Mining Innovation:

An overview of Canada's dynamic, technologically advanced mining industry

prepared for

The Mining Association of Canada

by Global Economics Limited

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FOREWORD

Canadian mining has undergone a profound change to a high-tech industry and is now one of the world's most dynamic and technologically advanced. With its strong links to other high technology industries both as a user of their technologies and as a supplier of inputs, it is a driving force in Canada's new knowledge-based economy. The industry continuously innovates in an environment of high risk and ongoing structural change. For example, demand and prices for minerals and metals fluctuate widely, outcomes in exploration and development are uncertain and foreign and domestic political situations are often unpredictable. Metals prices have been on a downward trend, narrowing profit margins. International competition has intensified with globalization. At the same time, the industry has placed higher priority on enhancing environmental performance and improving occupational health and safety. To improve competitiveness, the Canadian mining industry has focused on reducing costs, increasing productivity, and expanding into new markets with new product lines – and has succeeded by making important technological advances.

This report, prepared by Global Economics Limited, focuses on the key technological advances in the minerals and metals sector, particularly in Information Technologies, and how they have contributed to the industry's impressive productivity performance. The report finds that new technologies in mining have created a virtuous circle of growth and innovation that circulates through two-way linkages between mining and the rest of the economy.

Canadian mining has all the characteristics of a dynamic, technologically advanced industry. The primary metals sector had the highest overall ranking in Canada for use of advanced technologies between 1989 and 1998. Total factor productivity grew by 3.1 percent in the mining sector between 1984 and 1998, almost three times Canada's overall productivity growth and a healthy distance ahead of U.S. productivity growth. The mining industry is one of the largest investors in Canada: mining and oil and gas extraction investment is expected to be 15.5 percent of total private and public investment in 2001. Mining industries create high-tech jobs in which a large percentage of workers have post-secondary education.

The industry considers the most important advances to have been in the application of Information Technologies (IT). Some of these are:

! New technologies in exploration increase productivity and minimize damage to the environment. Exploration innovations include *global positions systems (GPS), airborne geophysics and low-impact seismic methods.*

! Faster, more accurate drilling and blasting in emerging underground telecoms such as *telemining* lead to higher ore recovery and profitability. Health, safety and workplace quality also improve. *Automated Load-Haul-Dump (LHD) fleets* lower operating and maintenance costs.

- *Internet technology* has vastly improved information exchange with third parties and remote sites. Operations and maintenance are far more integrated and maintenance costs, the single largest controllable expense in mining operations, are lower.

- A consortium of fifteen of the world's largest mining companies (including Alcan, Inco, Noranda and Barrick Gold) have formed a global *online business-to-business (B2B)* exchange to reduce procurement costs. The steel industry and nonferrous metal industries could save 5 to 15 percent as the result of e-procurement.

- Some of the most important innovations involve the organization and management of mining and quarrying facilities that come with information technologies. The rapid pace of change increases the importance of multi-disciplinary knowledge and generic skills. Beyond 2000 *global communications systems and e-commerce* are expected to radically transform business procedures and the nature of human resource management.

- Canada is also a world leader in technological advances in *mining environmental management* and among the most innovative in recycling. New technologies add value to production processes and address environmental concerns of landfill disposal of large volume and potentially hazardous products .

Canadian mining industries are directing their product lines more towards higher value-added downstream products. Higher margin specialty products used in new technological innovations have growth rates several times the growth in demand for base metals. New products have contributed to sustainable development because their higher value-added makes them easier to transport and they are designed with an awareness of their environmental impact. Technological innovations outside the industry have also created new demands for currently mined metals: consider that it takes 37 minerals and metals just to turn on your computer, including gold, nickel, aluminum, zinc and iron, which are some of Canada's more notable metals. Indeed, the "top ten" metals produced in Canada are widely used in the high-tech industries. Some examples: (See Table 10 for an expanded list)

1. Nickel Extra fine nickel powders used in capacitor chips	**2. Gold** 35% gold alloy used in engine nozzle of space shuttle	**3. Copper** High-speed computer chip "Coppermine"	**4. Zinc** Zinc-oxide thermal coating protects antenna on Cassini space probe	**5. Iron ore** Iron oxide makes layered materials for high-density magnetic data storage
6. Uranium Radioactive chemical tracers used in nuclear medicine	**7. Platinum grp.** Used in multi-layer ceramic capacitors (MLCC)	**8. Silver** Used in light, compact superconducting telecommunications cables	**9. Cobalt** Superalloys are used for jet engines	**10. Lead** Batteries provide stationary power source in power systems for telecommunications and computer networks

Important linkages are growing between the mining sector and other high-tech sectors. Mining innovations *draw on new technologies from the medical, space and military fields*. For example, the Geological and Environmental Mapping (GEM) system is an IT using airborne imaging that will create a knowledge base relating to surface oil detection. *Reverse technology transfers* have also occurred, such as a zero-gravity drill that will be used in space and might have further applications for deep sea exploration. Mining companies are *taking to host countries their expertise* in designing the safest and most technologically advanced mines. Also, Canadian firms sell to mining companies about $570 million of *environmentally related products* each year, of which 40 percent are exported.

Most of the goods and services demanded by mining companies are *specialized products that are largely technical or scientific*. Over 2,200 firms based in Canada supply specialized mining goods and services and the market is rapidly expanding. Canadian mining suppliers are also developing a world class *geoscience infrastructure*. Canadian companies hold 70 percent of world markets for airborne geophysical equipment and Canadian geophysical equipment manufacturers, software developers and data interpretation companies have captured 60 percent of the world market.

The *economic spinoffs* are substantial. Mining production and investment generate direct demand in supplier industries and additional demand as ensuing rounds of expenditures work their way through the economy. A $1 billion increase in output in mining and primary metals directly increases the demand for goods and services in Canada by $615 million. The original $1 billion increases demand by $839 million when subsequent rounds of expenditures are taken into account. One billion dollars of investment in mining and primary metals directly increases demand by $993 million, and $1.3 billion after subsequent rounds are counted.

If the Canadian minerals and metals sector is to remain a world leader in the new economy it must continue on a path of innovation. This can only be achieved by ensuring Canada's fiscal and policy frameworks remain competitive and by removing the disincentives to innovation and investment. The following recommendations would advance these objectives:

1. *Explicitly recognize the economic and strategic importance of Canada's mining industry.*

   Mining surpasses other industries in large part because it has transformed into a high-technology resource sector. It is a paradox, then, that mining has been miscast as part of the "old" economy because it is resource-based. The danger of creating the false dichotomy between "old" and "new" is that governments may direct an industry strategy toward what they perceive to be the "new" economy winners to the detriment of all companies that must meet the competitive challenge.

Ironically, this could hamper the very innovation governments are trying to encourage. The economic and strategic importance of the mining industry should be considered when the federal government crafts its innovation policy.

2. *Ensure that a sound, progressive globally competitive policy framework is maintained.*

The federal government has contributed to an innovation-friendly environment by adopting macroeconomic and structural policies that have created a framework for solid economic growth and more investment certainty. Meanwhile, foreign jurisdictions have become more tax competitive and our current domestic tax regime is losing ground.

Corporate tax cuts have a clear impact on investment, productivity and economic growth if they are applied in a balanced and fair way across industries. Excluding mining from the recent federal corporate tax rate cut sends a negative signal because there is an assumption that mining already benefits from selected incentives in the current tax system and thus has a lower effective tax rate. The Resource Allowance is not an incentive: it was put in place to compensate for provincial mining taxes and royalties. A repeal of the Resource Allowance in exchange for a 21 percent corporate tax rate would leave the industry worse off. Furthermore, the Accelerated Capital Cost Allowance and Canadian Exploration Expenses reflect inherent risks of large capital investments and exploration that occur in the mining sector.

Federal and provincial governments collect $4.8 billion annually in capital taxes. Capital taxes, such as the Large Corporation Tax, are profit-insensitive because they apply to the asset base of corporations rather than to profits. Capital taxes make R&D and exploration more difficult to fund because the taxes cut more deeply into profits or add to losses during downturns, an important concern for mining because it is highly cyclical. Capital taxes also punish innovation by taxing investments in new technologies. An inconsistency in Canada's innovation policy is thus created: the early stages of innovation are encouraged through generous tax credits on R&D but the adoption of innovation is discouraged with the capital tax. Mining is doubly affected because of its high level of investment and innovation and because mining and smelting companies tend to be large. Other profit-insensitive taxes such as payroll taxes, property taxes and user fees also discourage innovation in the mining sector.

While discussions continue on these important issues, Canada's tax competitiveness is eroding. Reform is needed now. The federal government should:

- extend the corporate tax reduction that was announced in the 2000 Budget to the mining sector and preserve the current federal tax provisions provided to the minerals and metals sector.

- eliminate the Large Corporation Tax;

- take a broader view of tax policy and initiate tax reform discussions with the provinces and territories. Work toward reducing corporate and mining tax rates in provincial jurisdictions and encourage the elimination of capital taxes in these jurisdictions.

3. *Look at ways to partner with government to advance the federal "innovation agenda"*.

Some lessons to take from the recent staggering decline in technology stocks are that no one sector can be counted on to generate a country's prosperity and that pre-selecting industry champions is a difficult thing to do. The government has made progress in creating a framework where "new economy" industries and government can form dynamic partnerships to advance the innovation agenda. The agenda will be advanced further when all "high-tech" industries contribute, including major high-tech innovators like the Canadian mining industry.

THE MINERALS AND METALS SECTOR IN BRIEF

! The Minerals and Metals Sector (MMS) includes mineral exploration, mining and quarry industries, primary metals, fabricated metal products and nonmetallic mineral products industries. There are about 277 metal, nonmetal and coal mines, 3,000 stone quarries and sand and gravel pits, and 54 nonferrous smelters, refineries and steel mills in operation.

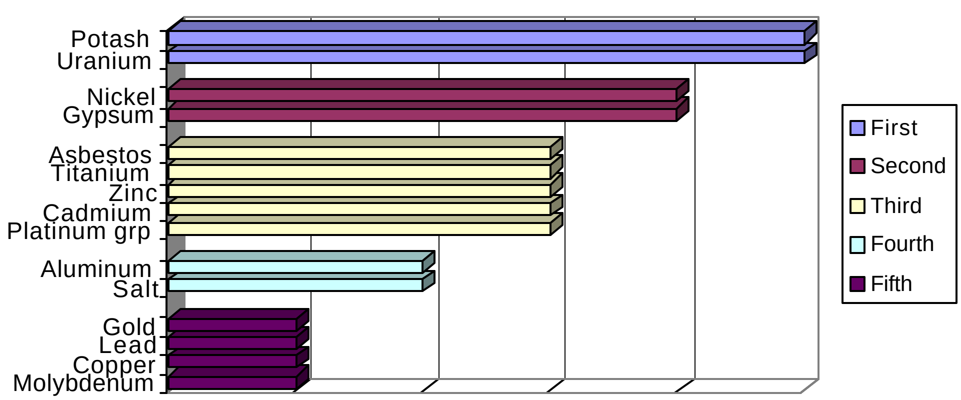
! Canada is among the top five world producers of 15 mineral commodities. (Figure 1) Mining companies can compete successfully against foreign companies who have even richer reserves than in Canada but who have not invested as heavily in new technologies. Metals and minerals exports were $49 billion in 2000, or 12.8 percent of total exports in the economy.

! The minerals and metals sector contributed $28 billion or 3.5 percent of national Gross Domestic Product in 2000. This contribution is significant in a diversified economy and comparable to the communications industry and the electric power, gas and water utilities industries. The share has remained in the 3.5 percent to 4.5 percent range since the 1980s.

! Mining employment contributes importantly to the mining-dependent northern and remote communities. Mining and minerals processing industries directly employed 401,000 workers in 2000: 54,000 in mining (Stage1), 61,000 in smelting and refining (Stage 2), 102,000 in non-fuel semi-fabrication (Stage 3) and 184,000 in fabricating (Stage 4).

Figure 1
Canada's Ranking in Terms of its Share of World Production of Minerals and Metals, 1999

Source: Natural Resources Canada, U.S. Bureau of Mines



- Productivity growth is an essential determinant of Canada's standard of living. Innovation, investment and human capital improvements contributed to an impressive annual average total factor productivity growth in the mining industry of 3 percent between 1984-1998 – three times the rate of the overall Canadian economy.

- The sector employs highly skilled, high-technology workers who are among the highest wage earners in Canada. Average weekly earnings in the mining, quarrying, smelting and refining industries were $1,069 in 2000, far surpassing the $779 in manufacturing and $532 in the service industries.

