# RESEARCH AND DEVELOPMENT IN THE MINERAL SECTOR


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# FOREWORD

This study is designed to examine funding trends in research and development (R&D) in the mineral sector in Canada. The activities of federal and provincial governments, industry, and universities in mineral–related R&D are included. The relevance of mineral–related R&D is considered in the light of the economic importance and probable future of the mineral sector, in order to evaluate the current funding trends. Comparisons are made with other academic disciplines and resource sectors in Canada, and with mineral R&D and the mineral industry in seven other Organization for Economic Cooperation and Development (OECD) countries. The OECD countries considered are Australia, Finland, France, the Federal Republic of Germany, Sweden, the United Kingdom and the United States. These countries have different approaches and attitudes towards R&D in general, and towards mineral R&D in particular, largely because the mineral sector plays differing roles in their economies. Comparisons with them will provide Canada with useful insights into its mineral sector R&D funding needs.

Where possible, the themes and conclusions are buttressed by statistics. However, it quickly became obvious in the course of this study that there were no easily derived data that encapsulated the various themes or allowed quick conclusions. As far as possible, data used were from published data sources. These sources were supplemented by special compilations, interviews, on–site visits and correspondence on a limited basis. Strong reservations must be noted about these fragmented data, and caution should be taken in their use as a guide for policy formulation. It is essential that the reader take into consideration:

- the reliability and consistency of published R&D data (which in many cases are questionable);
- the economic context, impact and stage in the life cycle of the mineral industries studied, and the jurisdiction in which policy initiatives are being considered.

Simple statistical analysis and manipulation of R&D data will not provide easy answers to policy questions. Critical evaluation and judgement based on understanding are far more important inputs to the policy process. Data are merely raw materials. It is hoped that this study will provide reasonably reliable data for some of these raw material needs. The study is also designed to provide some understanding of the relationships and dynamics involved in the economics, politics and technological evolution of the mineral sector, and the role of R&D in this process.

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# SUMMARY OF CONCLUSIONS

Canada has the potential for good long-term development of its mineral resources, and needs to maintain a competitive position for crude minerals in export markets. Therefore, Canada should strongly support the mineral exploration and mining sectors. This conclusion is reinforced by the finding that most of the other countries in this study, which represent much of the world's mining technology and mining education expertise, are in or are approaching the decline phase of their mining industries' life cycles. They are also dependent on imported crude minerals, and are turning their R&D focus away from primary resources towards substitution and efficiency in the use of raw materials. This pattern of R&D focus is not appropriate for Canada, although it is in fact being followed.

Canada should stress R&D in extractive metallurgy with a special emphasis on environmental and health aspects and on conservation of energy. This can give Canada a comparative advantage in smelting and refining over the United States and Western Europe, where the cost pressures resulting from dependence on raw materials and energy and from environmental controls make such R&D investments relatively unattractive.

Canada should make special efforts to compensate for and reduce the negative effects of the prevalent separation of scientists and engineers from management and formulators of public policy.

These three initiatives, if adopted, should help Canada to realize the benefits of its mineral endowment, to keep its mineral sector viable for the long term, to take advantage of opportunities arising from the decline of the primary mineral sectors in other countries, and to avoid being left behind by newly emerging countries with mineral potential.

The views expressed in this report and in the background study are those of the author and not necessarily those of the Centre for Resource Studies and its sponsors, or of The Canada Centre for Mineral and Energy Technology (CANMET).

# RÉSUMÉ DES CONCLUSIONS

Le Canada possède le potentiel pour développer, à long terme, ses richesses minérales et demeurer compétitif sur les marchés d'exportation de produits de base. Par conséquent, le pays doit subventionner la recherche et le développement (R–D) dans le domaine de l'exploration minérale et de l'exploitation minière. Cette conclusion se fonde sur le fait qu'il y a raréfaction des ressources et déclin de l'industrie minière dans la plupart des pays mentionnés dans ce rapport, bien que leur compétence en ce domaine soit reconnue à l'échelle internationale. Ces pays dépendent sur les importations de produits de base et s'orientent davantage vers l'identification des produits de substitution et l'utilisation plus efficace des matières premières. En raison de ses abondantes richesses naturelles, le Canada devrait suivre une voie différente.

Une importance accrue doit être accordée aux activités de R–D en métallurgie extractive tout en favorisant des mesures portant sur la protection de la santé et de l'environnement et la conservation de l'énergie. De cette façon, les secteurs de la fonderie et du raffinage seraient avantagés par rapport à ceux des États–Unis et de l'Europe de l'Ouest où une forte augmentation des coûts en raison de la pénurie de matières premières et de ressources énergétiques, et des mesures imposées pour la protection de l'environnement font que de tels investissements en R–D sont peu attrayants.

Au Canada, des efforts devraient également être faits pour modifier la politique actuelle qui maintient les scientifiques et ingénieurs à l'écart de la gestion et de la formulation des politiques gouvernementales.

Si ces trois initiatives étaient approuvées, le Canada serait en mesure de mettre en valeur ses richesses minérales et d'assurer, à long terme, la rentabilité du secteur minéral. Il pourrait répondre à la demande de produits de base des pays étrangers dont les secteurs primaires sont en déclin, et faire face à la concurrence des pays qui sont en voie de développer et de mettre en valeur leurs richesses minérales.

Les opinions exprimées dans ce rapport et dans la documentation de base sont celles de l'auteur et ne peuvent, en aucun cas, être attribuées au *Centre for Resource Studies* ou à ses commanditaires, ou au Centre canadien de la technologie des minéraux et de l'énergie (CANMET).

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Although grateful for all the advice, information and help, the author accepts responsibility for the opinions expressed and conclusions reached, and for the interpretation of the source documents in Swedish, Finnish, German and French.

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# CONTENTS

FOREWORD .......... i

SUMMARY OF CONCLUSIONS .......... ii

RÉSUMÉ DES CONCLUSIONS .......... iii

ACKNOWLEDGEMENTS .......... iv

CHAPTER 1 INTRODUCTION .......... 1
- Purpose of the Study .......... 1
- Organization of the Study .......... 1
- Definitions and Scope of the Study .......... 2
- Data Sources and Use .......... 4

CHAPTER 2 A FRAMEWORK FOR THE ANALYSIS OF R&D ACTIVITY .......... 8
- The Framework .......... 8
  1. Stages in the Mineral Industry Life Cycle .......... 7
  2. Import–Export Dependence .......... 9
  3. The Economic and Sociopolitical Environment .......... 10
  4. The Cultural Factor .......... 11

CHAPTER 3 MINERAL–RELATED R&D AND THE MINERAL SECTOR IN CANADA .......... 13
- Introduction .......... 13
- The Mineral Sector: An Economic Measure of the Importance of Mineral R&D in Canada .......... 13
- Federal R&D Support for the Mineral Sector .......... 15
  - Intramural Federal Government Funding .......... 17
  - Extramural Federal Government Funding .......... 17
- Provincial Government Support for Mineral R&D .......... 18
- Industry Support for Mineral–Related R&D .......... 19
  - Mineral R&D Expenditures by Industry .......... 20
  - Industry R&D Organizations .......... 20
- Trends in Education .......... 23
  - Trends in Canadian Education .......... 23
  - Education in Mining and Metallurgy .......... 23
- R&D in Selected Scientific Disciplines .......... 24
  - R&D in Universities .......... 24
  - Comparison of R&D Trends in Selected Disciplines .......... 26
  - Mineral R&D in Universities .......... 27
- Comparison of R&D Expenditures in Other Resource Sectors .......... 27
  - Economic Contribution of the Resource Sectors .......... 29
  - Overview of Resource Sector R&D .......... 29
  - Sector–Specific R&D Data .......... 35
- Conclusion .......... 36

CHAPTER 4 INTERNATIONAL COMPARISONS: THE ECONOMIC CONTEXT .......... 39
- Stage in Life Cycle .......... 39
- Import–Export Dependence .......... 43
- Conclusion .......... 44

| | | |
|---|---|---|
| CHAPTER 5 | INTERNATIONAL COMPARISONS: POLICIES AND ATTITUDES | 49 |
| | R&D in Canada | 49 |
| | R&D in Other Countries | 50 |
| | Australia | 50 |
| | Finland | 51 |
| | France | 51 |
| | Federal Republic of West Germany | 52 |
| | Sweden | 53 |
| | United Kingdom | 53 |
| | United States | 54 |
| CHAPTER 6 | COMPARISONS OF NATIONAL R&D EFFORTS | 55 |
| | Total R&D Effort | 55 |
| | Mineral-Related R&D | 59 |
| CHAPTER 7 | CONCLUSIONS AND RECOMMENDATIONS | 63 |
| | Introduction | 63 |
| | R&D Statistics | 63 |
| | Stage in the Life Cycle | 64 |
| | Import-Export Dependence | 65 |
| | Economic, Social and Political Factors | 65 |
| | The Cultural Factor | 66 |
| BIBLIOGRAPHY | | 67 |
| APPENDIX A | SUMMARY OBSERVATIONS FROM BACKGROUND STUDIES | 75 |
| | Australia | 75 |
| | Finland | 76 |
| | France | 77 |
| | Federal Republic of Germany | 78 |
| | Sweden | 79 |
| | United Kingdom | 80 |
| | United States | 81 |
| APPENDIX B | PRICE INDICES, EXCHANGE RATES AND THE CANADIAN STANDARD INDUSTRIAL CLASSIFICATION OF THE MINERAL SECTOR | 83 |
| | Table B.1 Classification of the Mining, Basic Metals and Nonmetallic Mineral Products Industries According to the 1980 Standard Industrial Classification | 83 |
| | Table B.2 Implicit GDP/GNP Price Deflators, 1975–88 | 84 |
| | Table B.3 Exchange Rates, Various Years | 84 |
| | Table B.4 Comparison of Canadian Price Indices, 1981–87 | 85 |
| THE CENTRE FOR RESOURCE STUDIES | | 87 |

# TABLES

Table 3.1 Federal Intramural and Extramural R&D Support for Mining and Metallurgy, 1986–87 ... 16
Table 3.2 Summary Estimates of Provincial Mineral-Related R&D Expenditures, 1986–87 ... 19
Table 3.3 Mining and Metals Industry Total Intramural R&D Expenditures, 1979 and 1981–86 ... 22
Table 3.4 Indicators of Support for Mining and Metallurgy in Universities, 1980 and 1986 ... 25
Table 3.5 Comparison of Graduate Enrollment and NSERC Grants in Natural Sciences and Engineering Disciplines ... 27
Table 3.6 Summary of Major Resource Sector R&D Funding ... 32
Table 4.1 Measures of Mineral Industry Economic Activity: GDP, Value of Mineral Production and Exploration Expenditures ... 40
Table 4.2 Trade and Employment Impacts of the Mineral Sector ... 45
Table 6.1 Total National R&D Effort ... 58
Table 6.2 Indicators of Mineral Sector R&D Activities ... 60

# FIGURES

Figure 2.1 A framework for the analysis of research and development expenditures ... 7
Figure 3.1 Contributions of the mineral sector to GDP, 1980–87 ... 14
Figure 3.2 Share of mining in regional GDP and in total mine production, 1984 ... 14
Figure 3.3 Importance of the mineral industry in the Canadian economy, 1980–87 ... 15
Figure 3.4 EMR science and technology funding by recipient, 1980–81 – 1987–88 ... 16
Figure 3.5 R&D intensity in selected Canadian industries, 1986 ... 21
Figure 3.6 R&D intensity in the mineral industry, 1986 ... 21
Figure 3.7 Mining and metals industry intramural R&D expenditures, 1980–87 ... 22
Figure 3.8 Trends in university operating income, 1980–81 – 1985–86 ... 24
Figure 3.9 Sponsored research income, GDP and university operating income, 1980–81 – 1985–86 ... 26
Figure 3.10 Distribution of full-time graduate students by field of study, 1980–81 – 1985–86 ... 28
Figure 3.11 Distribution of full-time graduate students in natural sciences and engineering, 1980–81 – 1985–86 ... 28
Figure 3.12 Contribution of the resource sectors to total GDP, various years ... 30
Figure 3.13 Contribution of the crude resource sectors to total GDP, various years ... 30
Figure 3.14 Contribution of the resource sectors to total GDP and total industry R&D, 1987 ... 31
Figure 3.15 Contribution of the primary resource sectors to total GDP and total industry R&D, 1987 ... 31
Figure 4.1 Mineral industry GDP as a percent of total GDP, 1985 ... 47
Figure 4.2 Value of mineral industry GDP, 1985 ... 47
Figure 4.3 Mineral industry employment as a percent of total employment, 1985 ... 48
Figure 4.4 Importance of mineral sector exports, 1985 ... 48
Figure 6.1 National R&D effort, 1985 ... 56
Figure 6.2 Business R&D effort, 1985 ... 56
Figure 6.3 Performance of R&D by institutions of higher education, 1985 ... 57

# CHAPTER 1. INTRODUCTION

## PURPOSE OF THE STUDY

This study was undertaken for CANMET. It attempts to create an understanding of funding trends in mineral R&D and of the importance of R&D to the mineral sector. This task involved:

- providing information on trends in the level, sources and focus of R&D funding in the mineral sector in Canada;
- setting this information in context by providing information on the role of R&D in the mineral industry, and on the role of this industry in the Canadian economy;
- providing information on trends in education in mining and metallurgy in Canada;
- comparing R&D trends in mining and metallurgy in Canada with trends in other disciplines;
- comparing the mineral sector and its R&D with other resource sectors in Canada;
- comparing the above information with similar data on mineral R&D activity in seven OECD countries: Australia, Finland, France, the Federal Republic of Germany, Sweden, the United Kingdom and the United States;
- considering the data on levels of and trends in mineral R&D activity in light of the current and future needs of the mineral sector and in relation to how other sectors and countries have dealt with a changing economic climate and industrial structure.

## ORGANIZATION OF THE STUDY

A vast amount of material on mineral-related R&D activity has been compiled and summarized in this report. Eight background studies provide the basis for this study: seven reviews of R&D policy and mineral R&D in the OECD countries used for comparison purposes, and a detailed examination of the situation in Canada. These background reports are, for the most part, presentations of data with some analysis, but with little or no comparative treatment. The comparative analysis and assessment are provided in this volume. Readers are referred to the background studies for a more detailed look at the individual countries.

Chapter 2 of this study defines a four-part framework for the analysis and comparison of R&D needs and policy responses, and discusses the effectiveness and appropriateness of these reponses.

