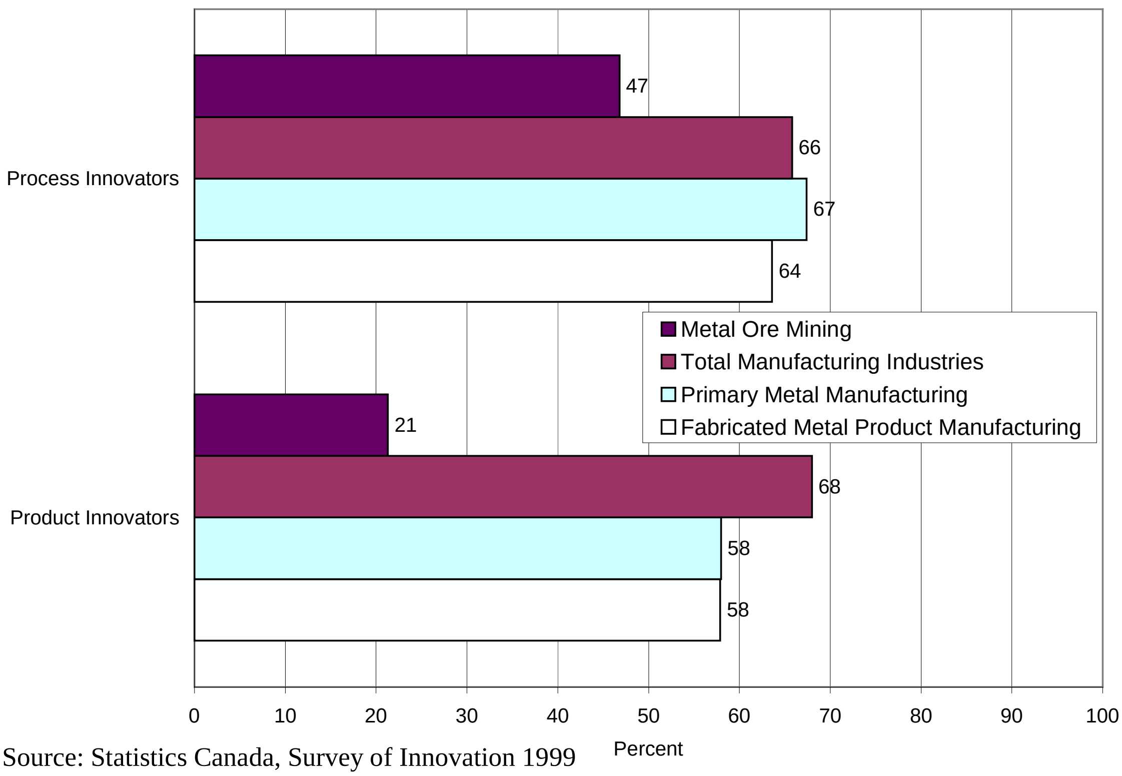
[8] Firms were asked to indicate the importance of a series of success factors on a scale of 1-5 where 5 is low importance and 5 is high importance. It is considered that firms indicating 4 or 5 for a given success factor find this factor important.

large market for the outputs of the metal ore mining industry is manufacturing, both domestic and foreign. Changes in production processes allowed extraction industries to meet the demands for raw materials imposed by the manufacturing sector.

Process innovations would provide more competitive advantage than product innovations. The percentage of process innovators in metal ore mining exceeds the percentage of process innovators in the primary manufacturing industries (Figure 2). Natural resource extraction industries in other countries have shown similar trends. The prevalence of process innovation in mining is supported by studies undertaken by the Australian Bureau of Statistics (1998). They found that of the 39% of all mining businesses[9] had undertaken process innovation from July 1994 to June 1997, compared to 11% of all mining business that had undertaken product innovation.

If there is a focus on process over product innovation in metal ore mining, why then, is the overall percentage of process innovators in metal ore mining so much lower than the percentage of process innovators in manufacturing and the primary manufacturing industries (Figure 3)?

Figure 3. Percent of innovative firms for metal ore mining, manufacturing, and primary manufacturing industries in the mineral sector.



Source: Statistics Canada, Survey of Innovation 1999

Activities in natural resource extraction industries experience boom and bust cycles subject to upturns and downturns in the economy. The reference period for the Survey of Innovation was 1997 to 1999. There is evidence that the reference period for the extraction industries was not the same as manufacturing. Several non-innovators in metal ore mining indicated that they had made changes to their production systems outside the reference period in the Survey of Innovation 1999. Other

[9] includes coal mining, oil and gas extraction, metal ore mining, other mining and services to mining

responses indicate that production system changes are slow and methods remain essentially unchanged.