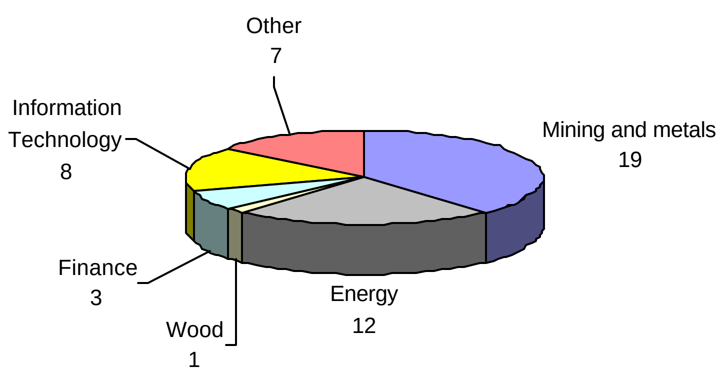
- Mining-related SMEs create thousands of high-tech service jobs and state-of-the art information products. For every $1 billion of output created by the mining and primary metals sector, direct demand for goods and services increases $615 million. The original $1 billion increases demand by $839 million when subsequent rounds of expenditures are taken into account. For every $1 billion invested in exploration, mine development and plant and equipment, direct demand for goods and services increases $993 million. After subsequent rounds are counted, the original $1 billion increases demand by $1.3 billion.

- The mining industry invested $323 million in 2000 in Research and Development. Five Canadian mining companies were among the top 50 corporate R&D investors in 1999.

- High productivity and innovation have enhanced global competitiveness in the mining and metals sector. Nineteen of the fifty fastest growing Canadian companies between 1994 and 1999 were minerals and metals companies. (Figure 2)

Figure 2
Fifty Fastest Growing Companies by Revenue in Canada, 1994-99

Source: Globe and Mail Report on Business, July 2000



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1 INTRODUCTION

The Canadian mining Industry has undergone a profound transformation to a high-tech industry and is now one of the world's most dynamic and technologically advanced. With its strong links to other high technology industries both as a user of their technologies and as a supplier of inputs, it is a driving force in Canada's new knowledge-based economy. Mining-related enterprises produce and export state-of-the art information products and services, creating thousands of high-tech jobs in the mine equipment and supply sectors. Society has benefited from low-cost mineral and metal products, product innovations, good jobs, greater wealth and responsible stewardship of Canada's natural resources.

Innovation and productivity gains have granted the industry a competitive edge in global markets. Continued innovations and productivity improvements are essential if the industry is to remain a global leader. At a time when Canada has a productivity gap – and a 30 percent gap in real incomes – relative to the U.S., the mining industry has a key role to play in Canada's technological future.

This report looks at the key technological advances in the minerals and metals sector, particularly in Information Technologies, and how they have contributed to the impressive productivity growth in the sector. The report identifies how the Canadian economy has benefited from advances in the sustainable development of the minerals and metals sector and from growing linkages between the mining sector and other sectors in the new economy. Linkages form as products and complementary technologies create a virtuous cycle of growth and innovation that extends to the global economy. The report concludes with some recommendations to enable the mining sector to continue to play an essential role in Canada's future prosperity.

Dispensing with misconceptions about the "New" and "Old" economy

"The characterization of parts of the economy as 'new' and parts as 'old' serves a media convenience for presenting issues as simple binary choices. Implicitly it sets up these choices in opposition to one another. Thus new equals good equals buy, while old equals bad equals sell."

David Humphreys Chief Economist, Rio Tinto, London

Mining surpasses other industries in productivity growth in large part because it has transformed into a high technology sector. It is a paradox, then, that as technological innovation has become more important to Canada's growth and prosperity, mining has been miscast as part of the "old" economy, that is, a low technology industry of declining importance. For example, a recent presentation by the Export Development Corporation (2000) cites mining as "a prime example of what people mean by the old economy", an industry that is no longer a key economic driver and whose lagging performance is manifested in declining metals and minerals prices. The "new" economy seems to have been typecast as the knowledge-based service industries, but it is far more than that. "New" includes innovations such as robotics and new Business-to-Business commerce found in the mining industries. It also includes the new forward and backward linkages forged between mining and other high technology industries with the invention of high performance metals and the demand for high technology supplies and services to mining, as well as the global diffusion of new mining technologies such as GEM and acid mine drainage control. In the case of mining, a line cannot be drawn between the high-tech, knowledge-based sector and the resource sector based on physical assets. As a *high-tech resource* sector, mining is an alloy of the new and the old.

Moreover, the decade-long decline in metals and minerals prices is not the result of a "sunset" industry's declining demand and erosion of long-term profitability. Declining prices reflect the declining costs of production in large part because of the productive and innovative success of the mining sector worldwide – rather like what occurred with computers. And, as David Humphreys of Rio Tinto points out, sustained future demand for metals and minerals is likely. Information technologies are highly dependent on traditional metals. A personal computer, for example, contains about thirty different minerals. New high-tech industries require investments in office buildings, homes and shopping centres, which require metals and minerals in their construction. Finally, there is untapped potential for growth in the demand for metals and minerals in developing nations whose incomes are at a level where the growth in demand for metals and minerals tends to be at the highest.

The danger of creating the false dichotomy between "new" and "old" is that governments may direct an industry strategy toward what they perceive to be the "new" economy winners and misallocate resources to the detriment of the real winners, which could hamper the technological innovation and productivity they are trying to encourage. There is also a problem of perception: talented university students and potential investors who have the wherewithal to drive and finance innovation may pass up opportunities in the resource sector if they are misled about its future prospects.

1.1 Factors Affecting Innovation in Mining

Structural change and risk

In the past decade the mining industry has contended with important structural changes in the global economy. Metals prices have been on a downward trend; Natural Resources Canada's $US metals price index (which includes copper, lead, zinc, nickel, silver and gold weighted by the share of Canadian production) has fallen about 20 percent in the 1990s. Industry structure has undergone globalization and consolidation and international competition has increased from new mineral producing countries. Regulatory constraints relating to the environment and health and safety have tightened considerably. Mine closures are increasingly costly and future costs could rise steeply depending on future environmental policies. The Canadian mining industry has adapted to increased international competition and regulatory pressures by innovating to lower costs and productivity, and expanding into new markets with new product lines.

Innovation can be risky for investors. High technology projects tend to be capital intensive and thus require large investments and their payoff is uncertain and may not occur until far in the future. In this regard, investors in high technology take similar risks to investors in the mining sector. Mining companies operate with a high level of risk on an ongoing basis.

- *Market risk*. The mining industry is generally a price-taker in an international market with high fluctuations in demand and prices. Export price contracts tend to be fixed in US dollars and so prices are also vulnerable to currency fluctuations. Cost control and productivity improvements are crucial to attain a competitive advantage.

- *Exploration risk*. Because mines have finite deposits, the mining industry's survival depends on investment in new projects. Exploration is high risk and it can cost as much as $50 million to find a new deposit. Often exploration must be funded through high cash flow from ongoing projects, given that lenders demand high rate, short term loans to cover the risk.

- *Development risk*. Development costs are high, and often require significant debt financing with the associated financial risks. Every mine must be designed to meet the unique features of the ore body, and so costs are unpredictable. Maintaining production often requires additional capital investments because of lower ore grades or deeper mines than expected.

- *Domestic political risk*. New mine locations are usually in remote areas with poor infrastructure. They often need major investments in transportation, energy, communications, town and port facilities and social infrastructure to make the production and transport of mining products viable. Regulatory, tax and intergovernmental politics can add to the cost of providing this infrastructure. Aboriginal land claims, if left unresolved, can add to litigation and uncertain outcomes.

- *Foreign political risk*. Market access conditions can change dramatically with the initiation in foreign countries of tariff and non-tariff barriers. Mining has historically faced excessively high tariffs in export markets while competing with foreign competitors who have newly discovered ore bodies. Mines located in foreign countries can be subject to changing regulations and tax regimes. Recently, there has been an increasing trend toward non-tariff barriers in export markets.

Thus, the mining industry operates in an environment of high risk and ongoing structural change while continuing to adopt risky high-tech innovations. Success is conditional on legal, political and social institutions and a tax system that enhance investment certainty and recognize the risk inherent in the mining industry. Some pre-conditions for success are an economy open to trade and investment with an efficient and accessible financial system, a legal system that grants intellectual property rights, an efficient and effective regulatory and land access system and a culture of high quality management that embraces innovation.

Drivers and impediments to research and development

According to the 1999 survey commissioned by the Mining Association of Canada (MAC), *Innovation in the Canadian Mining Industry*, most mining companies perform more R&D in order to improve their competitiveness. (Table 1) They undertake R&D to reduce costs and improve productivity by developing new processes and improving existing processes. Overall, companies are somewhat neutral about the importance of innovations to develop new products, although certain companies do place a high priority on developing new products to increase value-added. Mining companies also consider environmental compliance and voluntary improvements in environmental performance strong priorities. Improved health and safety also rank as important drivers of R&D.

Table 1
Reasons cited by Canadian mining companies for increasing R&D spending

Drivers	Ranking out of 5
To reduce costs	4.7
To improve existing processes	4.7
To develop new processes	4.7
To comply with environmental regulations	4.6
To improve environmental performance	4.3
To improve occupational health/safety	4.1
To improve existing equipment	4
To comply with health/safety regulations	3.9
To develop new products	3.6
To comply with other regulations	3.4

5 = very important, 4 = somewhat important, 3 = neutral, 2 = not so important, 1 = not at all important

Source: The Mining Association of Canada (1999)

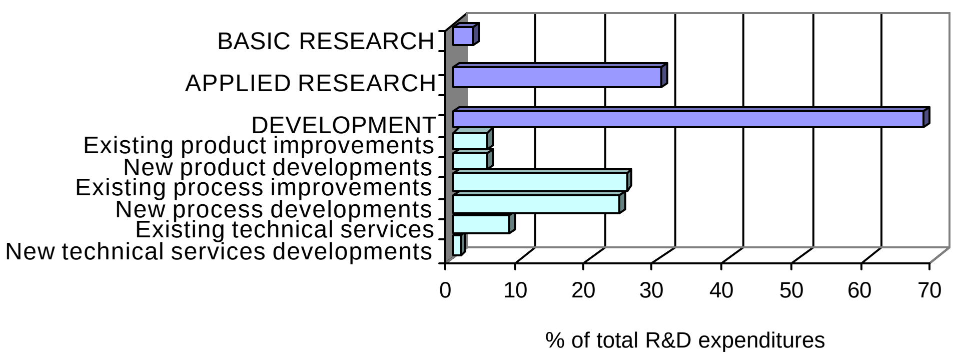
The MAC survey on innovation finds that mining companies perceive few barriers to R&D within their own companies except for insufficient funds for research, which they rank as somewhat important. Companies do not deem shortages of personnel, weak management, and inadequate equipment or facilities to be important barriers. This would suggest that as long as cash flow is available, management is committed to undertaking R&D projects and supporting them with the necessary staff, equipment and facilities.

1.2 Major Technological Advances in Mining

Innovation in the mining sector has distinctive features. It is complex, given the many dimensions of the production process from exploration to extraction and processing to resource management, recycling and mine restoration. It can take the form of improving processes to drive down costs, which is where the innovations have been concentrated in the past, or creating new, value-added products. It can occur in-house or can involve collaboration with other suppliers of research services, competitors, universities and governments. It has evolved through a life-cycle where incremental changes occurred for many years and then at critical junctures certain technologies combined to radically transform mining processes and products.

R&D can be devoted to basic research, which involves the invention of new products and processes, or to applied research and development, which usually involves the development of new processes or adaptation of existing technologies. The focus in mining is strongly on applications and development. The 1999 MAC survey on innovation finds that about two-thirds of expenditures are earmarked for developmental R&D and virtually the rest to applied R&D. Only 3 percent is devoted to basic R&D. Thus the mining sector places by far the greatest emphasis on the later stages of research application and development than on the early stages of pure research. (Figure 3)

Figure 3
Allocation of R&D Expenditures as a Percent of Total R&D Expenditures, 1999
Source: The Mining Association of Canada (1999)



With the downward trend in international metals and minerals prices through the nineties, many companies have placed greater emphasis on research projects related to improvements in the efficiency of processes and somewhat less emphasis on the development of new products. The MAC survey on innovation shows that about 10 percent of expenditures are devoted to the development of existing or new products. Almost 50 percent is devoted to developing or improving processes, and about 10 percent to developing or improving technical services.

The 1999 MAC survey presents the innovations in Canada that mining companies believe had the most influence on mining in the last five years. (Table 2) Exploration R&D has led to the development of geomatics and mapping. Software improvements have occurred in computer process modelling and fuzzy logic. Process improvements have occurred in areas such as automated drilling, heavy equipment, and robotics. New products have been developed for rechargeable batteries, specialty metal powders and galvanized metals. Environmental research has occurred for acid mine drainage and aquatics and improved metal and tailings recycling, making Canada a world leader in the environmental impacts of remediation technology.