Chapter 3 provides a summary of the background study on Canadian mineral sector R&D and the mineral industry. A review of the role of this sector in the Canadian economy is followed by an examination of federal, provincial and industrial support for mineral-related R&D activities. Educational trends in the fields of mining and metallurgy are compared. Brief comparisons of R&D funding levels and other relevant factors for natural sciences and engineering disciplines other than mining and metallurgy, and for resource sectors other than the mineral industry, are provided.

Chapter 4 begins the analysis of mineral-related R&D with a discussion of the economic context, as illustrated by the first two factors in the framework. Canada's mineral industry is placed in the mature phase of its life cycle, and its import-export dependence is examined. Brief comparisons with the mineral industries in other countries are made, to provide a setting for analyzing R&D needs and policy actions.

Chapter 5 continues the analysis with a look at the third and fourth factors in the framework: the socioeconomic and policy context and the cultural factor.

Chapter 6 contains a comparison of mineral R&D in Canada with that in the seven other OECD countries considered. R&D levels and trends are examined in the light of the discussion in chapters 4 and 5, to see what lessons can be learned about future directions for mineral R&D activity in Canada.

Chapter 7 concludes the study using the framework of Chapter 2 to summarize the analysis of the later chapters. Recommendations are made for R&D action by governments, industry and universities to support a strong and competitive mineral sector.

One–page summaries of the international background studies are presented in Appendix A, and Appendix B provides foreign exchange rates, Canadian price indices and national GDP/GNP price deflators.

## DEFINITIONS AND SCOPE OF THE STUDY

**The mineral industry**, for the purpose of this study, comprises the mining and basic or primary metals industries. The nonmetallic mineral products industry is also considered, although with much less emphasis. The **mining industry** is concerned with the extraction of crude minerals, while the **basic metals industry** and the nonmetallic mineral products industry involve some degree of processing of crude minerals. Processing includes the smelting, refining, casting, rolling and extruding of nonferrous metals (including aluminum), the activities of iron and steel foundries, the production of pipes and tubes, and other primary steel production. Nonmetallic mineral products are chiefly potash, asbestos, clay and structural products, glass abrasives, and refractories, and do not include coal products. Physical metallurgy is included as well in some of the data series in this study, simply because it is often difficult to separate it from extractive metallurgy. The general intention, however, is to omit physical metallurgy from the study, largely because of the problem of isolating data on metallic materials from the category of materials research, which is increasingly where physical metallurgy data are found. For Canada, the companies engaged in the activities covered in this study are classified under the Statistics Canada Standard Industrial Classification (SIC) codes shown in Appendix B Table B.1. The other countries studied have similar classification schemes, at least at the aggregate industry levels of "mining", and "basic metal manufacturing". OECD statistics attempt to standardize broad industry classifications.

**Minerals**, for the purpose of this study, are metallic minerals and nonmetallics including coal, industrial minerals and structural materials. Oil and gas are not included in this study.

For purposes of this study, **R&D** is defined as "creative work undertaken on a systematic basis to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications".[1] This is the OECD definition and it appears that, for the most part, the foreign countries examined as part of this study adhere to it in their classification of R&D. Statistics Canada also uses the OECD definitions in its R&D surveys and data series. Essentially, this approach distinguishes between **science and technology** (S&T) activities and its subset, R&D. The broader S&T category is composed of R&D and RSA, the latter being **related scientific activities** which include education and training, other related S&T activities and other industrial activities. In applying these definitions, Statistics Canada collects and publishes data using the following categories:

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[1] OECD, *The Measurement of Scientific and Technical Activities* (The Frascati Manual), Paris. 1981, p. 25

- for federal government statistics, S&T and its two components, R&D and RSA;
- for industry statistics, R&D only;
- for education statistics, R&D only.

The RSA component of Statistics Canada data includes data collection (which for the mineral sector includes geological surveying) and information services (again for minerals, this includes maps, core libraries, mineral inventories and other data bases, and reports and publications).

For industrial R&D statistics, Statistics Canada relies on industry responses to a survey. Industry, however, tends to follow the Revenue Canada definition of R&D, reporting only those R&D expenditures that are eligible for special treatment under the Income Tax Act. As a consequence, some expenditures that might be considered routine upgrading of operations may be reported by industry as R&D, and some R&D expenditures may go unreported because they do not qualify for special tax treatment. On balance, it is difficult to determine whether industrial R&D expenditures in the mineral sector are under– or over–reported. This is a problem with respect to the foreign data as well.

Various measures of **R&D intensity** are possible, including R&D as a percent of value added or of GDP value, and R&D as a percent of value of production or sales revenue. The former measure is preferable, since it relates R&D effort more closely to each sector's real economic contribution. However, in some instances the second measure of value is the only one possible, given the R&D and economic data available by industrial category.

There are several commonly used **aggregate measures of R&D** effort. Gross expenditures on R&D **(GERD)** include expenditures from all sectors, including governments, business enterprises, institutions of higher education, other organizations and foreign sources. It is seldom possible to derive statistics of GERD broken down by industrial sector, since in most cases only the industry R&D data are provided by type of industry. Government data are categorized by socio–economic objective. GERD therefore can be used for international comparisons of overall national R&D expenditures, and for an overview of trends in national R&D intensity over time when presented as a percent of gross domestic or national product, but not for economic sector comparisons. The composition of GERD can be examined in terms of who provides the funds or who performs the R&D activity. A frequently used statistic is Business Expenditures on R&D **(BERD)** which may also have either a funding or a performing perspective. OECD sources and Statistics Canada only present intramural expenditures in their BERD series by type of industry. They also identify sectoral sources of industrial R&D funding (i.e., government, industry, other). The business sector in OECD data series includes both public and private sector enterprises.

A country is described as **export dependent** for a certain commodity or sector, if domestic production of the commodity or in the sector exceeds domestic requirements, and therefore current production levels depend on export markets for sales. The commodity or sector may also play a significant role in the trade balance, depending on the proportion of total exports it represents.

**Import dependence** refers to a situation where domestic production of a commodity or sector does not meet domestic requirements, whether for consumption or for processing and possibly for re–export.

The **time period** covered by this study is generally from 1980 to 1987. This period is very short for observing and analyzing economic trends, particularly for a sector such as mining, where lead times are so long. It is also not a typical period for the mineral sector, which showed an unusually strong beginning, followed by a severe deterioration of demand and prices for most commodities. However, this time period has been dictated by the availability of data, particularly for R&D expenditures. In some cases even less data are available, while in others, longer series can be assembled. As many data as possible have been assembled and are provided in the background studies. For consistency, a 1980–85 timeframe is generally used in this summary and synthesis volume. This reduces the timeliness of the data, but was dictated by data availability.

The **currency units** used in Chapter 3 to describe the Canadian mineral industry are constant 1981 Canadian dollars. Percent change is real change, based on 1981 dollars. For the international comparisons in the tables in chapters 4 and 6, 1985 U.S. dollars have been used. Percent change again is real, based on real domestic currency values. Appendix B contains the exchange rates that were used for currency conversions.

## DATA SOURCES AND USE

The principal data sources for Canada are published data prepared by Statistics Canada and by Energy, Mines and Resources Canada. In some cases, special tabulations of unpublished material have been received from these organizations as well. These sources are by far the most detailed and reliable of any available. The major drawbacks to their use are time lags in some of the data series, the lack or inconsistency of categories, and the confidentiality requirements which prevent detailed breakdowns of some types of information.

For the foreign studies, important published data sources included studies released by the OECD and other international organizations, government statistical agencies, and other government agencies including geological survey organizations and the appropriate ministries responsible for the mining and energy industries. A wide variety of additional published sources was used for qualitative and quantitative information, including government reports and publications, earth sciences journals and bulletins, and university and company reports.

Beyond these readily available published sources, CRS has obtained additional data by a number of methods. For Canada, original data were sought in four major areas: provincial government expenditures on mineral R&D activities; university activities related to mining and metallurgy; a special compilation from the Natural Sciences and Engineering Research Council (NSERC) on its support for mineral-related R&D; and R&D activities of mineral industry firms and organizations. While the detail of primary data makes them attractive, the lack of uniformity, and in some cases low survey response rates, are negative factors.

For the foreign country studies, the published data sources were supplemented by interviews and correspondence with industry, government, university and other representatives in each of the seven other OECD countries examined. These proved to be very useful, since they provided a good qualitative sense of R&D activity and of the role and future of the mineral sector which otherwise might have been obscured by examining statistics alone. They also provided access to additional data sources. Lists of interviews and correspondents are appended to the individual background studies.

In the course of collecting the background information and data for this study over the past two years, it has become apparent that R&D statistics, like most statistics and probably more than most, can be very misleading. When examining the data presented in this study, three factors should be kept in mind. First, the R&D expenditure data series that are widely available and comparable in methodology are relatively short (roughly 1980 to 1986) for establishing trends; they are not reliable, and they are in fact still not comparable in terms of quality, definitions and degree of statistical break down. Reported R&D expenditures differ between countries according to systems of reporting, tax law and government incentive programs.

Second, in order to make sense of the R&D expenditure data available, it is necessary to set them into the overall context of the economic role of the mineral sector in each country. Unfortunately, the period 1980–86 for which data are available, is hardly a typical one for the evaluation of long–term trends in the mineral sector.

Third, and most important, the R&D practices of other producers, however successful, cannot be transferred directly to Canada and expected to work here. They must be examined in the light of the needs they were designed to meet, and the economic, political and social factors that shaped them. Their relevance must then be assessed in the light of Canada's needs and special characteristics. Only then can the lessons learned be applied to remedy our weaknesses and to build on our strengths.

# CHAPTER 2. A FRAMEWORK FOR THE ANALYSIS OF R&D ACTIVITY

There are many possible approaches and levels of analysis in evaluating R&D policies and funding programs. This chapter outlines the approach of this study for using the data constructively, and for deriving lessons that Canadian governments and the mineral industry can learn from experiences in other places and other times. Much may already be intuitively obvious; however, few people have the luxury of time for the sort of systematic data collection and comparative analysis that is necessary to back intuition with supporting arguments. It is useful to create a simple framework for observation and analysis (Figure 2.1), by identifying four factors within each country that are particularly important determinants of the R&D needs of the mineral industry, of the policy responses triggered by those needs, and of the effectiveness of the responses. The four factors are:

- the stages in the mineral industry life cycle;
- import–export dependence;
- the sociopolitical environment;
- the cultural factor.

The first two factors are dominant in determining the mineral industry's needs, and influence the R&D responses as well. They are dynamic and interdependent; for example, for a mineral–exporting country, the winding down of the life cycle of a commodity or a branch of mineral production means falling exports, and possible eventual import dependency. These factors are also clearly measurable in quantitative terms. The third factor, a collection of economic conditions and social and political goals and policies unique to each country, shapes the R&D responses to the industry's needs, and affects the focus of the effort and the level and sources of R&D funding. It is more qualitative and elusive than the first two, but not impossible to describe usefully. The fourth, the cultural factor, is one of attitudes, and is an often unrecognized but crucial determinant of the effectiveness of the R&D responses. In some of its manifestations, such as percent of engineers in various sectors and levels of R&D and management, it can be measured. In general, however, it must be described qualitatively, and in terms of degrees, rather than absolutes.

Looking at past, present, and future mineral–producing countries in the light of these four factors, it is possible to see patterns of behaviour that can assist policy makers in reaching conclusions about opportunities and the necessary future direction for mineral industry R&D in Canada.

| DETERMINANTS | DETERMINED |
|---|---|
| stage in life cycle | R&D needs |
| import–export dependence | policy responses to needs |
| sociopolitical environment | effectiveness of responses |
| cultural factors | |

Figure 2.1 A framework for the analysis of research and development expenditures

## THE FRAMEWORK

### 1. Stages in the Mineral Industry Life Cycle

The mineral industry life cycle, for a single commodity or a range of commodities, follows a more-or-less continuous curve. Nevertheless, it is possible to divide the curve into sections over time. Four divisions are suggested here, arbitrary divisions that provide a useful basis for observation and for comparison: the initial stage, the early years of growth, maturity and decline.

*The Initial Stage*

This stage is now evident in the establishment of mineral production capability, principally for export, in a number of less developed countries that are frequently identified as threats or potential threats to Canadian mineral export markets because of their low-cost, high-grade deposits. It usually involves rapid growth of production and of exports of primary materials. The stage is generally characterized by dependence on imported technology and expertise to find the minerals and bring the deposits into production. Once a cash flow is generated, little of it is directed at reinvestment in R&D. Rather, it goes principally for debt repayment and for social and political priorities in other areas. Nor is there much domestic capability for R&D in the initial stage, since it takes time for a country to build up an infrastructure of skilled human resources, educational facilities, and scientific and professional organizations.

*Growth Stage*

The second stage is generally one of less dramatic but continuing growth and of building up domestic resources to replace foreign technology and skills. Development of domestic capabilities is not inevitable; some countries, particularly newly independent ones with a host of other overwhelming problems, do not seem to achieve much success in this. Others – and India, Brazil, China and other Pacific nations come to mind – initiate R&D efforts focused on productivity improvements. expansion of production, and expansion of markets for production in excess of domestic requirements. They establish university programs, R&D facilities, and mining and processing equipment manufacturing capability. Many have the assistance of international aid programs in these tasks. Deposits continue to be low-cost and high-grade because depletion effects have not yet been felt.

Unfortunately, none of the countries included in this study are in the first two stages of growth. Their addition would provide useful information to Canadian policy makers and R&D managers, since they are a growing source of competition, both in mineral production and in mineral technology. However, reliable economic and R&D data for most of these countries are not available in sufficient detail to allow worthwhile conclusions to be made.

*Maturity*

This is a stage of relative stability, with the potential for long-term slow growth . The term maturity is meant to connote full development rather than imminent decline. Depletion effects are countered by technological innovation. The length of time a country's mineral industry, or a branch of it, spends in this phase depends on:

- the size and quality of the mineral endowment;
- the effectiveness of mineral-related R&D;
- the quality of exploration and production technology;
- the rate of exploitation;
- and, on the demand side, markets and prices.

For major producers such as Canada and Australia, this stage can span decades, or even centuries. The mature industry's R&D needs are much more diverse and less clearly defined than in the earlier stages of rapid growth and expansion of market share. In addition to production and productivity, the goals of R&D expand to include health, safety and environmental protection, improvements in product quality, and the development of new products. The goals should also include long-term basic R&D aimed at major process and product innovation to maintain a competitive position in the event of depletion of more accessible higher-grade and lower-cost deposits.

Because this stage is long term and slow in growth, it is vulnerable to erosion by short-term mineral supply and demand cycles that overlap the long-term trend lines. As a result, production-related R&D needs may go relatively unrecognized, hampered by cuts in funding in hard times, and worse, by complacency in good times. The maturity stage demands strong and unwavering commitment to R&D to ensure continuing innovation and competitive strength.