Why do the extraction and related primary manufacturing firms innovate?

Data from the Survey of Innovation show that metal ore mining firms have innovation objectives that focus mostly on the production process. The top innovation objectives chosen by over half of the innovative metal ore mining firms relate to production: to increase production capacity, to reduce labour costs, to improve production flexibility and to reduce energy consumption (Table 2). Although increasing production capacity was the second most commonly indicated innovative objective of manufacturing (75.3%) and both primary manufacturing firms including primary metal manufacturing (79.7%) and fabricated metal product manufacturing (81.8%), the top objectives of innovation for manufacturing firms focus on improving product quality and extending product range (Table 2). Improving product quality objective was chosen by the highest percentage of innovative manufacturing and both primary manufacturing firms. The contract between innovation objectives of extraction and manufacturing firms from the viewpoint of improving product quality is striking. This was an objective of less than one-third of innovative metal ore mining firms compared to over 80% of both primary manufacturing industry and manufacturing firms overall.

Table 2. Selected objectives of innovation for innovative metal ore mining, manufacturing, and innovative primary manufacturing industries.

Objective	Percent of innovative firms choosing listed objective			
	Metal Ore Mining	Manufacturing	Primary Metal Manufacturing	Fabricated Metal Product Manufacturing
To increase production capacity	67.5	75.3	79.7	81.8
To reduce labour costs	59.7	58.7	73.1	62.8
To improve production flexibility	51.9	65.5	62.5	67.1
To reduce energy consumption	51.3	22.9	33.8	19.7
To improve product quality	31.0	82.5	80.3	82.6
To extend product range	27.8	71.6	51.7	64.4
To replace products being phased out	3.1	36.9	22.6	31.9

Source: Survey of Innovation 1999

The focus on production-related innovation objectives in metal ore mining firms would lead to changes to the extraction process rather than the development of new products. This helps to explain the dominance of process innovation in metal ore mining over product innovation.

The Conference Board of Canada (2001) also found that innovation in the natural resource industries focuses more on process innovation than the development of value-added products. They found that the emphasis is often on process innovation as a way to drive down costs, especially when commodity prices have a large influence on profit margins.

Metal ore mining firms see themselves as serving as extractors of a raw material with established production techniques. When asked to indicate why they did not innovate, the majority of responses were that they are extractors of a raw material such as gold that could not be improved upon (i.e. industry standards for purity). The second most common reason for non-innovation were that the extraction techniques and equipment in the industry are standard or have remained unchanged since initial set-up and, as a result, there was no need for change.

Where do ideas for innovation come from?

Metal ore mining firms rely heavily on internal sources of information for innovation. The top two sources of information for metal ore mining include production staff (92%), and management staff (75%).

How is knowledge transmitted within the mineral sector innovation system?

How does the knowledge that facilitates technological changes in the extraction process get transmitted? There are many ways to acquire knowledge that leads to innovation. Knowledge acquisition need not be exclusively through innovative activities carried out within a firm such as internal R&D. Technology acquired can be in the form of patents, non-patented inventions, licences, know-how, trade marks, services with a technological content, use of consultancy services, contracting out R&D, acquisition/transfer of technology through the purchase/sale of an enterprise, through the purchase/sale of equipment, and mobility of skilled personnel, to name just a few.

Table 3. Selected manufacturing firms with products used by selected natural resource industries.

	% of all firms		% innovative firms in this industry	relative innovation rank
	with products used by selected natural resource industries	with products used by the mining industry		
Electrical Equipment, Appliance and Component Manufacturing	47.5	37.5	89.8	5
Agricultural, Construction and Mining + Industrial Machinery Manufacturing (3331 & 3332)	46.6	28.8	88.0	6
Machinery Manufacturing (excluding 3331 & 3332) [Commercial and Service Industry Machinery Manufacturing + Ventilation, Heating, Air-Conditioning and Commercial Refrigeration Equipment Manufacturing + Metalworking Machinery Manufacturing + Engine, Turbine and Power Transmission Equipment Manufacturing + Other General Purpose Machinery Manufacturing]	35.3	28.0	86.9	8
Navigational, Measuring, Medical and Control Instruments Manufacturing + Manufacturing and Reproducing Magnetic and Optical Equipment	32.0	16.4	91.3	4
Chemical Manufacturing (excluding 3254)	31.2	22.7	87.7	7

Source: Survey of Innovation 1999

Acquisition of technologies is one mechanism for the transmission of S&T knowledge, facilitating technological change. New technologies can be acquired through the purchase of equipment. The third most frequently chosen source of information for innovation of metal ore mining firms was suppliers of equipment, material and components (70%). The top innovative activity of metal ore mining firms chosen by 95% of all innovative firms was acquisition of machinery, equipment or other technology linked to new or significantly improved products or production/manufacturing processes. In fact, close to one in five (17%) manufacturing firms have products used by mining industries.