Table 2
Canadian innovations having the most influence on mining in the past five years

Results from MAC survey on innovation
! new technologies for processing nickel and copper ores and minerals
! lowering engine emissions and energy reduction
! geo-technology
! inversion of geophysical signatures
! robotic and remote mining technology
! mining automation/equipment automation
! fuzzy logic and computer process modeling
! application of statistical methods to mineral processing
! IT and other computer applications
! column flotation
! improved understanding of geological models
! laser surveying technology
! GPS applications to mining equipment and open pit mines
! Landsat images for exploration
! inversion of geophysical signatures
! battery products for hybrid electric vehicles
! process monitoring and control
! recovery of magnesium from asbestos tailings
! processing fine-grained massive sulphide ores
! paste back/paste fill technology
! Acid Mine Drainage and Acid Neutralizing Capacity
! selective leach technology
! tailings management

Source: The Mining Association of Canada (1999)

2 HIGH TECHNOLOGY: THE ROAD TO HIGH PRODUCTIVITY

"Productivity is not a problem in every industry in Canada. Canada's natural resource industries, or example, have in many cases incorporated high-tech into their production techniques and become tops in their fields internationally".

Peter Harder, Deputy Minister, Industry Canada

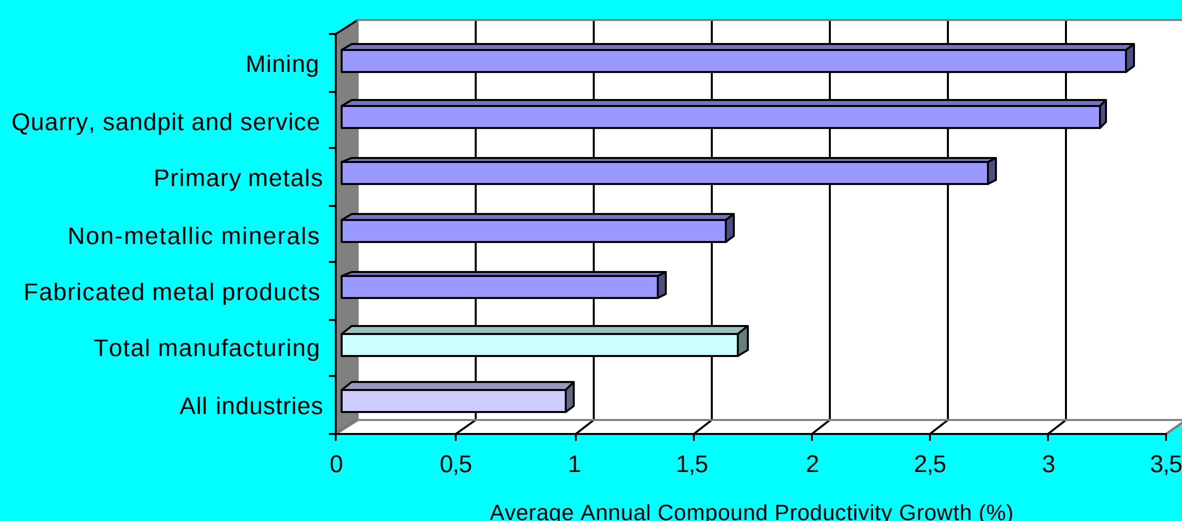
2.1 Productivity Growth in the Minerals and Metals Sector

Mining Productivity Outstrips Other Canadian Industries

Total factor productivity in the mining sector grew by an annual average of 3.1 percent between 1984 and 1998, almost twice the 1.7 percent growth in the manufacturing sector and three times Canada's overall productivity growth of 0.95 percent Mining, primary metals and quarries were among the top ten leading industries in annual average total factor productivity in 1984-98. Productivity in the coal industry grew an average of 8 percent per year, outstripping some of Canada's high-tech industries such as electronics (6.6 percent) and communications (1.6 percent). (Figure 4)

Figure 4
Average Annual Total Factor Productivity Growth in the Mineral Sector and Total Economy , 1984-1998
(Using number of hours worked)

Source: Centre for the Study of Living Standards



trong productivity growth in the mining industry did not lead to labour shedding in the 1990s, suggesting that mining employees are essential to the gains in productivity. The share of employment in the mining and minerals sectors relative to the Canadian goods producing sector has remained constant since the early 1980s. Total employment in the minerals and metals sector, at 401,386 in 2000, is at a ten-year high.

Mining productivity in Canada exceeds U.S.

Between 1984 and 1998, average annual total factor productivity growth in the primary metals sector well exceeded the United States (2.4 percent vs. 1.5 percent). Fabricated metals also outperformed the U.S. competition (1.41 percent vs.1.36 percent). The superior performance in Canadian mining occurs across a broad range of metals. For instance, a Canadian miner produces 4.2 tonnes of iron ore per hour compared to 3.7 tonnes in the United States. Gold and uranium miners in Canada also have a higher hourly yield than their counterparts in the U.S. (Table 3)

Table 3
Productivity levels in selected metals industries, United States and Canada

Commodity	United States	Canada
Gold (troy oz/hr)	0.29	0.33
Iron ore (t/hr)	3.7	4.2
Uranium (kg/hr)	2.3	7.2
Coal (t/hr)	5.9	5

Sources: Natural Resources Canada, Statistics Canada and U.S. Census Bureau

A RAND (2001) study, *New Forces at Work in Mining: U.S. Industry Views of Critical Technologies*, offers some insight into why productivity in Canadian mining companies has outpaced that in U.S. mining companies. The same trends that drove Canadian companies to higher levels of innovation – historically low commodity prices, consolidation, globalization and regulatory constraints – have, according to U.S. mining managers, resulted in greater risk-aversion and cutbacks in technology R&D. Technological change in U.S. mining has focused more on short-term incremental improvements rather than breakthrough innovations. Thus, the culture of innovation does not seem to have developed in the same way in the U.S. mining sector as in Canada. U.S. managers observe that companies do not seem to be fully exploiting technology crossovers within companies, across the mining industry or into non-mining sectors. They also note a paucity of R&D collaboration among suppliers and mining operations.

2.2 Research and Development

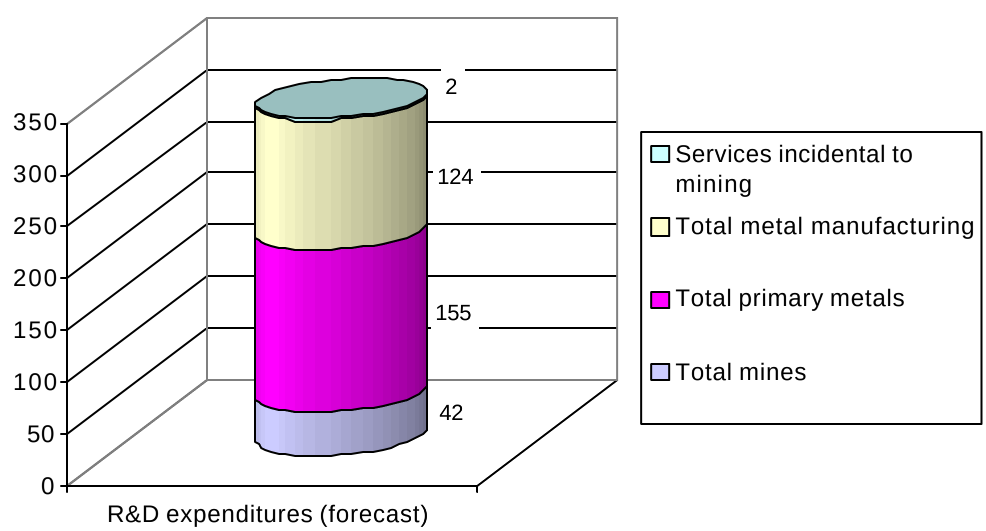
"You can't do capital investment without technology. Technology is the real lever."

Donald Holdner, Vice-President Technology, Noranda

In 2000, R&D expenditures related to mining totaled $323 million or 3.3 percent of industrial sector R&D in Canada. This is over five times the total spent on all other resource industries combined. It is also considerably more than the R&D spent on motor vehicle parts and accessories, or the combined R&D in construction, transportation equipment, communications and utility industries. Mining companies spent $42 million, smelting and refining companies $155 million, and fabricated minerals and metals $124 million towards metal product research. (Figure 5)

Figure 5
Research and Development Expenditures Related to Mining, 2000

Source: Statistics Canada Cat. No. 88-202-X1B



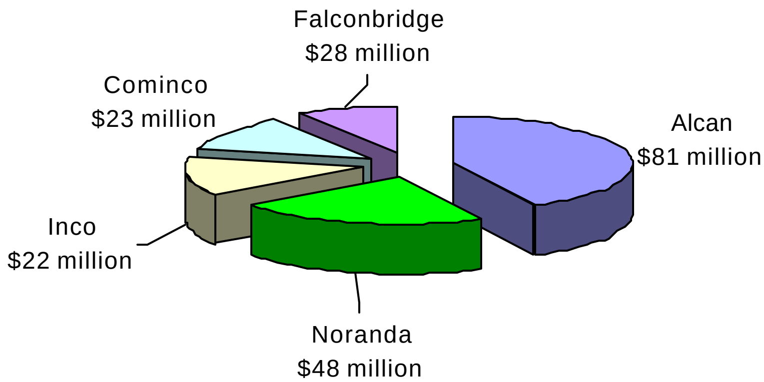
The MAC survey on innovation (1999) estimates that R&D spending accounts for about 1 percent of total company revenues on average and that three-quarters of Canadian mining companies are engaged in R&D. The R&D facilities surveyed employ about 1.4 percent of all mining workers.

R&D is a long- term and synergistic investment, and therefore requires a long term comprehensive commitment. Accordingly, mining companies often have their own technology centers. The MAC survey shows that in 1999, 42 percent of Canadian mining companies had an R&D center. Over one-half of mining companies conduct their research primarily in-house, just over one-quarter contract research to third parties and about three in ten participate in research consortia. The majority of companies report that federal and provincial labs, the National Research Council, Centres of Excellence, NRCan/CANMET do not contribute at all in assisting them with R&D.

Large mining companies are more likely than small ones to engage in R&D in-house because they have the advantage of economies of scale and access to global markets. The *Canadian Corporate R&D Database* compiled by the Globe and Mail Report on Business (2001) ranks five Canadian mining companies in the top 50 private sector R&D investors in 2000. (Figure 6)

Figure 6
R&D Spending of Canadian Integrated Mining Companies Representing "5 of the top 50" Corporate R&D Spenders, 2000, $US

Source: Globe and Mail Report on Business, July 2001



Patents and licences

Recent patent activity of mining companies suggests that they are successful innovators. The 1999 MAC study on innovation showed that 37 percent of mining companies who conduct R&D applied for patents in 1998. The average number of patents held is 30, but a minority of companies holds the bulk of the patents. Noranda, for example, currently owns more than 450 patents on 175 inventions, including seismic monitoring, the Magnola process, tele-remote UG vehicles and zinc powder alloys.

Firms are also engaged in licensing technology from Canadian and non-Canadian sources. Two-thirds of mining companies have at least one license. Licensing allows companies to apply and modify new technologies developed in other companies. Firms also licence their innovations to others. Noranda, for example, licences remote-controlled mining technology and geophysical data processing software to other companies.

An Industry Canada study (2000) ranks the top technology industry sub-categories in terms of their number of patents between 1987 and 1996. The study finds that the mining-related categories of Metal Working, and Earth Working and Wells ranked in the top ten technological sub-categories for Canadian patents between 1987 and 1996. Both of these categories had more patents than Computer Hardware or the Software and Medical Instrumentation sub-categories. These categories also had relatively more patent activity than their U.S. industry counterparts.

2.3 Investment in Exploration and Physical Capital

Exploration and development

Minerals exploration and deposit appraisal resemble research and development in that they both involve large investments attached to a high level of risk. Exploration also involves the continual experimentation with innovative techniques to find new ore reserves. Natural Resources Canada (2000c) reports that Canada is one of the top global exploration locales, with about 11 percent of the total exploration budgets in the world's larger exploration and mining companies in 1999. Canadian-based companies have a vital presence abroad, holding more than 3,000 mineral properties in over 100 countries and planning to proceed with 30 percent of the larger company projects abroad. They dominate the exploration market in Canada, the United States, South America, Central America and Europe. Between 1992 and 1999, the holdings of foreign properties of mining companies listed on the Canadian stock exchange grew at an annual average compound rate of 12 percent and now make up over one-half of the total mineral property portfolios held by these companies.