*Decline*

There is no sharp demarcation between maturity and decline, and sometimes no certain way of distinguishing between a cyclical or a structural downturn during maturity and an irreversible decline. Old age does not necessarily indicate decline. As long as there are economic deposits and reserves, good geological potential, and markets for the output, a competitive position can be maintained. Nevertheless, for all producers, depletion will eventually lead to decline, at least until the world's easily developed deposits have been exploited and new generations of technology bring new generations of deposits on stream. All the countries in this study except Australia and Canada are either approaching or are in the decline phase in primary mineral production, and to a lesser extent in processing as well.

In decline (as in downturns during maturity), initial reactions tend to include an increase of industry initiatives such as exploration and R&D aimed at cost-cutting and productivity improvement, and of government initiatives such as incentives or subsidies for exploration and development, and short-term community and labour force assistance. Sometimes the two public policy thrusts come into conflict, as is now the case in the U.K., France and Germany, where rationalization of the coal and steel industries to cut costs exacerbates the job losses in these sectors. Exploration assistance on the other hand has the opposite effect, since it results in increased employment, at least in the short term.

In a genuine permanent decline, the social assistance focus shifts to economic diversification. The exploration subsidies will be dropped if no potential is seen, as has happened in the U.K., Sweden, Germany and Finland; they may be directed offshore if import dependency is considered to be a potential problem, as happened for many years in France and Germany and briefly in Finland. Eventually, exploration and primary production R&D programs will decline, and the emphasis will turn to materials conservation, substitution, and higher-value-added activities, as has happened in all the European countries in the study.

## 2. Import-Export Dependence

This second key variable shows a wide range among the countries included in this study, and within commodity categories. Finland and Sweden, for example, import all their energy minerals and are increasingly dependent on imports of metallic minerals for the production of fabricated metal products (much of which they export). England has long since depleted most of its known economic metallic mineral deposits and has had a brief reprieve in energy minerals. The United States, like Europe, is increasingly dependent on imports of almost all mineral commodities to meet its domestic demand. Canada and Australia, on the other hand, produce a broad range of energy, metallic, and nonmetallic minerals in excess of domestic requirements and depend on export markets for these materials, mainly in unprocessed form.

Export dependency, like the growth stage of mineral production, should lead to an R&D focus on productivity improvements in all phases of discovery and production up to the stage at which commodities are exported, in order to maintain a competitive position and market share. Although primary mineral commodities are generally competitive only in terms of price, and not because of product differentiation, primary mineral exporters may also be able to increase their export potential through R&D in new product development and new applications. Unfortunately, it is more difficult to capture the benefits of R&D in these higher-value-added activities, since the advantage of access to low-cost raw materials loses its importance relative to other factors, such as speed of implementation and marketing skills.

Import dependency, on the other hand, whether for domestically consumed goods or for materials used in the production of goods for export, leads to strong pressures for R&D programs focusing on efficiency in the use of raw materials and on substitution away from imported materials. It may also lead to an increase in geoscience activities aimed at understanding the domestic geology and mineral potential, and to mineral exploration programs, either domestically or abroad. The degree to which security of supply is a national priority will affect the nature and intensity of the responses.

### 3. The Economic and Sociopolitical Environment

Economic conditions are of key importance in determining total R&D funding levels and focus in each country, particularly the level of defence spending, the relative importance of resources and manufacturing in the national economy, and the concentration and ownership (foreign/domestic and public/private) of the industry. In addition, there are many economic, social and political influences that specifically affect mineral policies and R&D responses, including fiscal and monetary policies (and exchange rates), concerns over security of materials and/or energy supply, quality of education, environmental protection, health and safety, trading blocs, and many more. Some are unique to individual countries, and some are found everywhere. A dominant goal in most of the countries studied is job creation, which in Canada and elsewhere is part and parcel of regional economic development and a driving force in resource policies. In most of the countries in the study, regional development needs have led to an emphasis on R&D in the area of industrial mineral potential.

A striking example of the effect of the pressure for job creation is found in the high-cost European coal industry, which, in one sense, does not mine coal at all: it mines jobs. European producers could buy coal elsewhere more cheaply, but they prefer to subsidize production in order to maintain employment and support communities and entire regions. The R&D focus in some cases implicitly recognizes this fact by virtually ignoring the major problem in coal production, high labour costs, since solving it would lead to massive layoffs.

Social and political forces rarely give rise to R&D programs that have scientific excellence, cost-cutting, or productivity gains as their principal focus. In some cases the R&D may increase the direct costs of production, although it reduces social costs or offers other benefits. Government-mandated R&D programs, for example for environmental protection or worker health and safety, generally grow in significance throughout the maturity stage of the industry. Other government policies and programs may also impose costs. Exploration incentive programs may promote activities in high-cost regions. Further processing requirements add costs, if alternative processing facilities are already available. These socially and politically motivated programs are very difficult to design and to evaluate, because there is often no direct measurable economic link between the costs of the programs and the resulting benefits, and little integration of technological expertise into the program design at the policy level.

## 4. The Cultural Factor

The fourth critical factor, one that shapes the effectiveness of each country's R&D effort, is cultural; it arises from the attitudes towards and utilization of science and technology within each country. Consider, for example, the spectrum of attitudes represented by C.P. Snow's "Two Cultures", with relative isolation of and lack of esteem for scientists and engineers at one end of the scale, and the integration of technology and management in Japanese industry and government at the other. Lester Thurow finds that the two-cultures attitude is "peculiar to the Anglo-Saxon world",[1] and leads to biases that handicap both education and industry. The two-cultures attitude leads to poorer education in the sciences, with split streams for science and non-science subjects, and virtually no exposure to science and technology for those in the non-science stream.

This attitude seems to be noticeably stronger in Britain than in Canada and probably stronger in Canada than in the United States and Australia, but it is a handicap in all four. Compared to Japan and Germany, Thurow argues, fewer students and a smaller proportion of top students enter the science stream in the United States because it is not seen as a career path to senior positions, and fewer students enter graduate courses in engineering for the same reason. The attitude leads to fewer technically trained production managers and senior executives, lower priority for R&D and for workforce upgrading, and resistance to process innovation and to investments that do not offer immediate returns. In other words, insufficient technical input into the policy process can and does lead to ineffective R&D programs. Furthermore, even with an outstanding R&D performance and a good level of R&D funding, lack of integration of science and technology into production can prevent the R&D successes from being translated into commercial successes.

[1] L. Thurow, "A Weakness in Process Technology", *Science*, 18 December 1987

# CHAPTER 3. MINERAL–RELATED R&D AND THE MINERAL SECTOR IN CANADA[1]

## INTRODUCTION

This chapter summarizes the Canadian background study to this report, in order to provide information on Canadian expenditure levels and trends in:

- R&D intramural activities of government;
- extramural support by government for mineral–related R&D;
- industry R&D activities;
- education in mining and metallurgy;
- R&D in other disciplines and other resource sectors.

Where possible, R&D effort in mining and the basic metals industry will be presented separately. First, information on the economic impact of the mineral sector in Canada is presented.

## THE MINERAL SECTOR: AN ECONOMIC MEASURE OF THE IMPORTANCE OF MINERAL R&D IN CANADA

In order to understand the economic importance of mineral R&D, it is helpful to examine the role the mineral sector plays in the Canadian economy.

Five key characteristics of the mineral industry in Canada in the period 1980 to 1987 can be identified.

- The combined mining and primary metals industries accounted for an average of about 4% of total Gross Domestic Product (GDP) (2.5% by mining, 1.5% by primary metals – see Figure 3.1).
- There were wide differences in the importance of the mining industry in the various regions of the country. This was especially true of Quebec, Ontario, British Columbia and the Territories but also of sub–provincial areas. The three provinces all produce a fairly large share of the total value of crude mineral production but have relatively little reliance on the crude mineral industry in their provincial economy (Figure 3.2). The reverse is true of the Territories.
- The combined mining and primary metals industries contributed much less to total employment than they did to GDP, representing an average of about 1% of total employment. Substantial reductions have occurred in both industries.
- The mineral industry contributed substantially more to total exports than it did to total GDP, an average of about 15% of total exports. Primary metals are somewhat more important than crude minerals. Canada is export dependent for most of its crude mineral production.
- In terms of share in total employment and exports, the relative importance of both the crude mineral and primary metals sectors has declined. The contribution of the latter to GDP has remained fairly steady, while the contribution of the former appears to be on the decline. Some indicators of the importance of the crude mineral industry to Canada are shown in Figure 3.3.

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[1] Based on M. Wojciechowski, "R&D Trends in the Mineral Sector in Canada", the background study to this report. Centre for Resource Studies, Kingston, December 1988, hereafter cited as Canada Mineral R&D Background Study

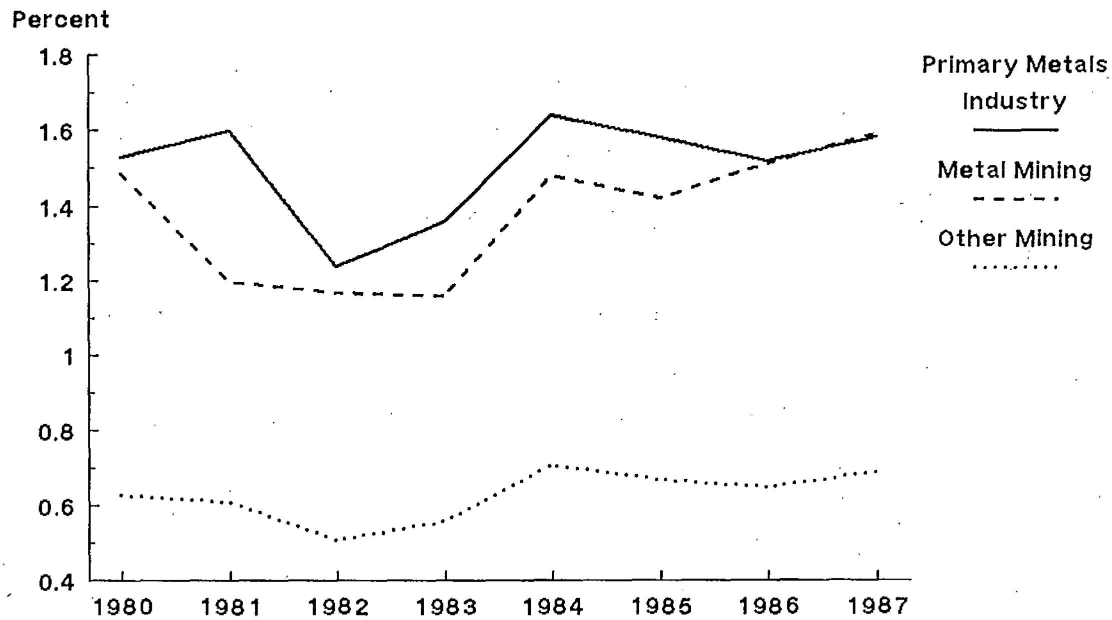


Figure 3.1 Contributions of the mineral sector to GDP, 1980–87

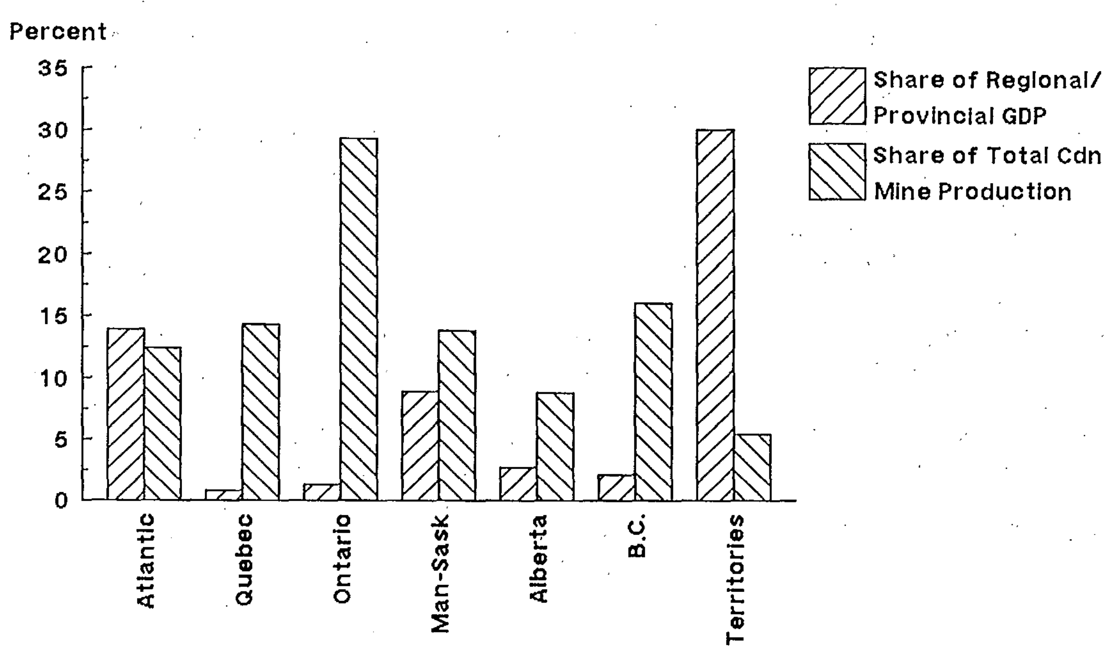


Figure 3.2 Share of mining in regional GDP and in total mine production, 1984

## FEDERAL R&D SUPPORT FOR THE MINERAL SECTOR

The federal government's science and technology (S&T) expenditures rose by 26% between 1980/81 and 1987/88, and represented about 4% of budgetary expenditures.[1] Federal support for the mineral industry arises largely within the intraumural S&T expenditures of Energy, Mines and Resources Canada (EMR). Additional R&D support comes from extramural funding provided by the federal government to provincial governments and industry, but principally to universities via the Natural Sciences and Engineering Research Council (NSERC). Federal support for mining and metallurgy R&D is summarized in Table 3.1.