Five of the manufacturing industries with the highest percentage of firms with products used by selected natural resource industries (more than 30% of firms) are among the top 10 innovators out of 35 industries (Table 3). Within this group of five industries, four are producers of machinery and equipment or instruments. Almost one in twenty (4.8%) of the innovative firms in Agricultural, Construction and Mining + Industrial Machinery Manufacturing industries indicated that over 50% of its sales were to mining industries. These firms can be described as dedicated suppliers.

Innovation rates in industries such as communications or computer equipment manufacturing are high. For industries involved in the extraction of natural resources, innovation rates tend to be low. In these cases, looking at the activities in the extraction industries in isolation cannot properly yield innovation rates. Rather, a part of the innovation takes place in industries supplying machinery and equipment to the harvesting industries.

Table 4. Innovative industries that indicated the highest percentage of innovative firms that engaged in the acquisition of machinery, equipment or other technology linked to innovation.

	% of firms that acquired machinery, equipment or other technology linked to innovation			% innovative firms	relative overall innovation rank	% process innovators	% innovative firms that are process innovators	Relative process innovation rank
	all	Innovators	Process innovators					
Semiconductor and Other Electronic Equipment Manufacturing	100.0	100.0	100.0	94.9	2	87.8	92.5	2
Metal Ore Mining	60.0	95.0	95.0	46.8	32	46.8	100.0	1
Railroad Rolling Stock Manufacturing + Ship and Boat Building + Other Transportation Equipment	76.2	95.0	96.5	74.7	24	61.6	82.5	18
Aerospace Product and Parts Manufacturing	86.8	94.4	98.1	83.9	13	73.3	87.4	6
Veneer, Plywood and Engineered Wood Product Manufacturing	69.7	93.5	98.1	64.8	30	55.9	86.3	7
Printing and Related Support Activities	83.9	93.4	95.4	84.9	12	77.6	91.3	3
Primary Metal Manufacturing	79.0	91.1	93.1	75.7	23	67.4	89.1	4
Sawmills and Wood Preservation	75.3	90.4	93.7	73.6	26	65.4	88.8	5
Furniture and Related Products Manufacturing	76.3	89.9	96.6	81.9	16	69.7	85.1	10
Logging	47.3	89.6	89.7	40.9	34	34.7	84.9	12

Source: Survey of Innovation 1999

Do mineral sector firms that acquire machinery and equipment have higher innovation rates than those who do not? Among innovative firms that indicated that they had acquired machinery, equipment or other technology linked to innovation, the top ten industries vary in their relative innovation rank (Table 4). The percent of process innovators that acquired machinery, equipment or other technology ranges from 89% to 100% of firms amongst the selected natural resource and manufacturing industries covered by the Survey of Innovation 1999. All innovative metal ore mining firms undertook process innovation.

Ninety five percent of process innovative firms in metal ore mining indicated that they had acquired machinery, equipment or other technology during the period 1997-1999. The acquisition of machinery, equipment and technology plays a key role leading to process innovation in metal ore mining firms. Although metal ore mining firms have lower overall innovation rates compared to manufacturing industries, when comparing types of innovation between industries, the percent of process innovators in metal ore mining exceeds that of both the manufacturing and primary manufacturing industries in the mineral sector. Eight of the ten innovative industries with the highest percentage of firms that indicated that they had acquired machinery and equipment are among the top ten industries for percentage of process innovation. Innovative firms that acquire machinery and equipment have higher rates of process innovation than firms that do not.

What types of skills are in demand in the metal ore mining industry? Is there a skills shortage?

Training is an important component of firm success for innovative firms. Employee training is the most frequently chosen firm success factor for innovative metal ore mining firms. It is the second most frequently indicated firm success factor for innovative primary metal manufacturing firms and third most indicated firm success factor for both innovative fabricated metal product manufacturing and innovative manufacturing industries overall (Table 5). Upwards of 80% of metal ore mining, manufacturing overall and primary manufacturing firms indicated that they had engaged in training linked to innovation introduction.