The pattern of exploration expenditures tends to follow the metals price cycle. Metal prices affect revenues, which determine the amount of financing available for new spending. The minerals and metals sector spent $504 million on exploration and deposit appraisal in Canada in 1999, down considerably from 1998 level of $656 million. Expenditures have declined since 1997 with falling metal prices, a paucity of venture capital and an uncertain business climate. A decline to $473 million is planned for 2000 with spending intentions for 2001 at $458 million. Total mineral development expenditures, which includes exploration and development expenditures as well as mine development expenditures and capital repair and maintenance is expected to be $3.3 billion in 2000, lower than previous years.
Since R&D and exploration spending tend to be cut back significantly during a downturn in prices and profits, factors that exacerbate the profit cycle are likely to hamper R&D and exploration plans. Profit insensitive taxes, for example, which represent an increasing share of total tax revenue, are likely to stand in the way of innovation and productivity improvements because they shrink the profit base at a time when R&D and exploration funds are already tight.

Investment in physical capital

Capital investment is a factor in improving productivity because it involves the update and expansion of productive capacity. Innovations may be initiated at the R&D phase, but they are adopted at the investment phase; thus new investment has embedded in it new technologies. In the Mining Journal (2000), Canadian mining companies describe their capital plans as involving such productivity-enhancing and cost-cutting measures as process improvement, modernization projects, expansion, new plants for new products, mill improvements, modification and retrofit, smelter improvements, increases of production rates and extension of production life.

The mining industry is highly capital intensive and one of the largest investors in Canada. Indeed, the ratio of gross fixed capital investment to value-added in the minerals and metals sector was 50 percent higher than the manufacturing sector in the 1990s. Total investment in mining and oil and gas extraction is estimated to be $24 billion in 2000, or 13 percent of total private and public investment in Canada. Investment spending intentions for 2001 are $29.5 billion, or 15.5 percent of total private and public investment. Of this, $25.3 billion is in oil and gas extraction (mainly oil sands), $1.75 billion in metal mining and $940 million in nonmetal mining and quarrying, and $1.3 billion in services to mining, oil and gas.

2.4 Skilled and Innovative Workers

"Brain power, not muscle power, will take us into the future."

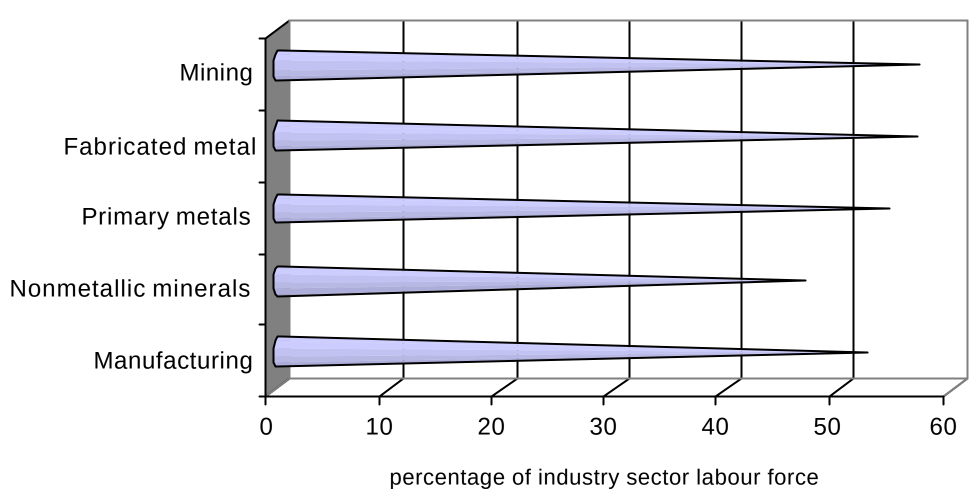
Scott Hand, Deputy Chairman and CEO, Inco

Human capital encompasses the knowledge and skills that workers gain through education, training and work experience. It acts as an engine of growth by creating knowledge spillovers; that is, it enhances the ability of workers to pass on their knowledge to others. It also serves to create new technologies and innovations, while making the adoption of new technologies easier.

Employees in the minerals and metals sector make wide use of new technologies. Statistics Canada has found that in 1999, 88 percent of mining companies use personal computers and 60 percent use e-mail and the Internet, exceeding the private sector average. As advanced technology becomes more available, a highly skilled and educated workforce becomes essential. Mineral industries generally have a higher percentage of workers with post-secondary education than the average in manufacturing in 1996. Only non-metallic minerals is lower than average . Fifteen years earlier only one-third of the sector's work force had post-secondary education. (Figure 7)

Figure 7
Percentage of labour force holding a post-secondary degree by industry sector, 1996

Source: The Mining Association of Canada Facts and Figures 2001



A study conducted by Human Resources Development Canada reports that in the mining sector the share of knowledge and management occupations to total mining employment was 18.4 percent in 1996, an 80 percent increase since 1971. Mining ranked an impressive third in the share of total employees in knowledge and management occupations after the government (25 percent) and the financial sector (32 percent).

Education levels in mining R&D jobs are particularly high. The 1999 MAC survey on innovation finds that 62 percent of workers employed in mining R&D are highly educated technicians and technologists or have bachelor's degrees, 12 percent have Masters' degrees and 14 percent have PhDs. To remain competitive, mining companies are directing efforts toward hiring well-educated R&D workers who have technical skills in the engineering, science and technology fields, and are at the same time innovative thinkers and communicators. Mining industries are placing a high value on teamwork, integrating skills from a variety of fields and looking outward and forward for new ideas. One challenge is to communicate the exciting prospects in mining to talented and well-educated young workers. (Table 4)

Table 4
Canadian mining companies' list of preferred fields and skills of prospective R&D employees

Fields	Technical skills	Generic skills
• research scientists • research technicians and technologists • engineers • technology managers • mineral processors • metallurgists • process engineers and technologists • chemists • materials scientists • process control • computer scientists	• practical application of R&D • analytical skills • operating experience • solid academic formation in extractive metallurgy • mineral dressing • solvent extraction • bacterial leaching • green process technologies • ability to integrate skills from a range of disciplines to solve mining problems (IT skills, mechanical/ maintenance engineering, materials engineering)	• problem solving • people/skills/good interpersonal skills • written and verbal communication • ability to work in teams • innovative thinking • ability to sense important emerging issues • ability to learn from all industrial sectors

Source: The Mining Association of Canada (1999)

In order to find and attract highly skilled and educated workers and to encourage life long learning, mining companies have initiated education and training programs in partnership with other companies, universities and government. Mining companies also support post-doctoral research at universities to build knowledge while training future employees. Some examples of mining company initiatives to improve human capital:

- In 1996, a group of mining companies and unions formed the Mining Industry Training and Adjustment Committee (MITAC), which develops training and adjustment programs. For instance, the Youth Opportunity Program arranges job placements in mining for recent science and technology graduates.

- Educational opportunities are often not as readily available in northern mining communities. COGEMA offers scholarships for northern students to attend post-secondary institutions.

- The Falconbridge Raglan mine has worked in partnership with local school boards to develop education and training initiatives and scholarships, as well as cross-cultural training programs in nearby Inuit villages.

- Learning to operate large complex machinery such as “jumbo drills” is challenging and time-consuming, taking up to 160 hours, and some workers do not have the requisite motor skills to become proficient even after training. Training can now be done more efficiently and cheaply with operator training simulators, which use 3-D models with motion-based physics and audio feedback in real-time. Performance criteria allow workers to measure their progress at each stage of the training.

- The Canadian Institute of Mining, Metallurgy and Petroleum (CIM) and EduMine have formed a partnership to provide online continuing education for professionals in mining and geosciences. Material is peer-reviewed by CIM members and sponsored by CIM in Professional Development Programs.

3 INFORMATION TECHNOLOGIES AND MINING INNOVATIONS

The RAND study (2001) reports that mining and quarrying industries consider Information Technologies (IT) to be the most important advances to the industry. IT can enable management and staff to maximize productivity and minimize costs in real-time and real space, fully integrating all stages of production with buyers and suppliers. IT advanced incrementally in mining for many years and then at critical junctures the interlocking of critical technologies radically transformed mining processes. (Table 5) At the dawn of computerization in the 1970s, when mainframe computers were slow and costly, IT comprised time-saving conveniences for business applications such as word processing and spreadsheet analyses for inventory control. During the 1980s, with the massive increase in the power of computer hardware and software and the advent of the Personal Computer, a fundamental change in the nature of mining started to occur. (Rauch, 2001) One innovation began to build on another; software packages became increasingly sophisticated and modeling and design techniques were adopted at all stages of production. In the 1990s, innovations reached a critical mass and important new communications and sensing technologies took a leap forward. Mine-wide production systems were developed and Global Positions Systems (GPS) and automated technology took hold. A profound change also occurred in the mind-set of corporate leaders in the mining industry: not only was innovation viewed as feasible, it was also viewed as essential. Many of the innovations in the 1990s are poised to become operational beyond 2000. Global communications systems and e-commerce are expected to radically transform business procedures. The widespread use of IT and automation are also predicted to change the nature of human resource management in mining.

Technological transformations did not occur until a nexus of certain critical technologies formed. For instance, the basics of 3-D seismology have been well understood for several decades, but it took the development of high-speed parallel computing before the technique was practicable, given that massive amounts of processing are required to compile the data in the sound waves that map out the geological formations. (Simpson, 1999b) Rauch (2001) points out that between 1985 and 1995, the computing time to process a square kilometer of survey data fell from 800 minutes to ten minutes. In 1980, the cost of analyzing a fifty square mile survey was US$8 million. Today the same survey would cost US$90,000. Complementary developments then magnified the efficiencies. Directional drilling was also not new, but became cost-effective when 3-D seismology increased the accuracy in the shape and location of reserves and increased the probability of successful drilling operations. Around the same time, measurement-while-drilling became far more accurate with the addition of sensors and computers to process underground data. The three technologies formed a virtuous spiral of innovation. Powerful sensors increased the payoff for technological advances in directi onal drilling, which in turn increased the payoff for higher resolution 3-D seismic imaging.

The introduction of Information Technologies into the mining sector is not without immense challenges. The six phases of mining -- assessment, exploration, deposit appraisal, mine development, processing and restoration – are highly complex and each has radically different information requirements. (Table 6) Mines are three-dimensional and the individual characteristics of mine sites vary substantially. Underground-to-surface communications create complex communications problems. An environment of blasting and drilling rock is inhospitable to sensitive computer equipment. The RAND (2001) study identifies the Information Technologies that are critical to meet the challenges:

- sensors for exploration and production to collect data on positioning and rock mechanical properties and to monitor equipment performance
- position monitoring such as GPS for tracking vehicle movements and precise location of individuals and machinery
- rugged on-board computer hardware that allow remote data acquisition and manipulation, with sturdy parts such as cameras, lasers and radio transmitters
- computer software with custom designed algorithms suitable for dynamic and inconsistent physical environments
- high capacity wired and wireless communications that can be section-specific and mine-wide, such as leaky-coax systems and fibre-optic based systems
- integration of equipment for better planning, dispatching, dynamic surveying and performance and productivity monitoring, and better matches to customer specifications

Table 5 - The Evolution of Information Technologies in Mining

1960s: **Clerical Bureaucracy**
Information systems are paper-based: business machines process systems such as payroll, inventory.

1970s: Dawn of computerization
Large firms make widespread use of mainframes for business applications.
Technical computer applications are rare; some early ventilation, mill and geo-technical modelling.
Little innovation in mining applications. Existing practices are emulated: e.g., tabulation of ore reserves.
Some innovations use mainframe systems for preventive maintenance and inventory control.

1980s: Revolution in PCs and software application
Advent of PCs allows integration of CADs, surveying, geological modelling and reserve estimation.
Production operators use computers for planning and design.
Dramatic increase in computer modelling, especially for geotechnical design.
Establishment of a new wave of commercial mine and plant design software packages.
Computer visualization in mine design emerges.
Still very limited communications in mines.

1990s: Advances in communications and sensing
New communications systems link people, machines, planning and control systems.
Monitoring of machine performance intensifies.
Widespread recognition of potential for mine-wide production systems.
New GPS and other means of location, survey, guidance and navigation become available.
Innovation widely recognized as feasible, and necessary to remain competitive.
Automated mine and plant systems technology well-established; implementation confined to a few companies.

2000 and beyond: Continued evolution of new information technology
New information technology may realize significant benefits from concurrent engineering, integrating external and distant expertise; remote operational control.
Greater Business Process Re-Engineering through mine-mill integration, holistic planning and design.
Standards, compatibility and interfaces between commercial software systems will be addressed.
Full impact of the internet will become evident; e-commerce will radically transform business practice of mining.
Operational practices will undergo radical change through new information and automation technology.
Telemining will be implemented in surface and underground mines. Full automation is unlikely.