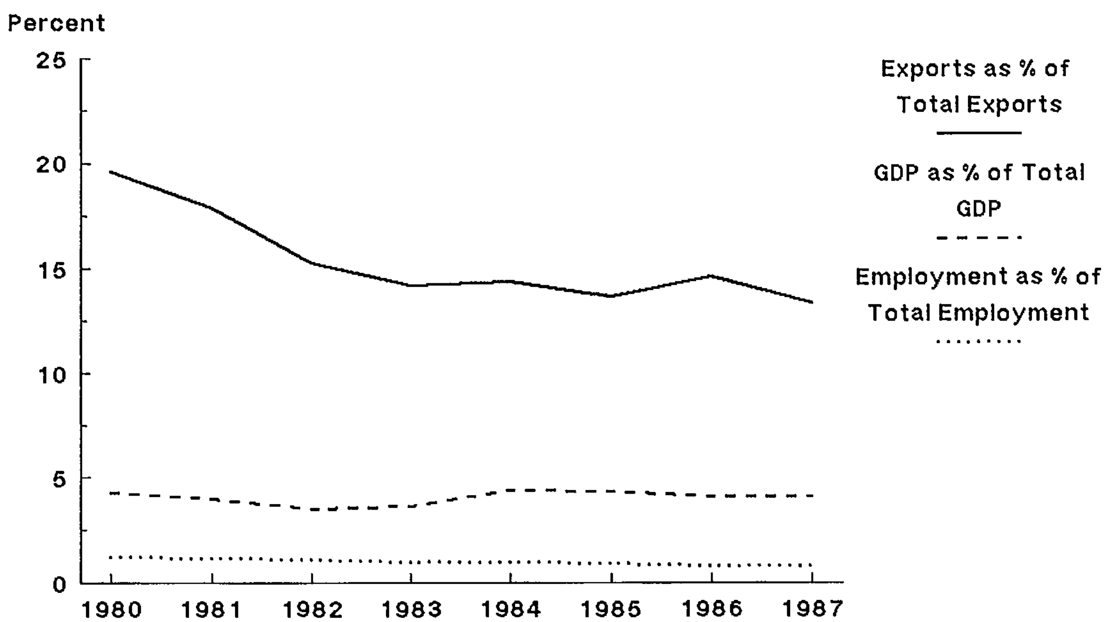


Figure 3.3 Importance of the mineral industry in the Canadian economy, 1980–87

[1] All expenditure figures in this chapter are shown in 1981 constant Canadian dollars deflated using the GDP price index (Appendix B, Table B.2), unless otherwise specified. Percent change is real change based on 1981 dollar values. Forecasts are generally given in current dollars because GDP price indices are not available beyond the current year. Multi-year cumulative totals are also given in current-dollar terms, where no breakdown by year is available.

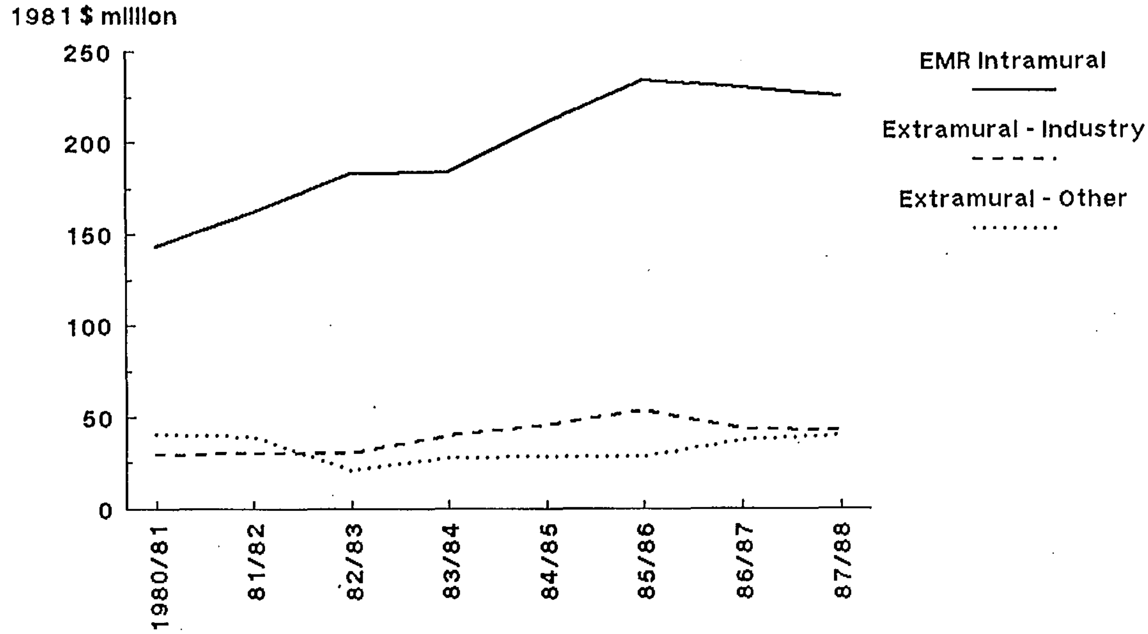


Figure 3.4 EMR science and technology funding by recipient, 1980–81 – 1987–88

Table 3.1 Federal Intramural and Extramural R&D Support for Mining and Metallurgy, 1986–87

| | 1981 $ thousand | % of total |
|---|---|---|
| Mining | | |
| CANMET | 10,436 | 27.7 |
| MDAs | (1,601) | 4.2 |
| Quebec MDA | 397 | 1.0 |
| NSERC | 163 | 0.4 |
| EMR grants* | 127 | 0.3 |
| Total | 11,123 | 29.5 |
| Metallurgy | | |
| CANMET | 21,467 | 56.9 |
| MDAs | (1,894) | 5.0 |
| NSERC | 5,026 | 13.3 |
| EMR grants* | 127 | 0.3 |
| Total | 26,620 | 70.5 |
| Total mineral industry | 37,743 | 100.0 |

Source: Tables 3.14 and 3.23, Canada Mineral R&D Background Study
MDA – Mineral Development Agreement
* Total for minerals simply estimated as a 50:50 split between mining and metallurgy

## Intramural Federal Government Funding

Figure 3.4 shows EMR S&T funding by recipient in the 1980/81 to 1987/88 period. For the most part EMR funding of S&T is intramural (almost 75%). The mandate of EMR includes the mining and metallurgy sectors and involves the development and implementation of mineral-related policies and programs. The intramural R&D is performed by the Canada Centre for Mineral and Energy Technology (CANMET), which, in the fiscal year 1988/89 will spend almost 70% of its total budget on R&D; the principal focus of CANMET is on R&D to promote efficiency and competitiveness in the mineral sector.

Unfortunately, more detailed statistics of CANMET funding by subactivity are not available prior to 1985/86, so that past funding trends cannot be analyzed at this level. Forecasts of future funding levels indicate that CANMET's overall budget will decline by about 12% between 1985/86 and 1990/91 in current-dollar terms. The decline in terms of the real value of expenditures will, of course, be even greater. The A-base, or basic funding used to maintain CANMET's long-term and continuing operations, is expected to remain fairly constant in current-dollar terms and hence to decline steadily in real-dollar terms because of inflation.

CANMET's mineral R&D efforts of concern here are undertaken in four areas of activity – mining, coal mining and preparation, mineral processing, and metals and materials. Funding in these areas represented $32 million (1981 dollars) in 1986/87 (Table 3.1). About one-third of this was in support of mining, while the remainder supported metallurgy. In CANMET's mining, mineral sciences, coal, and metals technology research laboratories, A-base funding has remained fairly constant in real-dollar terms, at least in the 1985/86 to 1987/88 period.

One significant aspect of the federal government's funding of mining and metals R&D is the series of Mineral Development Agreements (MDAs) undertaken with all provinces and territories except Alberta, generally in a 5-year time frame beginning in 1984 or 1985. The agreements are a combination of extramural and intramural funding, as the federal and provincial governments both provide funds and deliver programs. All the agreements are meant to strengthen and diversify the mineral sector and each includes a mining and mineral technology component. In total, the MDAs will provide $254 million (current dollars) in the 1984-91 period, of which $31 million will be for mining and mineral technology.

Somewhat more than half of this amount, or $17 million, will be funded by CANMET. Quebec has by far the most ambitious MDA in terms of total funding; the federal funding share is not handled by CANMET, although the funds are provided by EMR. The federal contributions are included in the CANMET totals in Table 3.1, except for Quebec which is shown separately. In 1986/87, about $3.5 million of CANMET's total support of $32 million was in the form of MDA funding, with a 45% to 55% split between mining and metallurgy.

## Extramural Federal Government Funding

Federal support for extramural mineral R&D can be divided into two categories: grants for research, mainly to universities and principally through the Natural Sciences and Engineering Research Council (NSERC), but also through EMR and through contracts for the provision of research and technical services. Support via contracting is often administered on behalf of other departments by the Department of Supply and Services, so that if DSS contracts are included there is a danger of double counting. Hence the second category is covered here only through EMR's expenditure totals noted previously.

*NSERC R&D Support for Mining and Metallurgy*

NSERC programs are divided into four planning elements: the research base, scholarships and fellowships, targeted research, and general support. The research base support provides operating, equipment, infrastructure and special project grants according to distributions determined by discipline-based committees. Targeted research support includes strategic grants and university/ industry grants. General research support, the fourth element in NSERC's funding program, consists mainly of grants given to university presidents which cannot be classified by discipline as can other grants. In 1986/87 NSERC provided about $5 million in grants for metallurgy research while only about $0.2 million was provided for research in mining. To some extent strategic grants reflect the current or short-term policy thrust and resulting importance assigned to various disciplines. None were reported for mining in the 1980/81–1986/87 period, while such grants represented a fairly substantial proportion of the support for metallurgy. Similarly, no fellowships were reported for mining, while about $70 thousand in fellowship support was given in the metallurgy area. It should be noted, however, that some additional NSERC support for mining-related research is made available under discipline code classifications assigned to the civil engineering committee.

*EMR Research Grant Support for Mining and Metallurgy*

EMR's grant program is concentrated in funding for the earth sciences and energy research rather than mining and minerals and is not large, relative to NSERC funding. Nevertheless, the amount of support going to mining R&D in 1986/87 was equal to the NSERC mining support, while metallurgy NSERC grants were about 40 times the EMR grants for metallurgy, as shown in Table 3.1.

## PROVINCIAL GOVERNMENT SUPPORT FOR MINERAL R&D

Despite the fact that minerals represent a significant proportion of GDP in some provinces, little in-house mining or mineral-related R&D is performed by the provinces. The major exception is Quebec, which has the lowest economic dependence on the mining industry next to Prince Edward Island (Figure 3.2) but which nevertheless has a provincial organization devoted entirely to mineral R&D, le Centre de recherches minérales (CRM). In addition, some in-house provincial R&D on mineral processing is funded by New Brunswick in its Research and Productivity Council (RPC). In Alberta, the Alberta Research Council (ARC) provides mineral-related research funding for various programs emphasizing energy sources and utilization, including coal.

Support for mineral R&D in the other provinces is generally small and has been triggered by the Mineral Development Agreements in most cases. Estimates for total provincial mining and metallurgy R&D expenditures for 1986/87 are presented in Table 3.2. These figures understate the full extent of provincial support, since it is difficult to estimate the level of non-MDA support, and Statistics Canada does not provide any details of provincial R&D expenditures. It must be noted that 1986/87 was the peak year for MDA expenditures, which will drop to almost zero by 1990/91. This may mean a reduction in the already low level of mineral-related R&D funded by the provinces.

Table 3.2 Summary Estimates of Provincial Mineral-Related R&D Expenditures, 1986-87
(1981 $ thousand)

| | Mining | Metallurgy | Total |
|---|---|---|---|
| Newfoundland MDA | 0 | 117 | 117 |
| PEI MDA | 0 | 0 | 0 |
| Nova Scotia MDA | 0 | 335 | 335 |
| New Brunswick MDA | 11 | 35 | 46 |
| RPC | 0 | 191 | 191 |
| Quebec MDA* | 397 | 0 | 397 |
| CRM | 2,348 | 2,631 | 4,979 |
| Ontario MDA | 0 | 0 | 0 |
| Manitoba MDA | 306 | 257 | 563 |
| Saskatchewan MDA | 0 | 0 | 0 |
| Alberta ARC (coal) | 1,707 | 0 | 1,707 |
| British Columbia MDA | 0 | 0 | 0 |
| Territories MDA | na ** | na | na |
| Total | | | |
| MDA | 714 | 744 | 1,458 |
| Other | 4,055 | 2,822 | 6,877 |
| Total | 4,769 | 3,566 | 8,335 |

Source: Tables 4.1 to 4.6, Canada Mineral R&D Background Study
*Some of this amount may be included in the CRM total
**na - Not available

## INDUSTRY SUPPORT FOR MINERAL-RELATED R&D

R&D in mining and metallurgy in the private sector in most countries is carried out by three principal groups: mining and/or smelting and refining companies; mining and metallurgical equipment manufacturers; and consulting and contracting firms. In Canada, however, there are very few domestic manufacturers of mining and metallurgical equipment. What equipment is manufactured here is largely produced by branch plants of foreign-owned firms which tend to do their R&D in their home-country. The third group, consulting and contracting firms, with very few exceptions, do no R&D in Canada. Thus almost all R&D in the Canadian mineral industry is funded and performed by the first group of companies and the following analysis concentrates on these companies.

The Canadian mining industry is fairly concentrated in terms of ownership, with a small group of well-known companies accounting for most of Canada's crude mineral production. These companies tend to be vertically integrated and diversified multinationals. The metal mining sector is highly concentrated, with relatively few firms in comparison to the nonmetals mining sector, which is characterized by a substantial number of small firms. Foreign control of mining industry assets has fallen significantly in the past two decades, and the core of the industry, metal mining, shows the least degree of foreign ownership of any of the mining sectors.

The nonferrous smelting and refining sector is dominated by a small number of vertically integrated companies, the same ones that dominate the mining industry. All of these companies possess reserves that have the potential to keep them in the forefront of world mineral production for decades to come. They are also the principal performers and funders of industry R&D in mining and metals.

The ferrous metal mining and processing sector tends to be characterized by a much greater degree of foreign control than the nonferrous sector, but has a similar degree of vertical integration.

## Mineral R&D Expenditures by Industry

Figure 3.5 shows the 1986 level of overall R&D intensity (current intramural R&D expenditures as a percent of sales of R&D performers) for selected Canadian resource–based industries, including mining and metals. The mining and ferrous metal industries are well below the total all–industry average for R&D intensity. The primary nonferrous metal industry does compare favourably, but only due to the inclusion of Alcan in the category; removal of Alcan expenditure figures would probably bring the ratio down from about 1.3 to 0.6. Figure 3.6 presents figures showing R&D intensity for various components of the mineral sector . R&D in nonmetal mining and in the mining service industries are relatively high but this is a fairly recent phenomenon; in 1979 these ratios were quite low.

These figures represent R&D performed, rather than own expenditures on R&D, which are lower, often much lower. In 1986 about 76% of total mineral industry intramural mining R&D was paid for with own funds. For ferrous metals the proportion was 100%, while for nonferrous metals the proportion was 34%. Most of the external funding represented intracorporate transfers (particularly within Alcan) rather than government support.