Table 5. Percent of innovative metal ore mining, manufacturing, and primary manufacturing firms with the following training and skill related activities and opinions.

	Metal Ore Mining	Manufacturing	Primary Metal Manufacturing	Fabricated Metal Product Manufacturing
Training employees is important to firm success	83.5	81.9	88.3	79.4
Engaged in training linked to innovation introduction	79.6	81.3	91.2	80.1
Hiring experienced employees is important to firm success	56.9	70.4	63.2	71.4
Hiring new graduates from universities is important to firm success	43.4	22.8	31.9	18.4
Hiring new graduates from technical schools and colleges is important to firm success	46.2	40.9	44.5	42.1
Agree that it is difficult to hire qualified staff and workers	43.8	63.4	54.0	67.7
Agree that it is difficult to retain qualified staff and workers	34.8	34.8	34.1	28.6
Lack of skilled personnel is an obstacle to innovation	24.3	37.4	41.3	45.4

Source: Survey of Innovation 1999

Hiring experienced employees was chosen by a smaller percentage of metal ore mining firms (57%) than manufacturing overall (70%) and the primary manufacturing industries. However, there is a stronger reliance on skilled labour with almost twice the percentage of innovative metal ore mining firms indicating hiring new graduates from universities as a firm success factor over manufacturing.

When it comes to skilled labour, metal ore mining firms have greater variety, drawing their employees from a wider resource pool than manufacturing industry firms. Almost the same percentage of metal ore mining firms (46%) indicated that hiring new graduates from technical schools and colleges was important to firm success as did the percentage of firms indicating universities (43%). This less than 3% difference contrasts with the importance of technical schools and colleges over universities for manufacturing and the primary manufacturing industries, where the difference ranges from 13-24%. This flexibility will impact on the size of the human resource pool from which these industries can draw and is reflected in the percentage of firms that agree that it is difficult to hire qualified staff. There is a smaller percentage of metal ore mining (44%) with the opinion that it is difficult to hire qualified staff compared to a range of more than half to more than two-thirds of the manufacturing and primary manufacturing industries. Although lower than manufacturing and primary manufacturing, the percentage of metal ore mining firms that agree that it is difficult to hire qualified staff and workers is just under 50%. This could indicate a shortage of skilled workers.

About one third of metal ore mining, manufacturing and primary manufacturing firms agree that it is difficult to retain their qualified staff and workers. The lack of skilled personnel is an obstacle to innovation for about one quarter of the innovative metal ore mining firms. It is more of an obstacle for manufacturing overall and the primary manufacturing industries, which have higher overall rates of innovation.

Introduction of new technologies

Methodology

The target population for the 2000 Survey of Electronic Commerce and Technology Survey (SECT) was all economic sectors, both private and public, with the exception of agriculture and construction. The total sample size was approximately 21,000 enterprises[10] with a response rate of 77% representing 93% of economic activity. Data based on a sample size of 177 mining and 3,700 manufacturing firms will be used to describe how these industries react to the introduction of advanced technologies.

How do extraction industries react to new technologies?

For enterprises that introduced significantly improved technologies, the majority of mining firms did so through the purchase of off-the-shelf technologies (Table 6). Some of these purchases would be

[10] Production surveys are typically establishment-based. A statistical enterprise is defined as "… the organisational unit of a business that directs and controls the allocation of resources relating to its domestic operations, and for which consolidated financial and balance sheet accounts are maintained…" (NAICS, Statistics Canada, 1998, p. 9).

from manufacturing industries. The introduction of improved technologies resulted in a requirement for training in mining and manufacturing firms in the mineral sector.

Developing new technologies is not common in the mining industry, undertaken by less than one in ten firms who introduced new technologies. It is more common in the manufacturing industries with about one-quarter of firms indicating that introduction of new technologies was done by developing them.

Table 6. Technology improvements of mining, manufacturing, and primary manufacturing industries in the mineral sector.