Source: The CIM Computer Applications and Automation Committee, www.cim.org. Table: Information Technologies Used During the Mineral Development and Mining Process.

Table 6
Information Requirements in the Mineral Development and Mining Processes

Phase	Stage	Information requirements
Mineral Resource Assessment	Surveys, research, synthesis	Geoscientific, mineral and economic surveys, research, compilations and synthesis by governments, research institutes and universities.
Mineral Exploration	Exploration planning	Mineral and metal market research. Review of geological and ore deposit information. Review of legal and political context.
	Regional reconnaissance and surveys	Remote sensing, aerial photography and airborne geophysics. Prospecting , geology and geochemistry. Appraisal, rating and selection of anomalies.
	Prospecting and ground survey of anomalies	Ground-based geological, geochemical and geophysical prospecting and surveys. Review and selection of significant anomalies.
	Verification of anomalies and showings	Geological mapping and other surveys. Trenching and sampling. Review of results and selection of targets.
	Discovery and delimitation	Stripping, trenching, detailed mapping, sampling, drilling and down-hole geophysics. Preliminary deposit inventory and evaluation. Environmental characterization and site surveys.
Mineral Deposit Appraisal	Deposit definition	Detailed mapping, sampling and drilling on surface or from underground. Systematic mineral processing tests. Detailed environmental and site surveys.
	Project engineering	Pilot tests and engineering studies. Design, cost estimation for mining, processing, infrastructure, environmental protection and restoration.
	Project economics	Market, price, cost and other financial studies. Technical environmental, economic, financial, social and political risk analysis.
	Feasibility study, production decision	Exhaustive due diligence review of the geological, engineering, environmental, economic, legal and site data. Evaluation of the profitability, risks and up-side factors.
Mine Complex Development	Construction of plant and infrastructure, mine preparation	Project and quality management methods. Training program for personnel and detailed start-up plan.
Mineral Production	Production, marketing	Production management using continuous quality improvement methods. Exploration appraisal and development of new ore zones both at the mine site and off-property. B2B links to suppliers. Information technologies for marketing.
Environmental Restoration	Mine closure, site reclamation and restoration	Mine closure and decommissioning. Environmental restoration and monitoring.

Source: Natural Resources Canada (2000b), 10

The Canadian mining industry has advanced in all these areas. Success has come from continued experimentation and recombination of technologies and an adoption of a culture of innovation at the earlier stages of the IT revolution. Those who invest in early generations of technology tend to be well placed for subsequent generations of innovations as improving technologies are recombined with earlier generations.

3.1 New Technologies in Exploration

The objective of exploration technologies is to locate large, high grade reserves with minimal ground disturbance and disruption to the environment. New technologies explore at lower cost, increased productivity and minimal damage to the environment and are able to locate previously unaccessible mine reserves. Exploration innovations include global positions systems (GPS), airborne geophysics and low-impact seismic methods that are environmentally friendly.

Dynamic GPS based surveying information are being developed to operate in real time as ore is extracted. Planning and visualizing techniques are being employed: stochastic simulations are used to provide ranges of ore distribution and to evaluate various mine design and expansion options. The use of satellites from optical and radar satellites to map geological formations and new imaging technologies are becoming economically viable.

New airborne technologies and down-hole seismic imaging (DSI) technologies are also becoming feasible. Noranda has developed an enhanced airborne electromagnetic technology that has allowed it to discover new deposits that would not have been found with traditional methods. New ore bodies discovered with this technology are valued at $1.5 billion. The Mining Journal (February 2001) reports that a partnership of Falconbridge, Noranda and the Geological Survey of Canada has demonstrated the feasibility of mapping ore zones at distances of three kilometres. Inco's UTEM is a down-hole electromagnetic tool for the discovery of massive nickel sulphides.

Innovations in exploration methods are taking a more environmentally friendly approach. Geophysical companies are adopting LIS (low-impact seismic) methods that minimize the environmental damage from cutlines bulldozed through forests. For instance, Western Geco has developed the Navpac navigation system using control points to overcome the limitations of a GPS system in poor visibility or dense forests. The HeliStaker, a GPS system with an antenna and video camera device, can be lowered through the trees and once coordinates are determined, a spring-loaded stake is driven into the ground. Niche-type drills such as the Expendable Tip Technology leave no disturbances in the surface and work in areas where conventional rigs cannot drill. More environmentally friendly and safer explosives reduce the problem of cleanup and add micro-organisms to the pentolite charge so that it breaks down over time.

3.2 Extraction and Processing Technologies

Innovations in extracting and processing technologies produce metals at lower costs and identify value in ore bodies that previously were not cost-effective to mine because they were lower grade or too deep. New technologies are also being adapted and developed to mine in harsh environments. Innovations include robotics and remote operations, improvements in mine design and automated handling systems. Space-age technology such as the *CanadArm* has been applied to robotics technology such as 3-D vision systems and robotic joints, tele-operation, auto-loading and guidance systems. Powerful software programs have widespread applications, from optimizing blasting capabilities by comparing loading information and blast results to optimizing grinding processes at gold mines under various operating conditions. Here are some examples of leading innovations using IT.

Telemining

Telemining combines underground telecommunication systems, positioning and navigating systems, engineering, monitoring and control systems, teledrifting and teleproduction. Miners operate and maintain underground loading, hauling and dumping vehicles (LHDs), from a surface-based control room. Geologists review computer information on tonnage and ore grades to refine drilling operations. Canadian mining industries are leading innovators in telemining. In 1996, Inco, Tamrock OY, Dyno Explosive Group and CANMET initiated a five year research alliance called the Mining Automation Program (MAP) to develop telemining. MAP is being tested in Inco's Research Mine in Copper Cliff, Ontario.

Telemining will dramatically improve the productivity of mining processes. Benefits will include better workplace safety, higher worker productivity (workers don't have to travel to the site and can operate more than one piece of equipment simultaneously) better equipment utilization (equipment can be used up to 23 hours a day with reduced maintenance) and profitability (more accurate drilling and blasting, faster throughput times and higher ore recovery).

Automated Load-Haul-Dump fleets

Automated LHD fleets lower operating costs because an operator can manage more than one LHD. They also lower maintenance costs because they can better coordinate equipment operation. They can be tailored to individual specifications and interface with other machines. The Canadian Mining and Metallurgical Bulletin (January 2001) describes a new generation of remote-control LHD that uses anthropomorphic telepresence to improve efficiency and safety in telemining. The LHD senses and presents feedback in a human-like fashion. The remote operator has the physical impression of being in the same location as the equipment.

IT and Integrated Systems

IT can process vast amounts of information, creating the opportunities to integrate entire operations, from exploration to processing to marketing and sales. Integrated systems can link accounting systems, dispatching GPS systems, production and inventory control. The fully integrated upstream mining processes will allow for a better co-ordination of production, shipping and marketing.

The Canadian Mining and Metallurgical Bulletin (January 2001) reports on modular mining systems that are used as process control tools to manage operations in real- time. Process control systems are widely used in other manufacturing industries, but underground mining has to this point been considered too complex to make use of the systems. Recent improvements in information and communications technology allow underground monitoring of the production cycle, which is now being tested in pilot projects. Simulation studies produce optimum crew structures and shift schedules and use of equipment, and identify bottlenecks in the process. The benefits are greater productivity from improved focus on priorities, better communication among crew and clearer expectations.

Organizational changes are essential to overcome barriers to integration. Studies show that success factors contributing to productivity gains may come as much from the management and work procedures as they do from the technological innovations themselves. One cannot simply overlay new technologies on outdated or ineffectual infrastructure and business processes. A fundamental paradigm shift from organizing around physical assets to information management must occur.

Internet technology has created a huge potential for improving information exchange with third parties and remote sites. There are also several Internet sites sponsored by industry, MAC and government that exchange information on mining technologies, markets and services. InfoMine provides a fully integrated source of worldwide mining and mineral exploration information. MineNet provides electronic mining yellow pages of products, software and services. The Canadian Mining Technology Network, sponsored by MAC and the Canadian Association of Mining Equipment and Services for Export (CAMESE) presents technical reviews of mining processes, product and service news and various useful linkages.

New technologies in maintenance

With increasing automation and large equipment, lost production costs from downtime have taken on greater importance in determining a mine's economic performance. Studies have shown that maintenance costs comprise the single largest controllable expense in mining operations, as much as one-half of total operating costs. Greater integration between operations and maintenance to optimize equipment operations and minimize downtime is the key to improving cost structures. An IT technique called "structured analysis" identifies the shared informational requirements of production and maintenance. Modeling the procedures and data flows identify the information shortfalls and redundancies, allowing an efficient system design of maintenance controls to resolve failures. The RAND (2001) study identifies areas that are now being developed and applied to operations and maintenance:

- On-board sensors and off-board diagnostics such as vibration analysis and vital-signs monitoring predict equipment failures and optimally schedule maintenance actions.
- Operational capabilities can be extended and downtime minimized with new and more robust engineering and materials such as better lubricants and "hot-swappable" components.
- With the increasing use of outsourcing for maintenance, costs can be reduced considerably with electronic transmission of diagnostic data.

New information technologies can only go so far unless they are combined with better work practices, such as more effective record-keeping and better follow-through between maintenance and subsequent operations.

3.3 E-commerce and B2B

In May 2000, a consortium of fifteen of the world's largest mining companies (including Alcan, Inco, Noranda and Barrick Gold) representing 60 percent of the market capitalization of global mining announced they will invest up to $100 M ($US) in a global online business-to-business (B2B) exchange to reduce procurement costs. Quadrem, the Mining, Minerals and Metals eMarketplace, launched a global pilot program with over 20 suppliers and 12 buyers in October 2000. Buyers perused catalogs and product information and pricing for various suppliers and made customized requisitions via the Internet. North America, South America, East and West Europe, Southern Africa and Australia participated.

David Humphreys, Chief Economist of Rio Tinto, London estimates that the steel industry and non-ferrous metal industries could save 5 to 15 percent as the result of e-procurement. Savings will come from lower transactions costs, streamlined procurement, reduced inventories, more standardization, greater transparency and more automated ordering. UBS Warburg estimates the cost savings for the U.S. mining industries to be in the order of 5 percent. One-third of the savings would be in the cost of supplies, such as components spares and chemicals. (Table 7)

Table 7
Mining Cost Structure and Potential eSavings in Cash Costs

Cost breakdown	percent of total savings	eSavings percent of total costs
Labour	27	5%
Energy	23	2%
Supplies	33	9%
Other	17	4%
Total	100	5%

Source: UBS Warburg, June 2000, from Humphreys (2000)

Humphreys also reports that some mining companies have begun to participate in Internet marketing and Internet auctions in order to expand markets for new products. They offer the chance to improve customer relations and reduce dependence on trade intermediaries. The greatest impact will likely be on less transparent markets such as minor metals.

3.4 IT and Human Resource Management

"As technology progresses, workers are becoming more critical to the success of mining and quarrying operations, not less."

RAND (2001)

Information Technologies offer decision makers a more complete picture of mine development and profitability and investment choices. Effective knowledge management involves extracting the essential information from a complex array of data, and then acting on the information. Some of the most important innovations, according to the RAND study (2001), involve the organization and management of mining and quarrying facilities. As mining equipment and processes incorporate information technologies, workers have gained unparalleled access to information and control of equipment. Their roles and responsibilities are evolving. Jobs require multi-disciplinary knowledge and generic skills. Tasks are being redefined away from following procedures and rules and toward solving problems and initiating solutions.

Health and safety innovations

Both the RAND (2001) study and the MAC (1999) survey on innovation report that health and safety innovations are more likely to be undertaken voluntarily than to comply with new regulations. Environment Canada (2000) reported to the United Nations Commission on Sustainable Development that industry partnerships with universities, the Canada Centre for Mineral and Energy Technology (CANMET) and other stakeholders have embarked on research and development into health and safety technologies such as:

- enhanced mine air quality to using automated, energy efficient underground ventilation systems throughout the mine

- critically lower threshold diesel emission levels to limit exposure to oil mists and diesel exhaust pollutants

- tools to optimize the safety and viability of deep mining operations based on rock behaviour processes

- new lightweight materials for vehicles that reduce fuel consumption and thus carbon dioxide production

New technologies in automated mining will improve health, safety and workplace quality dramatically in the future. For example, the Mining Automation Program (MAP) will allow workers to operate underground equipment in a surface-based control room, reducing the potential for injury from heavy equipment or dangerous work environments. In another example, an important cause of injuries and fatalities in Canadian mines has been mining-induced seismicity created by the sudden failure of rock under high stress. Technological advances in computers and electronic components have added to the knowledge of the causes of rock failures and the applications of new safety measures. In particular, source location information helps to identify zones of highly stressed rock and sensors can estimate the size and progression of the fracture.