Table 3.3 and Figure 3.7 summarize the available data on mining and metal industry support of R&D. It is immediately obvious that one company, Alcan, has been responsible for a substantial proportion of R&D undertaken by the industry in this decade. In 1986 it represented 63% of nonferrous metal R&D and 34% of total mining and metals R&D (the 1987 proportions were higher still). Another striking feature is the drastic reduction in "other" (i.e., non–Alcan) nonferrous metal R&D. Almost all the R&D in metal mining and primary metals is done by the few large firms which dominate the industry.

Few data are available on the division of industry research effort between process (e.g. extractive metallurgy) and products (e.g. physical metallurgy and materials) of the industry research effort, but some trends have been identified by industry representatives. In nonferrous metals it appears that about three–quarters of the research is in the area of extractive metallurgy and production processes, with the remainder in new product development and materials research. There is an increasing emphasis on product research, with Alcan leading the way. In ferrous metal R&D, roughly equal effort is devoted to processes, physical metallurgy and materials properties. R&D expenditures with an environmental focus represent a fairly large part of the effort (15%–25%), particularly within production process R&D in both the ferrous and nonferrous metal sectors.

## Industry R&D Organizations

There are no industry research facilities in Canada for conducting joint or collaborative mining or mineral–related R&D. There are, however, a growing number of organizations established to coordinate R&D conducted in–house or by contractors. Cooperative mineral R&D is in the very early stages in Canada, and involves very little actual funding support up to now. Most of the influence of these organizations involves identification of targets for existing R&D funding and facilities. However, there are indications that these organizations will be successful in improving communication, in increasing the overall level of funding support and in establishing new centres of excellence; for example, around the university, chairs are being established in mineral–related university departments.

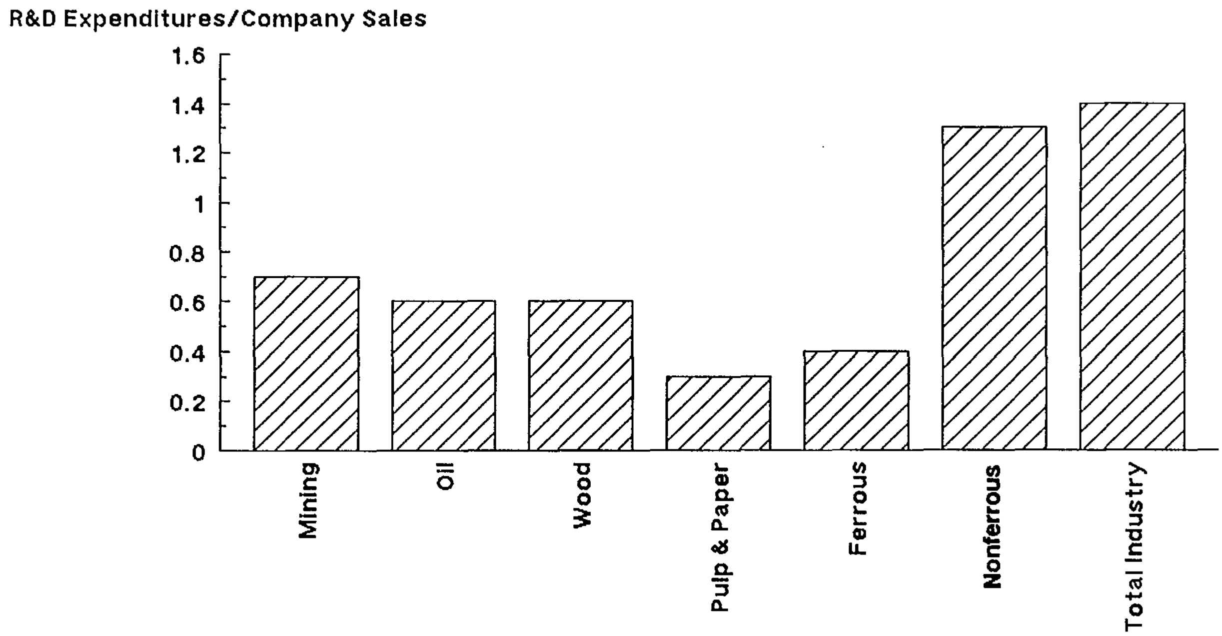


Figure 3.5 R&D intensity in selected Canadian industries, 1986

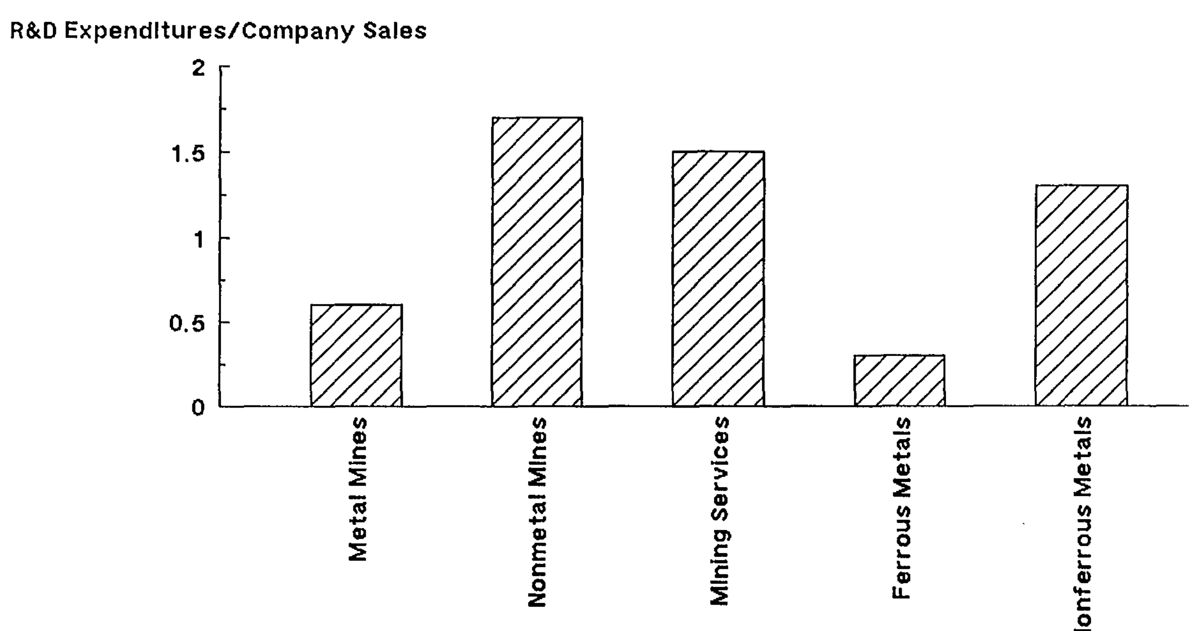


Figure 3.6 R&D intensity in the mineral industry, 1986

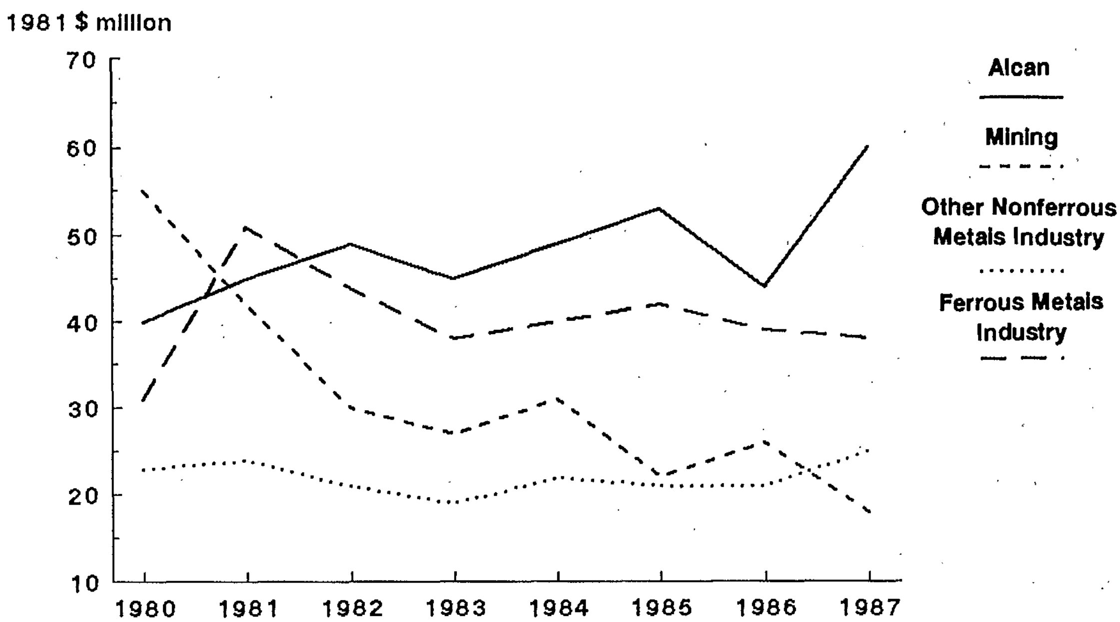


Figure 3.7 Mining and metals industry intramural R&D expenditures, 1980–87

Table 3.3 Mining and Metals Industry Total Intramural R&D Expenditures, 1979 and 1981–86 (1981 $ million)

| | 1979 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|
| Mining | | | | | | | |
| Metallic | 22 | 41 | 31 | 25 | 26 | 28 | 25 |
| Nonmetallic | 1 | 6 | 8 | 11 | 11 | 11 | 11 |
| Services | – | 3 | 3 | 3 | 3 | 3 | 2 |
| Mining total | 23 | 50 | 42 | 39 | 40 | 42 | 38 |
| Metals | | | | | | | |
| Ferrous | 23 | 24 | 22 | 18 | 22 | 21 | 21 |
| Nonferrous | | | | | | | |
| Alcan | na | 45 | 49 | 45 | 49 | 53 | 44 |
| Other | na | 42 | 30 | 27 | 31 | 23 | 26 |
| Total | 72 | 86 | 79 | 72 | 80 | 76 | 70 |
| Nonmetallic mineral products | 7 | 8 | 7 | 9 | 14 | 14 | 11 |

Source: Tables 5 and 14, Canada Mineral R&D Background Study

Cooperative industry research organizations include the Mining Industry Research Organization (MIROC) with an emphasis on health and safety matters, and HDRK Mining Research Limited with a focus on hard–rock mining techniques. Organizations that coordinate and promote research include the Canadian Steel Industry Research Association (CSIRA), that coordinates research in all R&D sectors in the technology of steel making; the Mining Industry Technology Council (MITEC), which has as its general goal the improvement of Canadian competitiveness in mining, and the Ontario Mining Association's Mining Research Directorate (MRD), which is primarily interested in rock mechanics and ground control.

## TRENDS IN EDUCATION

Post–secondary education provides Canada with the future researchers who will develop and implement the new ideas needed to maintain industrial competitiveness. Three principal indicators of university education in mining and metallurgy and in all disciplines combined are considered, in order to show trends in human resource potential. These characteristics are: university funding sources and levels, the number and rank of faculty, and degrees granted at both the undergraduate and graduate level.

### Trends in Canadian Education

Education funding trends can only be considered at the aggregate level, since education is a provincial responsibility and the provinces do not provide information on operating funds by department or discipline. The provinces provide about 80% of university general operating income. In total, operating income increased by less than 9% between 1980/81 and 1985/86. On a per–student basis, it decreased by 10%, and per faculty member it increased by 3% over the six–year period. Trends in university operating income relative to GDP, number of faculty, and number of students are shown in Figure 3.8. The number of university teaching staff has increased by about 6% in this period, to over 35 thousand in 1985/86. The health sciences have had the largest growth in teaching staff, followed by engineering and applied sciences. In undergraduate enrollment, however, mathematics and the physical sciences have seen the largest increases. The resource sector applied fields have seen a decline in enrollment, as have some branches of engineering, while the humanities, social sciences and biology have grown significantly.

### Education in Mining and Metallurgy

A survey of Canadian universities by the Centre for Resource Studies indicates that there are 12 universities with mining, mineral engineering, metallurgy or materials science departments. In addition, a number of universities teach mining–related courses in civil engineering departments, and metallurgy and materials–related courses in chemical engineering, chemistry and physics departments. Total mining engineering faculty increased in the 1980–85 period, but there has been no increase in metallurgy and material science teaching staff.

Degrees granted at both the Bachelor and Masters level have increased substantially in metallurgy (Table 3.4). The same has not been true for mining, where undergraduate degrees granted have fallen, while the number of Master's degrees granted has been somewhat erratic. The greater interest in metallurgy as opposed to mining is most evident in the number of doctorates awarded. Between 1980 and 1987, 32 PhDs were granted in mining compared to 153 in metallurgy.

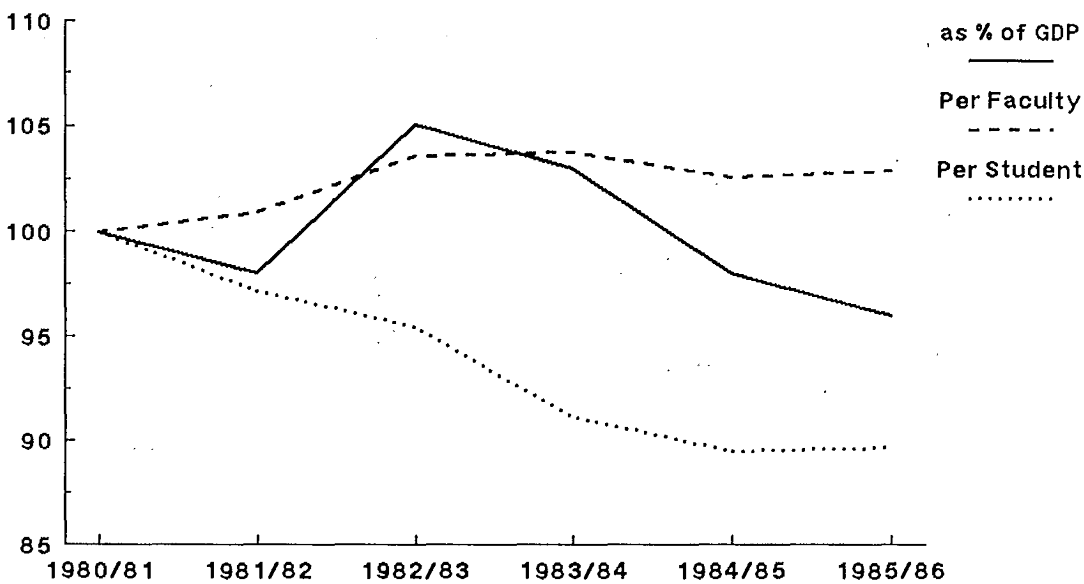


Figure 3.8 Trends in university operating income 1980/81 – 1985/86 (1980/81 = 100)

Queen's University has historically had the most graduate and undergraduate degrees granted in mining engineering. In metallurgy and metallurgical engineering no one university stands out as a major educator.