	% of enterprises introducing significantly improved technologies	% of enterprises with improved technologies, introducing new technology by:				% of enterprises with improved technologies requiring training
		Purchasing off-the-shelf technologies	Licensing new technologies	Customizing or significantly modifying existing technologies	Developing new technologies	
Mining (Except Oil and Gas Extraction)[11]	50.3	68.1*	12.3	46.3*	9.8	83.0
Manufacturing	50.6	70.8	14.8	51.0	22.8	73.4
Primary Metal Manufacturing	59.1	51.9*	10.2	59.2*	37.7*	71.7*
Fabricated Metal Product Manufacturing	39.3	73.2	20.0	43.6	19.6	74.9

* use with caution
Source: Survey of Electronic Commerce and Technology 2000

Conclusions

Metal ore mining, a natural resource extraction industry, is part of a larger system of innovation including resource management industries, primary manufacturing, construction, service industries, manufacturers of machinery and equipment and the conditions or context under which the firm operates. To get a complete picture of innovation within a system, component of this system must include all actors that are developing or participating in the innovation process.   Available innovation data allows an examination of innovation and information transmission in the extraction, primary manufacturing industries and manufacturing. Future surveys may provide further insights into relationships with other actors in this system.

Metal ore mining is characterised by a high percent of process innovation but a much lower rate of product innovation. Moreover, all innovative metal ore mining firms are process innovators with over half being process only innovators. In an industry that produces commodities (raw materials) with long and in some instances, almost infinite life cycles, it is not expected that there will be high rates of product innovation.

Innovation in metal ore mining relied heavily on the acquisition of machinery and equipment as embodied technologies. Mining firms react to new technologies by making off the shelf purchases of this new technology. The manufacturers of this machinery and equipment have high rates of

[11] Includes Coal Mining, Metal Ore Mining, Non-Metallic Mineral Mining and Quarrying, and Support Activities for Mining and Oil and Gas Extraction

innovation. Using the Oslo Manual's innovation indicator for one industry in isolation would attribute this innovative activity to the manufacturers of the machinery and equipment as product innovation. Unless the innovative activity of the suppliers of machinery and equipment is considered, this component of process innovation may not be recognized. In 2000, most mining firms introduced significantly improved technologies through off-the-shelf purchases.

Training is an important component of firm success for innovative firms. The importance of training in mining firms is emphasized knowing that in 2000, most mining firms that introduced significantly improved technologies required training. There is some evidence to suggest that there is a skills shortage in metal ore mining. Metal ore mining firms show no strong preference of one source of skilled labour over the other, be it from universities or colleges and technical schools. Firms can draw from a wide range of skills however, hiring and retaining qualified staff and workers is an issue for many innovative metal ore mining firms. Other survey data sources such as Statistics Canada's Workplace and Employment Survey (WES) could be explored to gain further insights into human resource issues of metal ore mining firms.

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Annex 1. Groups of Actors in the Mineral Sector Innovation System

RESOURCE MANAGEMENT

54136 Geophysical Surveys & Mapping Services
- Geophysical surveying services
- Gravimetric surveying services, geophysical
- Seismic geophysical surveying services

54137 Surveying & Mapping Services
- Aerial surveying
- Cadastral surveying services
- Geographic information system (GIS), base mapping services
- Land surveying services
- Mapmaking services
- Oceanic surveying services
- Photogrammetric mapping services
- Production of topographic materials & maps

Informatics/Computer Modelling/Decision Making Technologies
- 541510 CAD, CAE

54 Professional, Scientific & Technical Services
54133 Engineering Services
- mining engineering services

54162 Environmental Consulting Services
56291 Remediation Services

213 Support Activities for Mining and Oil and Gas Extraction
- Contract drilling
- Stripping services
- Draining or pumping of mines
- Fire fighting service
- Overburden removal services

EXTRACTION

21 Mining and Oil and Gas Extraction
211 Oil and Gas Extraction
212 Mining (except Oil and Gas)
2121 Coal Mining
2122 Metal Ore Mining
2123 Non-Metallic Mineral Mining and Quarrying

PRIMARY MANUFACTURERS

324 Petroleum and Coal Products Manufacturing
327 Non-Metallic Mineral Products Manufacturing
331 Primary Metal Manufacturing
332 Fabricated Metal Products Manufacturing

CONSTRUCTION

2313 Engineering Construction
- Building construction
- Highway, street and bridge construction

PURCHASED SERVICES

52 Finance and Insurance
53 Real Estate and Rental and Leasing
531190 Mining property leasing
532410 Mining machinery and equipment, rental

MANUFACTURING SUPPLIERS

333 Machinery Manufacturing
33313 Mining and Oil and Gas Field Machinery
3332 Industrial Machinery
33651 Mining locomotives and parts

CONTEXT: Education system, legislative and macroeconomic setting, financial institutions, market accessibility, communications infrastructure, funding programs

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