4 NEW TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT

Canada is a world leader in technological advances in environmental management, by virtue of the industry taking on the role of caretaker of the metals and minerals resources and their environment. In fact, The Mining Association of Canada was the first national mining association in the world to adopt a guide for best environmental practices. The environmental challenges are technically complex and affect many stakeholders and so are often tackled with a cooperative approach. A key strategy is to adopt best practices and new technologies that combine productivity improvements with better environmental performance. Several research initiatives have been launched by industry partners to improve environmental performance in the mining sector. In the Environmental Progress Report 2000, MAC presents the activities and innovations relating to mining and the environment.

4.1 Progress in Environmental Technologies

Greenhouse gas emissions

Greenhouse gas emissions (GHG) occur when energy is consumed during the production process. GHG intensity (emissions per unit of output) from metal mining and non-ferrous smelting and refining were 13.87 and 15.9 percent lower in 1999 than they were in 1990, one of the best performances of all Canadian industries. The industry accounted for about 6.5 percent of total industrial CO_2 emissions and 21.9 percent of total Canadian CO_2 emissions, and as the industry grows the challenge will be to further reduce energy requirements per unit of output. Efficiency improvements and cost savings often involve reduction in energy consumption and GHG emissions.

In 1998, oil sands developers invested $75 million in research and development to achieve more energy efficient technologies and processes. Syncrude plans to invest $500 million of its Syncrude 21 initiative in new technologies to improve environmental performance. Syncrude has developed and licensed energy-savings and emission reduction technologies such as naphtha recovery from tailings, low-energy extraction processes, and hydro transport and cyclofeeder systems. Falconbridge developed a ventilation automation project in 1998, which uses sophisticated command and control technologies to regulate ventilation fans and monitor air control, with significant reductions in indirect GHG emissions and energy cost savings.

Innovations to reduce energy consumption have also created spillover productivity improvements. Consider Cominco's computerized steam-management system installed in the mid-1990s, which introduced more efficient and timely energy controls. The more consistent supply of steam has improved temperature control and thus augmented zinc production.

Metals in the Environment Research Network (MITE)

The MITE research network comprised of MAC, the mining industry, government and universities was created to fill gaps in research on the risks that metals pose to the environment. Research domains include the sources of metals in the environment, how they move and transform in the environment and their effect on ecosystems and human health. The MITE network draws together multi-disciplinary expertise from geologists, toxicologists and environmental scientists to fill the gaps in knowledge about the environmental effects of metals. The mining industry and MAC have provided financial and in-kind support to this project. At a workshop in 2001, MITE reported on progress in research on areas such as the movement of metals in lakes and rivers and metal toxicity in freshwater fish. Current projects include the distribution of metals in the atmosphere and their effects on aquatic organisms.

Mine Environmental Neutral Drainage Program (MEND)

Acid drainage through abandoned mines is the largest environmental liability for the mining industry. It occurs when sulphuric minerals in tailings and waste are exposed to air and water and undergo oxidation, creating sulphuric acid. Untreated, it contaminates groundwater and can be hazardous to plants and wildlife and fish. MEND is a cooperative and voluntary research consortium of the mining industry, the Government of Canada and eight provincial governments to apply new technologies to prevent, treat and control acid mine drainage. New technologies include controlled inondation (water cover), multi-layer covers and techniques to analyze the geochemical characteristics of tailings. Through a $17.5 million investment in MEND over eight years, the liability due to acidic drainage fell by $400 million in 2000, and Canada is now a world leader in the control of acid rock drainage. After the completion of MEND in 1997, MEND 2000 was created to promote the transfer of technologies developed in MEND**.** The MEND 2000 Internet site provides important acidic drainage information and announces workshops and conferences.

Toxicological Investigations of Mining Effluents (TIME) Network

The causes of acute toxicity of effluents cannot always be readily identified . A multi-disciplinary partnership was established to investigate the causes and sources of effluent toxicity and pollution prevention and control techniques to consistently achieve non-actively lethal effluents. In 1999, MAC approved $175,000 per year for three years in research funds to study the factors underlying lethality of effluents. The TIME workshop 2001 reported on projects underway, including the development of consistent and cost-effective protocols to evaluate and treat toxicants, a literature review of the toxicity of various heavy metals in mining effluents and best management practices for ammonia.

Zero Emission Coal Alliance (ZECA)

Research is underway to at least double the net efficiency of coal-based power. The Coal Association of Canada and 16 other coal producing entities in Canada and the U.S. formed ZECA with an aim to pilot the technology within five years. This is a promising technology to address greenhouse gas emissions and offers potential savings for other mining-related activities such as smelting and refining.

Accelerated Reduction/Elimination of Toxics Program (ARET)

This voluntary initiative involving a consensus-oriented multi-stakeholder group aims to use good science to achieve a total reduction in emissions for more than 100 target substances by nearly 75 percent by 2000, using 1988 as a base year. All ARET-listed substances are below base-year levels. (Table 8)

Table 8 Reduction in ARET substances to 1999

Arsenic	-49%
Cadmium	-71%
Copper	-28%
Hydrogen Sulphide	-62%
Lead	-73%
Mercury	-93%
Nickel	-78%
Zinc	-81%

Source: The Mining Association of Canada (2000a)

New recycling methods

Metal recycling plays an essential role in sustainable development. Canadian mineral and metal companies are deemed to be among the most innovative in recycling and have adopted new recycling technologies that add value to production processes and address environmental concerns of landfill disposal of bulky and hazardous products:

! Hydro metallurgical processes can leach zinc from galvanized steel scrap and during the treatment of the lead paste component of spent batteries.

! Copper and aluminum wires are currently separated from the plastic coating, leaving the "chopping line residue". New separation techniques can recover the remaining metals and plastic polymers for industrial applications.

- Processes have been developed to allow the recovery of the co-polymer polypropylene plastic exterior of battery cases for reuse in commercial plastic products.

- The Noranda Horne copper smelter uses a unique process that handles complex materials so that it can recycle copper products and electronic materials such as computers, phones and chips. The smelter produces copper, gold, silver platinum and palladium. It has two facilities in California to process electronics by-products for smelting in Rouyan-Noranda.

- Noranda is opening a major recycling facility in partnership with Hewlett-Packard to ensure that end-of-life electronic hardware is reused or recycled in a way that conserves resources and promotes sustainable development.

4.2 Canadian Suppliers of Environmental Technologies

The trend toward new environmental technologies creates opportunities for suppliers of mining goods and services. Natural Resources Canada (2000b) reports that the demand by mining companies for technologies and services to comply with environmental regulations is expected to grow 5 to 10 percent per year in the next three years. Each year, Canadian firms sell to mining companies about $570 million of products related to air pollution control and the management of solid or liquid waste. The export market is strong too: 40 percent of the products are exported and almost 40 percent of Canadian suppliers have some kind of foreign representation abroad to market their products.

4.3 Global Diffusion of New Environmental Technologies

Sustainable development is a global issue and requires global participation in identifying and communicating new technologies. The International Council on Mining and Metals (ICME), an industry-funded non-governmental international organization with several Canadian member companies works to share and disseminate information on the most recent sustainable development policies and practices. The ICMM shares information and best practices in workshops on issues such as environmental management systems, toxicity of metals, the management of mine tailings, among others. The ICMM has also been involved in international policy issues and outreach programs to developing countries to encourage sustainable development in mining.

Because Canadian mining companies are leaders in environmental technologies, they take their expertise in designing the safest and most technologically advanced mines to host countries. For example, the World Heritage Committee extols the Antamina project as a model of cooperation to mitigate environmental impacts of mining. Antamina is a US$2.2 billion copper-zinc project in Peru designed with the participation of the international mining companies, non-governmental conservation organizations and local citizens. (Harrison, 2000)

5 LINKAGES BETWEEN MINING AND OTHER HIGH-TECHNOLOGY SECTORS

"*Innovation is the continuous process of discovery, learning and application of new technologies and techniques from many sources.*"

Someshar Rao, Industry Canada Researcher

Innovation processes in mining are often conjoined with technological developments elsewhere in the industry and the economy, creating spillovers and a virtuous circle of innovation, productivity, and prosperity. As one innovation enables another, continuous and accelerating recombinations begin to occur. State-of-the-art techniques developed in the rest of the economy enable new technologies to be developed in mining. They also create the demand for new products from the mining sector. New technologies in the mining sector not only improve productivity within the sector, but create the demand for new supplies and services to the mining sector, which in turn spur on new innovations. The mining sector is in a strategic position to act as a fulcrum for innovation because of its strong domestic and global linkages and its history of technological innovation.

5.1 Value-Added Products and Services

Innovations in materials

Canadian mining industries are directing their product lines more towards higher value-added downstream products. Higher margin specialty products used in new technological innovations have growth rates several times the growth in demand for base metals. Sales of these high value-added commodities increase profitability and moderate the variability in profits due to commodity cycles, thereby creating new wealth. New products also contribute to sustainable development because their higher value-added make them more efficiently transportable and they are developed with an awareness of their environmental impact.

The production processes in the new product lines often employ advanced technology. Statistics Canada (2000) calculates that the primary metals sector had the highest overall ranking in the use of advanced technologies between 1989 and 1998. In 1998, primary metals ranked in the top six in all four categories of technology use – design, fabrication, communication and integration.

Some new products are created to complement new technological processes developed in other industries. For instance, the Direct Nickel Alloying Process developed at the Cominco research facilities is the superior method to treat reactive steel, creating a new galvanized product that affords cost savings to galvanizers. Reactive steel contains elements such as silicon that cause it to galvanize erratically. Because steelmakers are switching to continuous casting and using silicon to deoxidize and strengthen steel, reactive steel production is likely to increase, creating demand for the new form of galvanized steel.

Other products become economically feasible only when new production technologies have been developed. Noranda developed the Magnola process for extracting high-value magnesium from asbestos tailings (the waste products of asbestos mining). The company combined several proven commercial technologies and breakthrough technologies and the process took almost 15 years of research. With the technology in place, Noranda is now able to create a new generation of magnesium alloys that are more cost-effective and resistant to high temperatures.

Often the new metal products are created to supply high-technology industries. For example, Inco has developed an array of new products that are linked to high-tech industries:

- Electromagnetic shielding prevents interference from stray electromagnetic waves and radio frequencies.
- Extra fine nickel powders are used in capacitor chips.
- Nickel foams enhance nickel metal hydride batteries to be used in hybrid cars.
- Highly pure nickel oxide is a component of ferrite, an input in electronic components in cell phones.

In the non-metallic minerals sector new materials are also meeting the demands in advanced materials technology. Growth areas include silica products, semi-finished natural graphite products and synthetic diamonds.

Demand by high technology industries for existing metals and minerals

Technological innovations outside the industry have also created new demands for currently mined metals. To list a few, copper is essential for integrated circuits and high-efficiency motors. Gold is a crucial component for sensitive electronics and high-technology products such as satellites and scientific instruments. Titanium is necessary for aircraft engines and supersonic aircraft airframes which must withstand temperatures up to 400^{oC}. Mica is an instrumental element for advanced industrial materials. Tantalum is used in cellular phones, computers, pagers, capacitors, artificial joints, super-alloys in jets. As an alloy it creates hard tools for cutting and special glass. Consider the combination of newly developed and existing metals used in the space-age innovation, CanadArm 2. (Table 9) The “top ten” metals produced in Canada are widely used in the high-tech industries. (Table 10)

Table 9 Some metals used in the Space Station Remote Manipulator System – the CanadArm 2

Material	Applications	Benefits
Precipitation hardening stainless steel Austenitic Stainless steel Martensitic stainless steel	Gears Shafts/business Components Fasteners	Low corrosion/stress corrosion Weldable High Strength
Nickel base alloys	High-strength fastener	
Titanium base alloys Aluminum alloys	Housings	Strength/weight ratio
Gold	Thermal blankets Hi-rel components Wire	Size shrinkage – needless metal
Nickel	Hi-rel components wire	Crimpability
Silver	Wire	Solderability
Aluminum	Hi-rel components	Major trend to copper interconnects
Chromium Platinum	Hi-rel components	Less “packaging”, less metal
Brass	Connector	
Copper	Circuit boards Hi-rel components Wire	
Lead/tin (silver)	Hi-rel components Board assembly	

Source: Macdonald Dettwiler (2001)