## R&D IN SELECTED SCIENTIFIC DISCIPLINES

### R&D in Universities

University research funding represents about 13% of total university expenditures and increased by 40% between 1980/81 and 1985/86. In comparison, university operating income showed virtually no growth. Almost all university research in Canada is sponsored research, supported by specific grants for specific purposes. Sponsored research income has grown steadily since 1980/81 and its growth is compared to the growth of GDP and university operating income in Figure 3.9.

The main funding source (about 60%) for sponsored research is the federal government. Within the federal government, the major funding source for R&D in natural sciences and engineering is NSERC. NSERC research base peer committee grants to mining and metallurgy increased by 73% in the period 1980/81to 1986/87, well above the 28% increase for all disciplines combined (Table 3.4). This is almost entirely due to metallurgy since mining grants are negligible. In terms of strategic grants, which are flexible in focus and give a sense of the direction government wants research to go, there appears to have been a decline in support for the resource-based disciplines while more high tech categories have prospered. No strategic grants were given to mining but such grants increased substantially to metallurgy, much more than the overall increase for all disciplines combined.

Total full-time graduate enrollment in universities increased by 22 the 1980/81–1985/86 period, while enrollment in the natural sciences and engineering increased by 43%. Figure 3.10 shows trends in total graduate student enrollment, while Figure 3.11 shows the distribution of graduate students within the natural sciences and engineering.

Table 3.4 Indicators of Support for Mining and Metallurgy in Universities, 1980 and 1986

| | 1980 | 1986 | % change |
|---|---|---|---|
| Undergraduate degrees granted | | | |
| Mining[a] | 123 | 107 | −13.0 |
| Metallurgy[b] | 83 | 130 | 56.6 |
| Total mining and metallurgy | 106 | 237 | 15.0 |
| Masters degrees granted | | | |
| Mining[a] | 22 | 26 | 18.2 |
| Metallurgy[b] | 23 | 78 | 239.1 |
| Total mining and metallurgy | 45 | 104 | 131.1 |
| Doctorate degrees granted | | | |
| Mining[a] | 3 | 3 | 0.0 |
| Metallurgy[b] | 15 | 26 | 73.3 |
| Total mining and metallurgy | 18 | 29 | 61.1 |
| Graduate enrollment[c] | | | |
| Mining and metallurgy | 193 | 357 | 85.0 |
| Total Canada | 44,658 | 54,611 | 22.3 |
| NSERC grants (1981 $ thousand)[d] | | | |
| Mining and metallurgy | 2,201 | 3,805 | 72.9 |
| Total NSERC | 114,171 | 145,694 | 27.6 |
| NSERC scholarships and fellowships (number)[e] | | | |
| Mining and metallurgy | 17 | 38 | 123.5 |
| Total NSERC | 2,046 | 3,107 | 51.9 |

Source: Tables 6.15, 6.16, 6.17, 7.2, 7.5, 7.6 and 7.12, Canada Mineral R&D Background Study

[a] Includes mining engineering, mineral dressing and mineral processing

[b] Includes metallurgy (arts and science) and metallurgical engineering

[c] 1980/81 and 1985/86

[d] Research base grants, 1980/81 and 1986/87

[e] 1981/82 and 1986/87

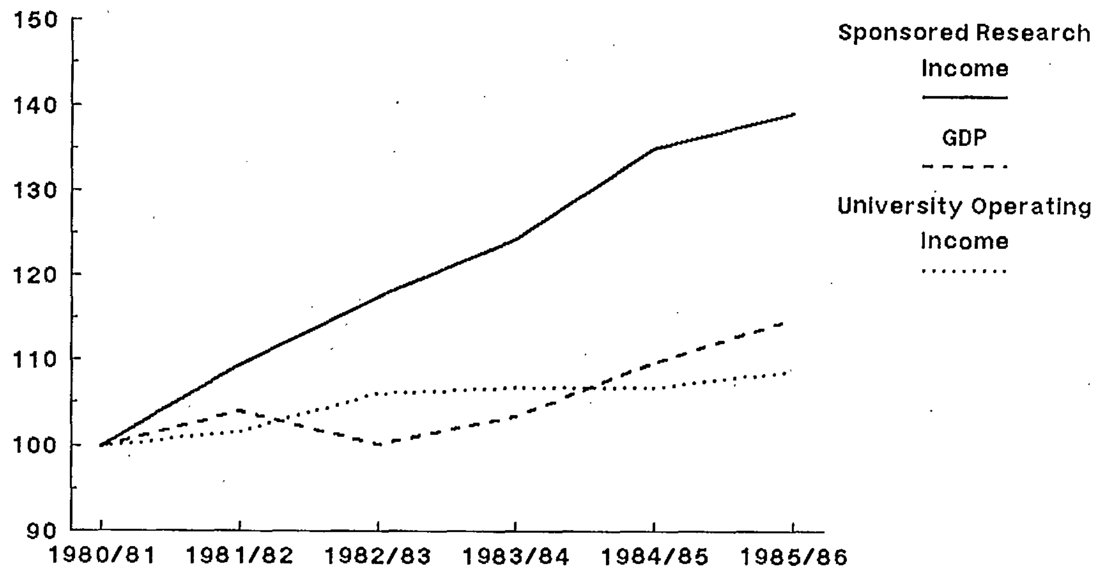


Figure 3.9 Sponsored research income, GDP and university operating income, 1980–81 – 1985–86 (1980–81 = 100)

## Comparison of R&D Trends in Selected Disciplines

Two indicators of trends in university R&D levels and focus are both available and useful: the level of Natural Sciences and Engineering Research Council (NSERC) funding support received by universities, and graduate student enrollment. Table 3.5 looks at both measures for selected disciplines within the natural sciences and engineering.

In mining and metallurgy, both graduate enrollment and NSERC research base grants have shown much higher increases in this decade than any of the broadly defined natural science and engineering disciplines. Mining and metallurgy combined show approximately 2.5% of both total graduate enrollment and total NSERC research base grants. Mining alone, however, accounted for 0.7% of graduate enrollment in 1985/86 but received only 0.1% of NSERC research base funding in that year.

Table 3.5 Comparison of Graduate Enrollment and NSERC Grants in Natural Sciences and Engineering Disciplines

| | Graduate enrollment | | NSERC research base grants | |
|---|---|---|---|---|
| | % of total 1985/86 | % change 1980/81–1985/86 | % of total 1986/87 | % change 1980/81–1987/88 |
| Biology | 16.8 | 25.3 | 24.0 | 29.7 |
| Chemistry | 9.3 | 38.4 | 12.1 | 1.0 |
| Physics and space | 6.8 | 37.4 | 17.9 | 34.5 |
| Earth sciences | 5.9 | 44.7 | 7.2 | 12.1 |
| Math., stats. and computing | 12.2 | 66.1 | 9.3 | 57.6 |
| Engineering | 33.0 | 59.2 | 24.7 | 34.3 |
| Mining and Metallurgy | 2.4 | 85.0 | 2.6 | 72.9* |
| Psychology | 16.0 | 26.0 | 4.2 | 33.4 |
| Interdisciplinary | na | na | 0.6 | 12.5 |
| Total | 100.0 | 43.0 | 100.0 | 27.6 |

Source: Tables 7 and 8, Canada Mineral R&D Background Study
* 1980/81–1986/87
na – Not available

### Mineral R&D in Universities

The survey of universities conducted by the Centre for Resource Studies provided information on the research funding levels and sources of funds in mining and metallurgical engineering departments. Unfortunately the results are incomplete, as not all departments were able to provide the requested information. The results therefore understate the total level of funding.

R&D grant and contract funding reported by mining and metallurgy departments totalled in the range of $9 million to $10 million per year between 1984 and 1986. About half of the funds were provided by NSERC, with other federal sources and provincial governments each providing roughly 15% to 20% of the total. Industry contributed between 10% and 15% of the funds. It appears that roughly 70% of the funding was for research related to metallurgy.

## COMPARISON OF R&D EXPENDITURES IN OTHER RESOURCE SECTORS

To put the analysis of mineral R&D into broader perspective, a comparison of R&D expenditures in the various resource sectors in Canada is presented here. The three major resource sectors in Canada are minerals (divided into petroleum and non–petroleum), agriculture (including fisheries) and forestry. Because of the way Statistics Canada data are presented, and to ensure broad comparability across sectors, the crude product, processing and fabricating components of each sector are combined. Unless otherwise indicated, the following analysis deals with the complete sectors.

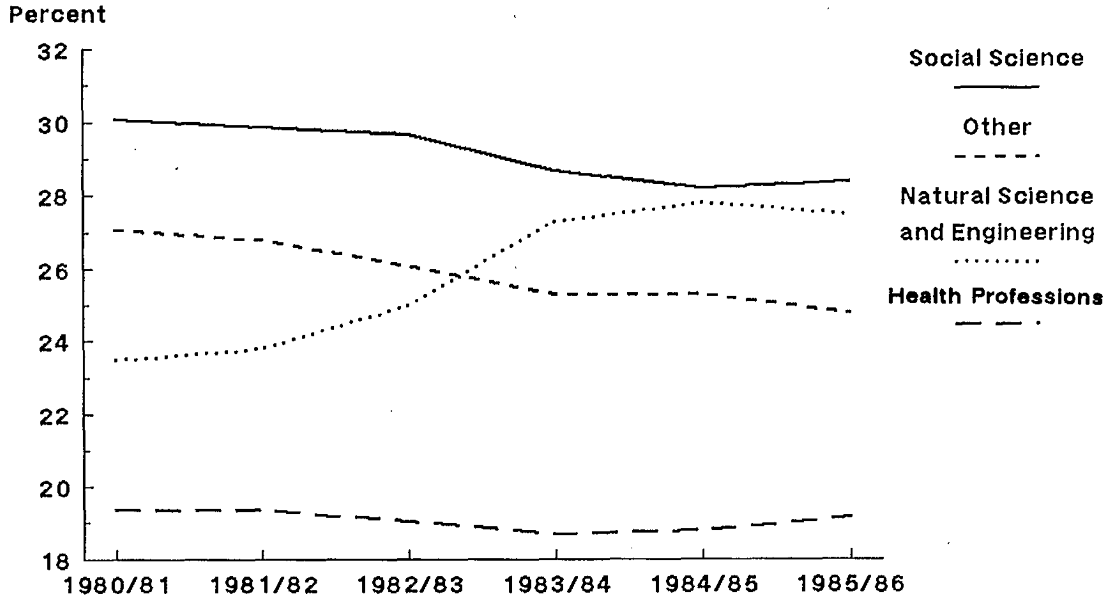


Figure 3.10 Distribution of full-time graduate students by field of study, 1980-81 - 1985-86

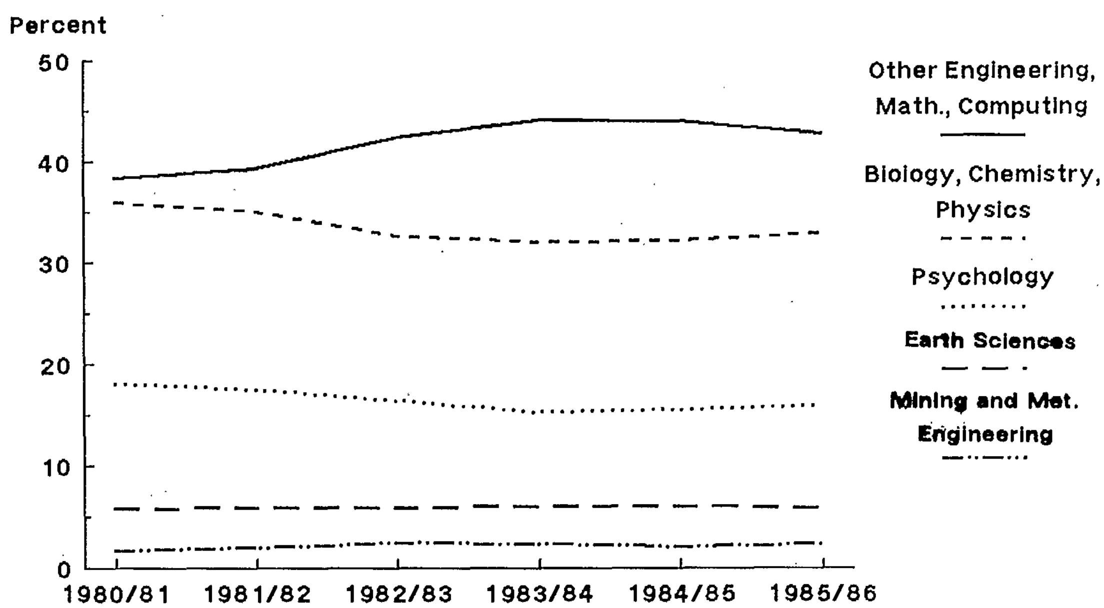


Figure 3.11 Distribution of full-time graduate students in natural sciences and engineering, 1980-81 - 1985-86

## Economic Contribution of the Resource Sectors

In general, the resource sectors as a whole have decreased their share of total GDP over the past decade from 25% in 1975 to just over 17% in 1987. This trend is evident in Figure 3.12. Figure 3.13 shows the contribution of the crude product component of these sectors to GDP, excluding the processing and fabricating stages. The agricultural sector has contributed the most to GDP in this decade, while forestry has contributed the least. The resource sectors' contribution to exports far outweighs their contribution to GDP, although it is declining. In 1980 they accounted for over 60% of exports, but by 1986 this had fallen to slightly more than 45%. In terms of employment, the resource sectors show still more variation. In 1985, agriculture provided the most jobs by far (with over 700,000 employees). The mineral and forestry industries were approximately equal (250,000 and 268,000 jobs, respectively), while the petroleum industry provided only 86,000 jobs. Some provinces, regions and communities are highly dependent on the resource industries for employment and economic activity.

## Overview of Resource Sector R&D

A summary of some of the major funding sources for R&D in the resource sectors is shown in Table 3.6. It is virtually impossible to arrive at firm figures representing the level and intensity of government R&D funding by sector: the data are simply too sparse. The figures in Table 3.6 are not additive and are by no means all-inclusive. They are presented only as an indication of funding sources, levels and trend directions in the various sectors.

Oil and gas exploration expenditures are extremely high in relation to value added, compared to mining expenditures. This reflects in part the expectation of major petroleum finds, and the relatively low production cost.

In R&D expenditures, one conspicuous figure is Agriculture Canada's high level of support for agricultural R&D, which is a function of both economic history and the extreme lack of concentration of ownership in the sector. Industry support for metals R&D, largely from Alcan, is also conspicuous. The R&D intensity numbers (yearly average R&D funding as percent of 1986 GDP, within the relevant part of the sector) should not be cited as absolute indicators of R&D intensity, since the R&D funds are simply averages of crude aggregates over various time periods. They do give some sense of relative intensities.

Comparing the contribution of each sector to total industry R&D and total GDP in 1987 is instructive. Figures 3.14 and 3.15 compare these measures for each sector in its entirety and show the primary component of each sector. Both the mineral and petroleum industries contribute more to total R&D than to GDP. The reverse is true of forestry and agriculture and, although the latter is the most important resource sector in terms of GDP contribution, its industry sector nevertheless makes the smallest contribution to R&D of any resource sector. The ratio of current intramural R&D expenditures to sales in the resource sectors indicates that they are generally at or below the average industrial R&D intensity for Canada, and well below the levels needed to maintain a competitive position in technologically intensive industries.

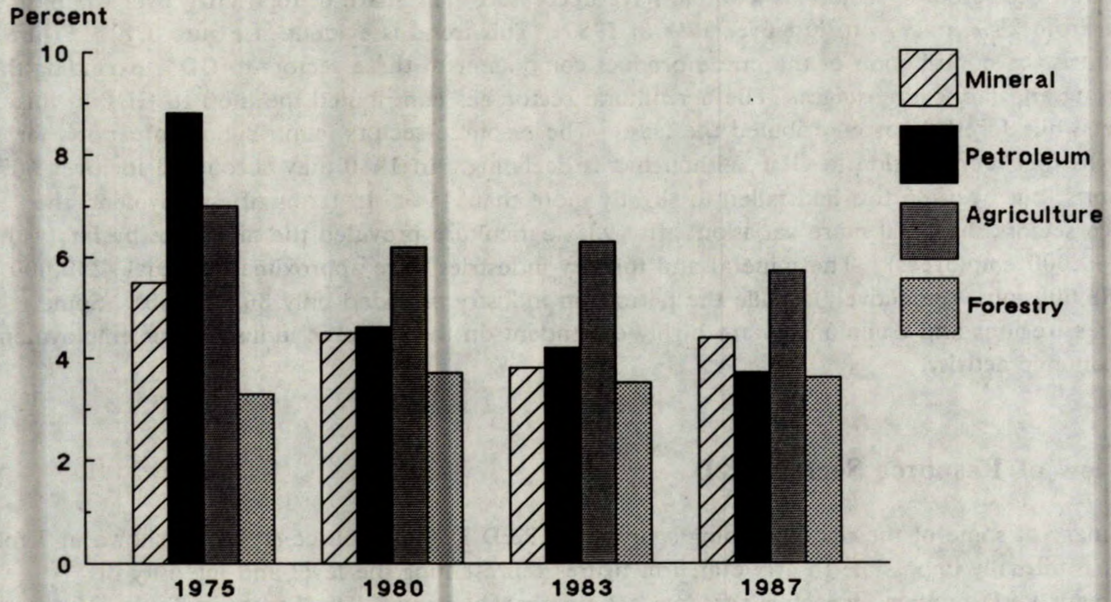


Figure 3.12 Contribution of the resource sectors to total GDP, various years (sector GDP as percent of total GDP)

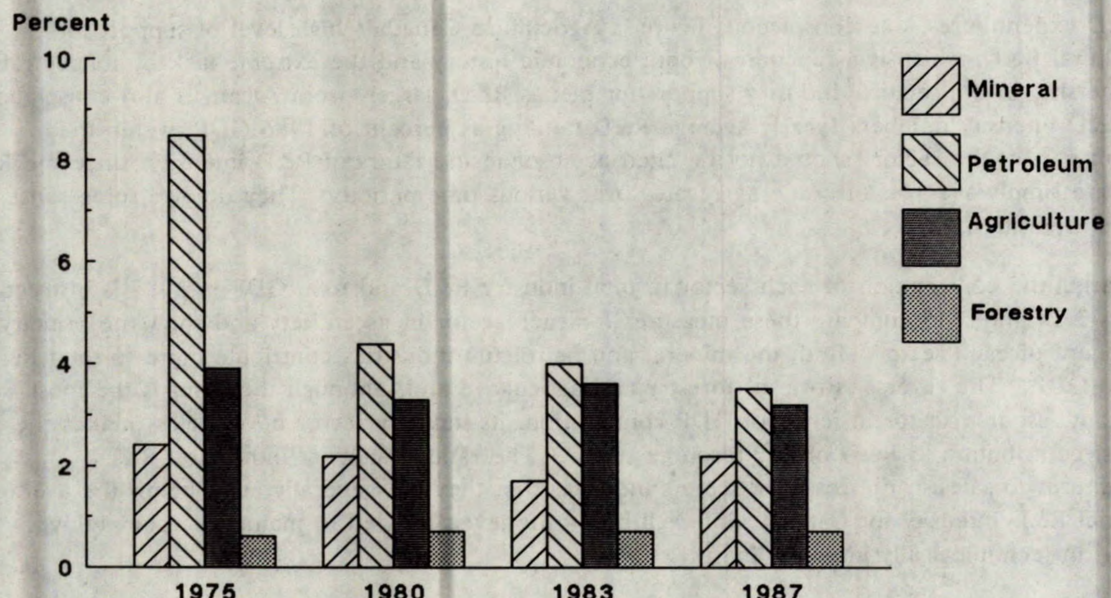


Figure 3.13 Contribution of the crude resource sectors to total GDP, various years (crude resource sector GDP as percent of total GDP)

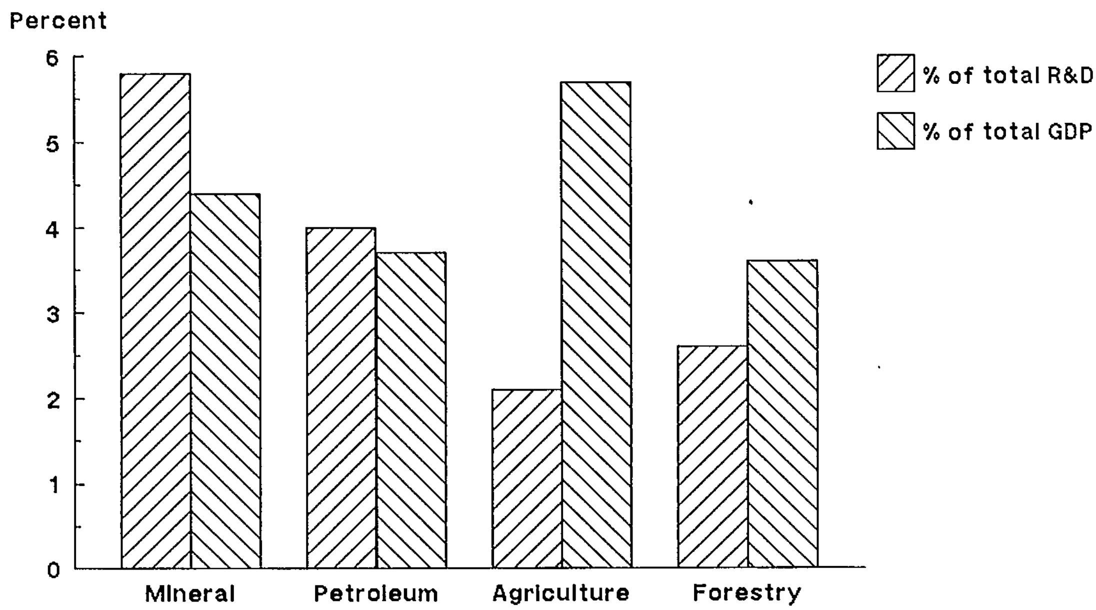


Figure 3.14 Contribution of the resource sectors to total GDP and total industry R&D, 1987

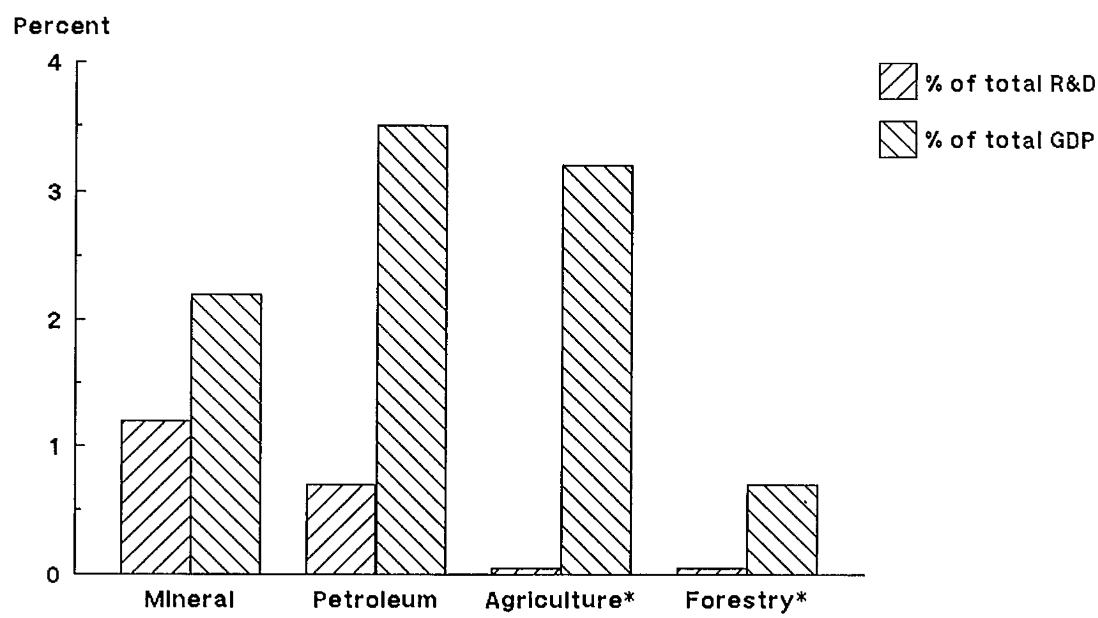


Figure 3.15 Contribution of the primary resource sectors to total GDP and total industry R&D, 1987
* R&D values unknown but very small, according to Statistics Canada, 88-202

Table 3.6 Summary of Major Resource Sector R&D Funding

| Sector | Source | Yearly average funding (1981 $ million) | Percentage change over period | Period | Yearly average as % of 1987 sector GDP[a] |
|---|---|---|---|---|---|
| Earth science | | | | | |
| Geoscience and exploration | Federal | | | | |
| | GSC total | 61 | 88 | 1982/83–1986/87 | 0.3 |
| | GSC A–base operating | 19 | –29 | 1980/81–1986/87 | n/a |
| | Provincial GS | | | | |
| | Total | 48 | 22 | 1981/82–1985/86 | 0.2 |
| | A–base | 39 | –4 | 1981/82–1985/86 | 0.2 |
| | Industry | | | | |
| | Mining exploration | 474 | 22 | 1980–87 | 6.0 |
| | Oil and gas exploration | 3.963 | –57 | 1980–87 | 30.0 |
| R&D | Federal | | | | |
| | GSC | 51 | 86 | 1982/83–1986/87 | 0.2 |
| | NSERC total ES | 14 | 36 | 1980/81–1986/87 | 0.06 |
| | EMR grants | 0.6 | –23 | 1980–87 | 0.0 |
| | Provincial surveys | 21[e] | 25[e] | 1981/82–1985/86 | na |
| | Industry | 2[e] | na | | na |
| Mineral sector | Federal | | | | |
| | CANMET[b] | | | | |
| | Total | 61 | –12 | 1985/86–1987/88 | 0.5 |
| | A–base | 33 | –12 | 1985/86–1987/88 | 0.3 |
| | EMR grants[c] | 0.7 | –21 | 1980–87 | 0.01 |
| | NSERC mining | 0.2 | na | 1980/81–1986/87 | 0.0 |
| | metallurgy | 4 | 91 | 1980/81–1986/87 | 0.03 |
| | Provincial | | | | |
| | MDA | 1 | na | 1984–91 | 0.01 |
| | CRM | 6 | 17 | 1980/81–1987/88 | 0.9 [d] |
| | Alberta (ARC coal) | 2 | 16 | 1982/83–1987/88 | 0.2 [e] |

Table 3.6 (cont'd)

| Sector | Source | Yearly average funding (1981 $ million) | Percentage change over period | Period | Yearly average as % of 1987 sector GDP |
|---|---|---|---|---|---|
| | Industry | | | | |
| | Mining | 42 | −26 | 1981–87 | 0.5 |
| | Metals | 99 | −35 | 1981–87 | 2.4 |
| | Nonmetallic | 11 | 38 | 1981–86 | 0.6 |
| Petroleum (primary) | Federal | na | na | | na |
| | Provincial | na | na | | na |
| | Industry | 56 | −70 | 1980–87 | 0.4 |
| Agriculture (primary and processing) | Federal | | | | |
| | Agriculture Canada[f] | 245 | 61 | 1980/81–1986/87 | 1.1 |
| | Agriculture minus Forestry | na | na | | 0.9[e] |
| | Federal/prov. agreements[g] | 10 | na | 1982–90 | 0.05 |
| | Provincial | | | | |
| | Ont.–ARI[h] | 26 | −1 | 1981/82–1986/87 | na |
| | Quebec | 14 | 110 | 1980/81–1986/87 | na |
| | Industry | 62 | 22 | 1980–87 | 0.3 |
| Forestry (primary and processing) | Federal | | | | |
| | CFS[i] | 57 | 23 | 1984/85–1986/87 | 0.9 |
| | PRUF[j] | 2 | na | 1985 | |
| | Forest Development Agreements[k] | na | na | | |
| | Provincial | na | na | | |
| | Industry | 15 | 0 | 1980–87 | 0.2 |
| | PPRI[l] | 13 | 9 | 1980–87 | 0.2 |

Table 3.6 (cont'd)

Sources: Various tables in Canada Earth Sciences Background Study. GDP values from Table 8.2 in source cited.

na – Not available
n/a – Not applicable

[a] Sector GDP for Earth Sciences is taken as primary minerals plus primary petroleum
[b] CANMET's mineral technology expenditures, taken as 100% R&D for this table
[c] Mining and mineral technology
[d] $6 million as percent of Quebec 1984 mining GDP
[e] $2 million as percent of Alberta 1984 mining (excluding oil and gas) GDP
[f] Author's estimate
[g] Included in Agriculture Canada above. Current dollars
[h] ARI – Agricultural Research Institute
[i] CFS – Canadian Forestry Service
[j] PRUF – Program of Research by Universities in Forestry
[k] Forestry Development Agreements involved relatively little R&D. Total funding 1982–90 is federal. $421 million and provincial. $406 million current. mainly for forest management
[l] PAPRICAN – Pulp and Paper Research Institute (joint industry and government funding)

## Sector–Specific R&D Data

*R&D in the Earth Sciences*

Earth science R&D, geoscience activities and exploration are essential in the development and maintenance of the ability to find mineral deposits for both the mining and the oil and gas industries. Most earth science R&D and geoscience are undertaken by the Geological Survey of Canada (GSC) and the various provincial geological survey organizations. GSC total geoscience and exploration expenditures averaged $61 million per year in the 1982/83–1986/87 period and has since increased substantially. However, long–term support through A–base operating funds (as opposed to temporary add–on funding programs) actually has declined fairly steadily and is projected to continue declining. A large part of GSC support for the earth sciences comes from its funding of the federal geoscience component of the MDAs, which is temporary funding.