Table 10 Some hi-tech uses of Canada’s ten leading metals

	Characteristics of metals	Use of metals/alloys
Gold	B never rusts B benign to all natural environments B among the most electrically conductive B most ductile of all metals (can be made into tiny threads and very thin sheets) B most reflective and least absorptive material of infrared energy B protects from high temperatures	B 35% gold alloy used in the main engine nozzle of the Space shuttle, where temperatures reach 3300^0 C B printed circuit boards have gold circuitry B protects on-board computers from heavy ion bombardment on Galileo space probe B hair-thin gold wires process broadcast signals in microcircuitry of TV and Cable B gold compact discs create the perfect error free sound B infrared properties used in night-time security cameras B gold-coated acrylic windows help eliminate frost B catalytic properties can turn hazardous gases into harmless gases

	Characteristics of metals	Use of metals/alloys
(Table 10 cont'd) **Nickel**	B resistance to corrosion B high strength B suitable alloying agent	B aerospace industry leading consumer of nickel-base superalloys B electromagnetic shielding B extra fine nickel powders used in capacitor chips B nickel foams enhance nickel metal hydride batteries used in hybrid cars B highly pure nickel oxide a component of ferrite, an input in electronic components in cell phones B micro turbines made from nickel alloys run on methane from decomposing landfill sites B micro-electrical mechanical systems (MEM) used in sensors to detect chemical and biological weapons
Zinc	B reactivity with steel B corrosion resistant B electrochemical properties B low melting point B fluidity and ductility B strength B suitable alloying agent B essential nutrient B healing properties B zinc oxide withstands extreme temperatures and ultraviolet exposure	B fingerprinting process using vacuum metal deposition can raise fingerprints years later B water purification from high purity zinc-copper alloy B zinc oxide varistors provide circuit protection B zinc-air batteries used in cell phones, laptop computers B ductile zinc cladding protects electrical umbilical lines on remote offshore oil rigs B zinc-oxide thermal coating protects antenna system on Cassini space probe during its 7-year voyage to Saturn
Iron Ore	B steel is strong, durable and extremely versatile B iron and steel least expensive of world's metals B iron oxide yields nontoxic, non-bleeding weather resistant and lightfast pigments	B radioactive iron (iron 59) in medicine B iron tracer element in biochemical and metallurgical research B stainless steel tanks used in "green" non-toxic dry-cleaning technology B iron oxide used to make layered materials (magnetic and non-magnetic) for high-density magnetic data storage, and focusing elements for neutron beans
Copper	B excellent thermal and electrical conductor B good tensile strength B relatively high melting point B resistance to corrosion B ductile: can be drawn into wire or long, flexible rolls	B electric cables and wires, switches in telecommunications B electroplated protective coating and undercoats for nickel B new computer chip (called the Coppermine) has higher clock speeds and lower power consumption B new alloy with 3% beryllium particularly vibration resistant

	Characteristics of metals	Use of metals/alloys
(Table 10 cont'd) Uranium	B hard B high density B radioactive	B nuclear medicine – radioactive chemical tracers, radiotherapy atomic dating B powering nuclear submarines
Silver	B superconductive (thermal and electrical) B light B high optical reflectivity B catalytic properties Bsilver halides are photosensitive	B electronics because of high conductivity B linings for chemical reaction vessels B light, compact superconducting cables B silver zeolite coating on steel creates an anti-microbial surface for self-cleaning and bacterial-resistant homes
Platinum metals	B outstanding catalytic properties B wear and tarnish resistant B resists chemical attack B excellent high temperature characteristics Bstable electrical properties	B catalysts for control of automobile emissions B bushings for making glass fibres used in fibre-reinforced plastic B electronics, in multi-layer ceramic capacitors (MLCC) B in conductive and resistive films used in electronic circuits
Lead	B soft, malleable B low melting point B high resistance to corrosion B high density (shield against radiation and sound waves)	B non SLI batteries provide stationary sources of power in uninterruptible electric power systems for computer and telecommunications networks B TV tubes and glass, computer screens to protect from radiation B X-ray and gamma ray shielding B load-levelling equipment for electric vehicles
Cobalt	B imparts wear resistance and heat resistance to alloys B magnetic	B superalloys for jet engines B chemicals (paint dryers, catalyst, magnetic coatings) B permanent magnets B cemented carbides for cutting tools

Sources: : National Mining Association, Paydirt (June 2001), Minerals Council of Australia, Pocket Guide to World Zinc (2000), US Geological Survey, Techbeat (1998)

Technology transfers among sectors

Mining innovations draw on new technologies from the medical, space and military fields. For example, the Geological and Environmental Mapping (GEM) system is an information technology using airborne imaging that will create a knowledge base relating to surface oil detection. This will be used for exploration, development, environmental monitoring and pipeline planning. The same technology will be used for complementary activities such as emergency disaster response planning and geohazard mapping. A consortium of mining companies, the Canadian Space Agency and Canadian Centre for Remote Sensing, are cooperating on the project, which is expected to be completed by the end of 2001.

Reverse technology transfers are also occurring. The Canadian Mining and Metallurgical Bulletin (2001) reports that a zero-gravity drill is being developed in Sudbury's Northern Center for Advanced Technology by a consortium of companies. The space community will be able to apply this technology to extract samples from extraterrestrial bodies . Once the technology is tailored to space exploration, the particular features – fully autonomous operation and time lags between command and execution – could have further applications to deep sea exploration.

5.2 Suppliers of Mining Goods and Services

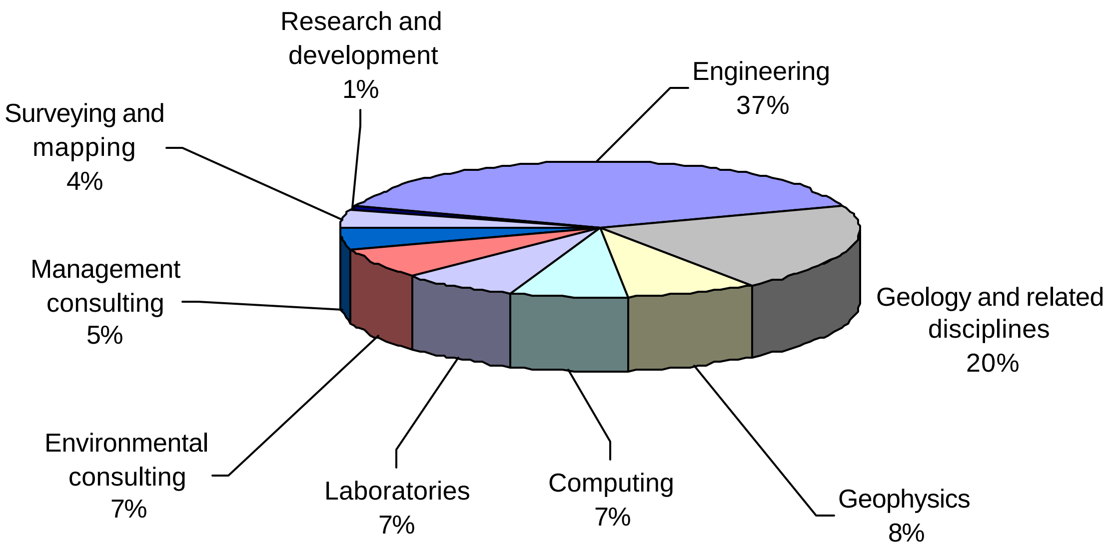
Small and medium-sized businesses are often limited in their ability to market new technologies. They may lack the economies of scale to succeed in relatively small domestic markets and may not have the contacts or resources to expand into global markets. The mining sector has provided a launch for SMEs both domestically and globally. When mining companies compete globally in diverse world markets, the industries serving them tend to target the countries where the company locates and are able to increase their own international competitiveness and market access. The worldwide market for goods and services to operate existing mines is about US$200 billion annually and to build new mines is about US$50 billion, and for mineral exploration about $3 billion.

Natural Resources Canada (2000b) reports that most of the goods and services demanded by mining companies are specialized products that are largely technical or scientific. Over 2,200 firms based in Canada supply specialized mining goods and services. Goods account for 55 percent of the sales and services 45 percent. The market is rapidly expanding: revenues from the sale of specialized products to mining companies rose 15 percent between 1996 and 1997. The global demand is also growing rapidly and a disproportionate share of business is going to Canadian mining suppliers. Exports account for 30-50 percent of Canadian suppliers' revenues, having increased about 25 percent between 1996 and 1997.

Almost one-quarter of suppliers of specialized mining products are engineers, geologists, geophysicists geochemists or those in related disciplines. Of the industries comprising 95 percent of the professional, scientific and technical services sector, the largest group is engineering, followed by geology and related disciplines. (Figure 8)

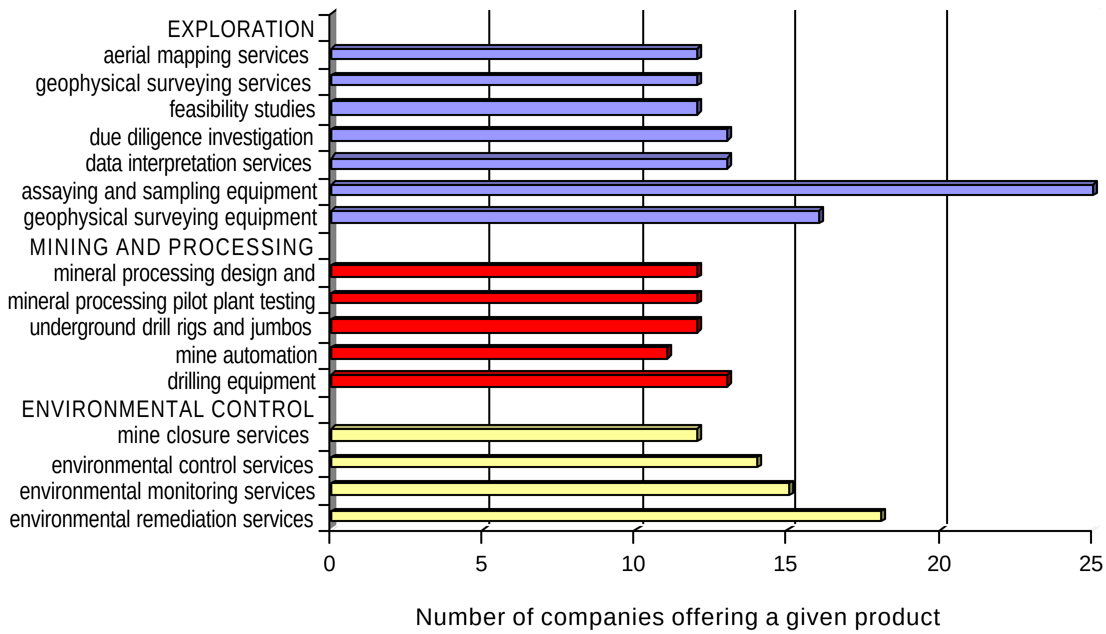
Figure 8
Canadian Suppliers of Specialized Mining Goods and Services:
Industries comprising 95% of professional, scientific and technical services sector

Source: Natural Resources Canada (2000b), 30



Canadian suppliers of specialized mining goods provide high technology goods and services in exploration, mining and processing and environmental control. In exploration, companies supply high technology geophysical and aerial mapping equipment and services as well as expertise in feasibility studies and data interpretation. Mining and processing involves design and pilot plant testing and equipment in highly automated drill rigs and jumbos, reflecting the move of many mining companies to outsourcing as communications have improved. Greater integration of systems allows vendors to communicate with the plant's own systems, making technology modules more flexible and outsourcing more common. Environmental control, monitoring and remediation services are also out-sourced. (Figure 9)

Figure 9
Canadian Suppliers of Specialized Mining Goods and Services:
Leading products ranked by number of suppliers



Source: Natural Resources Canada, based on CAMESE compendium of Canadian Mining Suppliers, 1999-2000, September 1999

Canadian mining suppliers are developing a world class geoscience infrastructure**.** NRCan (1998b) reports that more than 40 firms based in Canada provide geophysical services or supply geophysical equipment to domestic or overseas market. Canadian companies hold 70 percent of world markets for airborne geophysical equipment. Canadian geophysical equipment manufacturers, software developers and data interpretation companies have captured 60 percent of world market share.

5.3 Global Linkages

The 1998 study by Baldwin and Sabourin concludes that the technological disadvantage that many Canadian firms face can be ascribed primarily to smaller-sized plants and smaller-sized markets. Large firms have the resources to become better informed about new technologies, are more likely to have the technical and financial resources to acquire technologies and have the production processes that tend to enable the adoption of state-of-the-art technologies. Market expansion is an important factor because small markets will not be cost-effective if efficiency gains require long production runs. Thus by expanding globally, the mining industry has overcome this important limitation to adopting new technologies.

Exports in the minerals and metals sector reached $49 billion in 2000, 13 percent of total Canadian exports. Metals account for over three-quarters of total minerals and metals exports. Iron and steel are the largest export by value, followed by aluminum and gold. About 80 percent of Canadian minerals and metals production is exported .

Mining investment abroad in new technologies

Brewer (2000) identifies the relationships between globalization and new technologies for mining companies and their suppliers. Globalization involves the coordination of operations across countries and the greater information exchange with foreign suppliers and consumers. Because investments are more mobile, there is a constant search for ways to become more competitive. Globalization has occurred as world economies become more open and factors of production become more mobile. Global communications networks allow easier management and oversight of overseas operations and synergies to develop.

Mining companies who acquire deposits abroad are able to strengthen and diversify their companies. Canadian direct investment abroad has almost tripled from about $13 billion in 1990 to over $36 billion in 1999. Mining makes up about 60 percent of Canadian direct investment abroad (CDIA) in natural resources. (Brewer, 2000) Between 1992 and 1999, the number of mineral properties held abroad by companies listed on Canadian stock exchanges grew at an annual average compound rate of 12 percent.

Investment abroad encourages exports of machinery and other capital goods, intermediary products and know-how and specialized services. Canadian mining companies as well as companies that sell goods and services to Canadian mining companies are becoming dominant players in the world's mining and metals industries. Canadian mining companies who invest abroad often continue to do business with backward linkage industries. The OECD estimates that each $1 of foreign direct investment generates $2 in exports and $1.70 in a trade surplus. Suppliers who export to Canadian mining companies abroad from their Canadian base also begin to invest abroad themselves. For example, the Antofagasta region of Chile has grown rapidly in part because of Canadian mining investments and in part because of the growth of Canadian suppliers of mining goods and services.

New technologies at international pilot plants

One way to minimize shareholder risk of developing innovations is through the use of pilot plants. Inco's Goro Pilot Plant in New Caledonia is introducing new technology in nickel-cobalt while providing an excellent training ground for new workers. Inco plans to proceed with a US$1.4 billion project and commence production in 2004. The pilot project tested the mmercial feasibility of Inco's proprietary hydro-metallurgical and solvent extraction process. It will also use an environmentally sensitive land disposal system for tailings and extensive revegetation of mining areas. The new technology and training allows for high productive projects that can supply products to customers in South Korea, Taiwan and possibly China.

Exploration abroad and financial sector linkages

Canadians hold the largest share of the global exploration market in Canada, United States, South America, Central America and Europe – and Canadian financial markets have reaped the benefits. Canada has emerged as a world centre for mining finance. Canadian financial markets are now the main sources of equity financing for global mineral development. Almost three-fifths of the equity financing of mining companies was raised or organized by Canadian companies in 1999. As mining becomes more global, financial markets follow. Canadian securities companies and stock exchanges are making connections worldwide to promote the availability of financing.

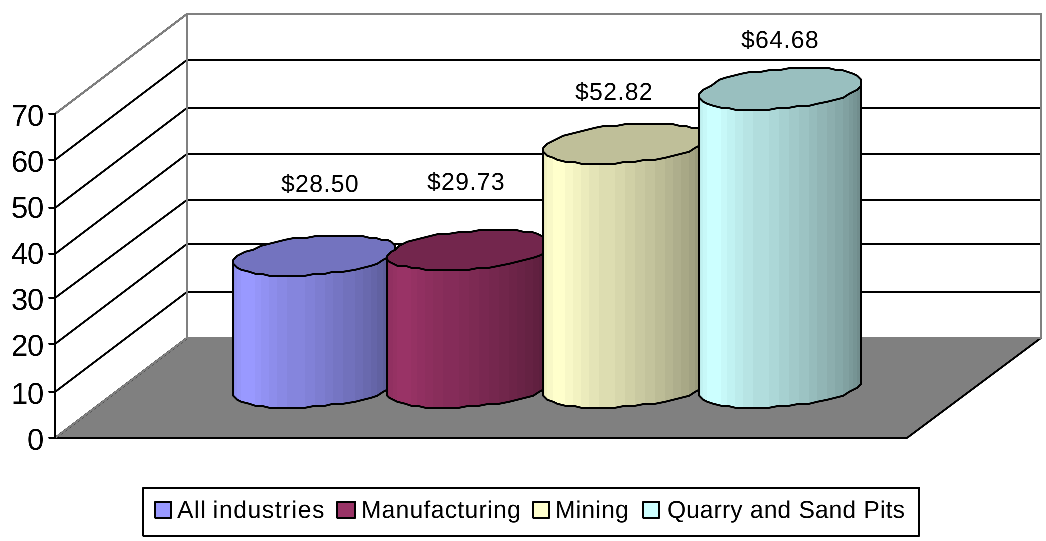
6 HIGH-TECH MINING AND CANADIAN PROSPERITY

6.1 Value-Added to the Canadian Economy

The value-added imparted by an industry sector is the difference between the value of the outputs and the value of the inputs, or the economic benefit from the further processing and manufacturing of minerals and metals. In 1998, mining and quarries in Canada were among the top ten contributors to GDP per hours worked, creating respectively $53 and $65 ($1992) of GDP per hour of work. This is about twice the all-industry average of $28. (Figure 10)

6.2 High Wages and Prosperity

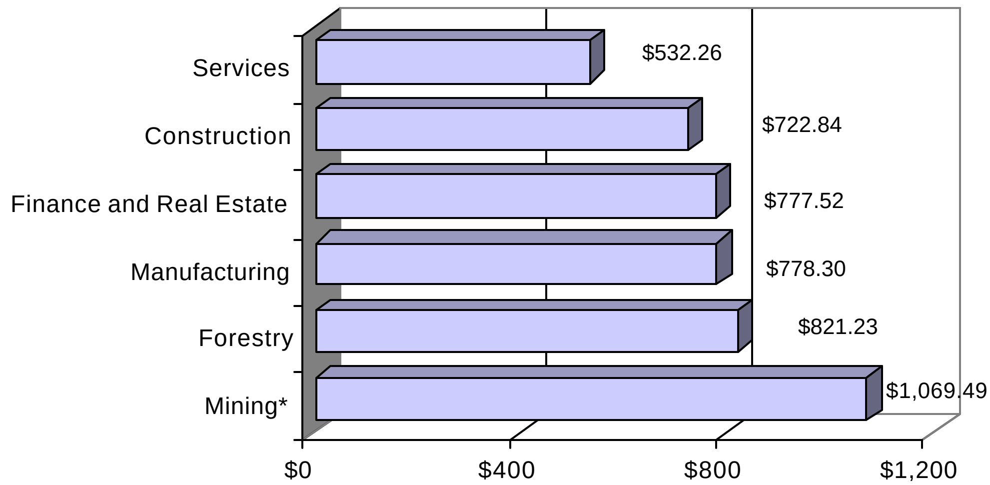
Figure 10
GDP per hour by industry ($1992)
Source: Centre for the Study of Living Standards



High labour productivity in the mining sector is reflected in wages and salaries, which are the highest of any industry in Canada. The Canadian mining industry paid approximately $4.3 billion in wages in 2000. Average weekly earnings were $1,069 in 2000 in mining and nonferrous smelting and refining, 40 percent higher than the $723 earned in construction and almost twice the $532 earned in the services sector. Three of the ten industries with the highest paid employees in Canada below to the Minerals and Metals Sector - Mineral Services, Mining and Primary Metals. (Figure 11)

Figure 11
Average Weekly Earnings by Industrial Division, 2000

Source: Statistics Canada, Labour Division



*Excludes crude petroleum and natural gas; includes quarries and sand pits and smelting and refining

6.3 Impact of Mining on the Rest of the Economy

Backward linkages

Mining production and investment generate direct demand in supplier industries and additional demand as ensuing rounds of expenditures work their way through the economy. In *Rock Solid*, Dungan (1997) uses 1992 input-output data to estimate the impact of the Canadian mining and primary metals industry (basically, Stage I and Stage II mining) on supplier industries. He finds that $1 billion of output in mining and primary metals directly increases the demand for goods and services in Canada by $615 million. Of this, $288 million comes from the mining sector, suggesting that there is a strong degree of vertical integration in mining and metals. When the subsequent rounds of expenditures are also taken into account, the $1 billion of mining and primary metals output increases demand by $839 million, of which $589 million comes from sectors other than mining.

The mining and primary metals industry also demands goods and services for investments in exploration, mine development and plant and equipment. Dungan estimates that $1 billion of investment in mining and primary metals directly increases demand for goods and services by $993 million. The full increase in demand, taking into account subsequent rounds of spending, is $1.3 billion.

Communities across Canada depend on the demand for goods and services from the mining sector. Natural Resources Canada (2000b) reports that domestically about 150 communities are heavily reliant on mining, and many are located in remote and rural areas. It is the backbone of many northern communities where First Nations people reside. Since mining companies tend to purchase over one-third of supplies and materials from suppliers within an 80 - kilometre radius of their operations, they become an engine of growth for local companies. As the mining industry adopts new technologies it requires more high-tech goods and services from the communities.

Forward linkages

Dungan's Input-Output analysis shows that a wide range of Canadian industries depend moderately on mining and primary metals inputs. Because the mining and primary metals sector has strong vertical integration, some of the strongest forward linkages are within the industry itself. The Input-Output analysis also shows significant linkages to a variety of machinery and transportation equipment sectors as well as cement, concrete products and road highway and airstrip construction. As mining productivity improves and competitiveness increases, these industries benefit from lower costs and higher quality of mining and primary metals products.

7 POLICY CONSIDERATIONS

If the Canadian minerals and metals sector is to remain a world leader in the new economy it must continue on a path of innovation. This can only be achieved by ensuring Canada's fiscal and policy frameworks remain competitive and by removing the disincentives to innovation and investment. The following recommendations would advance these objectives:

1. *Explicitly recognize the economic and strategic importance of Canada's mining industry.*

   Mining surpasses other industries in large part because it has transformed into a high-technology resource sector. It is a paradox, then, that mining has been miscast as part of the "old" economy because it is resource-based. The danger of creating the false dichotomy between "old" and "new" is that governments may direct an industry strategy toward what they perceive to be the "new" economy winners to the detriment of all companies that must meet the competitive challenge. Ironically, this could hamper the very innovation governments are trying to encourage. The economic and strategic importance of the mining industry should be considered when the federal government crafts its innovation policy.

2. *Ensure that a sound, progressive globally competitive policy framework is maintained.*

   The federal government has contributed to an innovation-friendly environment by adopting macroeconomic and structural policies that have created a framework for solid economic growth and more investment certainty. Meanwhile, foreignjurisdictions have become more tax competitive and our current domestic tax regime is losing ground.

   Corporate tax cuts have a clear impact on investment, productivity and economic growth if they are applied in a balanced and fair way across industries. Excluding mining from the recent federal corporate tax rate cut sends a negative signal because there is an assumption that mining already benefits from selected incentives in the current tax system and thus has a lower effective tax rate. The Resource Allowance is not an incentive: it was put in place to compensate for provincial mining taxes and royalties. A repeal of the Resource Allowance in exchange for a 21 percent corporate tax rate would leave the industry worse off. Furthermore, the Accelerated Capital Cost Allowance and Canadian Exploration Expenses reflect inherent risks of large capital investments and exploration that occur in the mining sector.

Federal and provincial governments collect $4.8 billion annually in capital taxes. Capital taxes, such as the Large Corporation Tax, are profit-insensitive because they apply to the asset base of corporations rather than to profits. Capital taxes make R&D and exploration more difficult to fund because the taxes cut more deeply into profits or add to losses during downturns, an important concern for mining because it is highly cyclical. Capital taxes also punish innovation by taxing investments in new technologies. An inconsistency in Canada's innovation policy is thus created: the early stages of innovation are encouraged through generous tax credits on R&D but the adoption of innovation is discouraged with the capital tax. Mining is doubly affected because of its high level of investment and innovation and because mining and smelting companies tend to be large. Other profit-insensitive taxes such as payroll taxes, property taxes and user fees also discourage innovation in the mining sector.

While discussions continue on these important issues, Canada's tax competitiveness is eroding. Reform is needed now. The federal government should:

- extend the corporate tax reduction that was announced in the 2000 Budget to the mining sector and preserve the current federal tax provisions provided to the minerals and metals sector.
- eliminate the Large Corporation Tax;
- take a broader view of tax policy and initiate tax reform discussions with the provinces and territories. Work toward reducing corporate and mining tax rates in provincial jurisdictions and encourage the elimination of capital taxes in these jurisdictions.

3. *Look at ways to partner with government to advance the federal "innovation agenda"*.

Some lessons to take from the recent staggering decline in technology stocks are that no one sector can be counted on to generate a country's prosperity and that pre-selecting industry champions is a difficult thing to do. The government has made progress in creating a framework where "new economy" industries and government can form dynamic partnerships to advance the innovation agenda. The agenda will be advanced further when all "high-tech" industries contribute, including major high-tech innovators like the Canadian mining industry.

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