Provincial earth science activities have averaged about $48 million in the 1981/81 to 1985/86 period. Provincial A–base expenditures in this area have also declined, though not to the same extent as the federal A–base. Together these declines seem to indicate a lessening commitment on the part of government to earth science research. Industry undertakes virtually no earthscience–related R&D, although its exploration programs put a great deal of geoscience data into the public domain.

*Research in the Mineral Sector*

This sector is covered in detail earlier in this chapter.

*Research in the Petroleum Industry*

Data on oil and gas industry R&D activities related to the combined category of exploration and production are compiled from survey information collected by the Petroleum Monitoring Agency (PMA). The survey represents about 90% of the industry and indicates that R&D peaked in 1981 and henceforth declined with a slight resurgence in 1985, followed by a substantial fall in 1986. The sharp fall in 1986 was due to the price drop in oil during that year and was accentuated by the 50% decline in federal support for the industry.

Statistics Canada reports substantially lower figures for crude petroleum and natural gas industry R&D expenditures than for those derived by PMA, but the pattern of expenditures is the same.

*Research in Agriculture*

Federal research in agriculture is largely intramural, based in the Research Branch of Agriculture Canada. The department's S&T expenditures represent about 25% of total expenditures and of this over 85% is R&D ($273 million in 1987/88). Extramural support for research in industry and universities is very small, amounting to only a few percent of its total R&D expenditures. Subsidiary federal–provincial agreements for agriculture and food development administered under the Economic and Regional Development Agreements have been signed by six provinces, with two others in the process of reaching an agreement. These agreements include funding for a substantial component of applied research in agriculture (about $90 million current dollars from 1982 to 1990).

It is generally quite difficult to obtain data on provincial and industrial research expenditures in agriculture. Only Ontario and Quebec have easily identifiable expenditure programs. Ontario funds agricultural research through the Agricultural Research Institute of Ontario, which had a fairly stable average budget of $26 million per year from 1981/82 to 1986/87. Over half of this budget covers a contract agreement with the University of Guelph. In Quebec the R&D budget appropriations of Agriculture, *Pêcheries et Alimentation Quebec* have more than doubled between 1980/81 and 1986/87 and have averaged $14 million per year.

*Research in Forestry*

Federal activity in forestry R&D is undertaken by the Canadian Forestry Service (CFS), which also administers a program of grants to universities for forestry research. Since 1983, the CFS has been part of Agriculture Canada. CSF total expenditures increased from $53.5 million in 1980/81 to $232 million in 1986/87. Research expenditures from 1984/85 to 1986/87 averaged $57 million per year, and increased by 23% over the 3-year period. Federal-provincial Forest Development Agreements have been signed with eight of the provinces but these are directed more at forest management than at research. The forest industry is unique among the resource industries in having its own cooperative research organization, the Pulp and Paper Research Institute of Canada (PAPRICAN), a joint venture of the federal government, McGill University, the University of British Columbia and the Canadian Pulp and Paper Association. PAPRICAN spent an average of about $14.5 million per year between 1980 and 1986.

## CONCLUSION

Mineral research and development is a vital component of the effort to maintain or improve mineral sector competitiveness and to search for new markets for mineral products. The mineral sector, and especially mining, has become less significant in the Canadian economy, but it nevertheless still retains an important role. It plays a substantial role in Canadian exports and, although it represents a minor proportion of total employment, it is a major source of jobs in certain areas.

The mineral industry is in its mature phase. Canada has good mineral potential, along with the technological ability to develop it. However, in recent years demand changes, price declines, and increased competition from other world suppliers have adversely affected the industry. In such an environment R&D is crucial to maintain a competitive position and to realize the industry's long-term potential.

Both business and governments contribute to the R&D effort in mining and metals in Canada (Tables 3.1, 3.2 and 3.3). In 1986 government and industry together spent about $47 million on mining, which represented about 0.5% of the 1986 mining GDP of $9,465 million. The federal government spent roughly $11 million, the provincial governments $5 billion and business about $31 million of its own funds. R&D actually performed by business was higher than its funding contribution, at about $39 million.

In metals-related R&D, the government and business sectors spent approximately $75 million in 1986 or 1.4% of primary metal GDP of $5,537 million in 1986. The largest portion came from industry ($45 million of its own resources) while the federal government contributed about $27 million and the provincial governments spent about $4 million. Business performance of metals-related R&D was $91 million, much of which came from Alcan.

Part of the total government spending on mining and metallurgy R&D in 1986 was derived from the MDAs – roughly $5.4 million of the total of $46 million. The MDAs will expire in 1990/91 and appear to represent the major mining and mineral R&D effort in many provinces.

The above estimates of R&D contribution are approximate. The actual total funding levels are higher. For example, much of the difference between business R&D expenditures and performance represents funds provided not by the federal governments but by other Canadian sources and foreign sources, including intracorporate transfers. In the primary metals sector, funding from these two sources of $45 million accounted for about half of the R&D expenditures in industry. Much of this funding was from Alcan International. Some of this funding may be derived from provincial governments, so some double counting may occur but, when added to government and business own expenditures, metals–related R&D totals $120 million or 2.2% of primary metal GDP.

Overall funding levels of R&D are one important indicator of the importance attached to mining– and metals–related research. Another is the focus of university research and teaching. It is in universities that much of the fundamental research is done, and it is also in universities that the future researchers and innovators will be found. In general, it appears that metallurgy is faring better than average, although mining receives very little R&D support and has fewer graduate students. Growth in graduate student enrollment, NSERC grants, scholarships and fellowships was higher over the period 1980–87 in the combined category of mining and metallurgy than in all disciplines combined.

The focus of government R&D has, in general, shifted away from the resource sectors. However, some resource sectors fare better than others. Agriculture receives the relatively best government R&D support with the highest intensity in terms of sector GDP and the fastest rate of increase. All the primary resource industries spend under 1% of sales on R&D; in most cases, under 0.5%. The mineral industries undertake a fair amount of intramural research (primarily in metals rather than mining). The petroleum industry has cut its R&D expenditures back sharply, and the forestry industry has held steady, at about the same level of R&D intensity as the mineral sector. Industrial R&D as a percent of GDP in all the resource sectors remains below the industrial average and is too low to support major technological innovation.

In summary, it appears that metals–related R&D is fairly strong, although much of it depends on the effort of one company. Support in universities also appears to be reasonably strong. The situation is less favourable in mining, where the total R&D intensity is much less and university R&D funding is weak.

# CHAPTER 4. INTERNATIONAL COMPARISONS: THE ECONOMIC CONTEXT

This chapter will examine where Canada and the seven other OECD countries studied stand in terms of the first two factors identified in the framework for comparison: the mineral industry life cycle and import/export dependence. Tables 4.1 and 4.2 present summary statistics characterizing the economy, the mineral sector, and the contribution of the latter to the former in each of the eight countries. As elsewhere in this report, the reader is warned of problems of comparability, reliability, and varying time periods in the data.

## STAGE IN LIFE CYCLE

None of the countries included in this study are in the initial stage or second stage of early and rapid growth in their mineral industries' life cycles. Most are in the decline phase: some have recently entered or are about to enter it, and others are well towards the later stages of the phase. The stage in the mineral industry life cycle in each country varies by commodity, but overall generalizations are possible.

Canada is in the third or mature phase for many of its mineral commodities. This phase is characterized by economic viability and growth potential and can last many decades, or even centuries. Commodity-by-commodity placement on the life cycle would require evaluation of reserves, location of producers on a cost curve, and location of each commodity on demand and intensity-of-use curves. The structural downturn in the Canadian mineral sector since the early 1980s has been misread by many observers as a permanent decline. Rather than a decline, it represents a readjustment to a new plateau, in response to changing circumstances of supply, demand, exchange rates, and relative prices for mineral commodities (Appendix B, Table B.4). Canada's excellent geological potential, and the demonstrated ability of the mining industry to respond when needed with technological improvements and cost-cutting measures to maintain a competitive position, confirm that the industry has a long future ahead of it. This view is reinforced by a recent study by Leo Verleun and Brian Mackenzie, which demonstrates that mineral deposits in the north of Canada, where the potential has barely been tapped, are more economic and offer a better potential rate of return than deposits in the south.[1] There will be shifts in location and in commodities, but the potential of the Canadian mineral industry is good.

Australia is the only other country among those studied to be in the mature phase of its mineral industry life cycle. The Australian mining sector has grown rapidly in recent decades. Although its importance has declined somewhat in the 1980s, it remains an important economic sector. It is like the Canadian industry in terms of GDP and employment, but is much more significant in exports. Like Canada, Australia has substantial reserves, with good long-term economic potential. Also like Canada, it undertakes relatively little domestic processing or fabricating of its crude mineral products, given the size of its mining industry.

All the other countries in this study may be considered to be in the decline phase of the primary mineral industry life cycle, although the United States might instead be classified as approaching the end of its mature phase. Its total mineral production is still much greater than Canada's (Table 4.1).

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[1] L. Verleun and B. Mackenzie, *Mining Potential in Northern and Southern Canada: A Comparison of the Quality and Viability of Base Metal Resources*. Centre for Resource Studies, Kingston, Ontario 1988.

Table 4.1 Measures of Mineral Industry Economic Activity: GDP, Value of Mineral Production and Exploration Expenditures, 1985 (value in 1985 U.S. $ billion or percent) or 1980–85 (percent change*)

| | Canada | Australia | Finland | France | West Germany | Sweden | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|
| Total GDP value | 316.7 | 155.1 | 54.0 | 510.2 | 625.0 | 100.2 | 454.3 | 496.6 |
| % change | 2.9 | 3.1 [a] | 2.7 | 1.3 | 1.3 | 1.8 | 1.8 | 2.4 |
| Per capita | 12,577 | 9,847 | 11,204 | 9,251 | 10,243 | 11,994 | 8,026 | 16,494 |
| Mineral GDP value | | | | | | | | |
| Mining | 8.7 | 4.5 [c] | .2 | 2.5 [b] | 5.0 [d] | .5 | 5.2 [c] | 26.6 |
| Basic metals | 5.0 | 2.5 [c] | .5 | 8.2 [b] | 13.6 [d] | 1.2 | 5.7 [c] | 35.2 |
| Total | 13.7 | 7.0 [c] | .7 | 10.7 [b] | 18.6 [d] | 1.7 | 10.9 [c] | 61.8 |
| % of total GDP | | | | | | | | |
| Mining | 2.7 | 3.2 [c] | .4 | .5 [b] | .8 [d] | .5 | 1.2 [c] | .7 |
| Basic metals | 1.6 | 1.8 [c] | 1.0 | 1.6 [b] | 2.3 | 1.2 | 1.3 [c] | .9 |
| Total | 4.3 | 5.0 [c] | 1.3 | 2.1 [b] | 3.1 [d] | 1.7 | 2.5 [c] | 1.6 |
| % change | | | | | | | | |
| Mining | 3.7 | −.2 [f] | −.6 | −3.4 [k] | 1.4 [d] | 4.2 | −21.7 [f] | −1.6 |
| Basic metals | 5.0 | −.6 [e] | −1.1 | −1.6 [k] | −2.9 | 1.1 | −2.3 [f] | −8.0 |
| Total | 4.0 | −2.4 [f] | −1.1 | −2.1 [k] | −1.9 [d] | 1.8 | −11.9 [f] | −5.8 |
| Fabricated metal products GDP[1] | | | | | | | | |
| Value | 4.3 | 2.0 | 0.8 | 5.8 | 13.7 [b] | 1.9 | 7.5 [i] | 61.8 |
| % of total GDP | 1.4 | 1.4 | 1.4 | 1.2 | 2.3 [b] | 1.9 | 1.8 [i] | 1.6 |
| % change | −1.0 | −1.9 | 2.8 | −1.9 | −2.6 [k] | .9 | −1.6 [f] | −2.1 |
| Value of mineral production | | | | | | | | |
| % change | | | | | | | | |
| Mining | −4.4 | .3 [g] | 4.4 | −3.6 | 0.1 | 4.7 | 4.5 | −5.0 |
| Basic metals | na | −3.4 [k] | −.8 | −3.7 | −4.1 | .6 | −4.4 [k] | −8.1 |
| Total | na | −3.1 [g] | −.3 | −3.7 | −3.1 | 1.1 | −9.2 [k] | −7.3 |
| Exploration expenditures | | | | | | | | |
| % change | −3.8 | −11.4 [h] | −2.5 | na | negative | −3.8 | 9.2 | −16.1 |
| % of production | 3.2 | 3.7 [i] | 4.7 | na | na | 5.1 [j] | .1 | .4 |
| Per km$^2$ | 36 | 41 | 53 | na | na | 58 | 10 | 20 |

Table 4.1 (cont'd)

Sources: Background study for each country: OECD, *Industrial Structure Statistics*, various years: OECD, *National Accounts*, 1973–1985, Volume II; U.S. Department of Commerce, *Statistical Abstract of the United States*, 1988; and *Australian Bureau of Statistics, Yearbook*, various years

na – Not available
* Average of annual percent changes based on real domestic currency values

[a] 1981 –1985
[b] 1984
[c] These are estimates based on data for value added. 1984 for Australia and 1983 for the United Kingdom
[d] Coal only is used for mining – it accounts for at least 85% of total mining
[e] Value added, 1980–1985
[f] Value added, 1980–1984
[g] 1980–1983
[h] 1982–1985
[i] 1983
[j] Exploration expenditures as a percent of GDP
[k] 1980–1984
[l] Value added is used as a proxy for sector GDP for each country except Canada

The United States has a history of mineral production not unlike that of Canada and Australia, with a similar commodity distribution but larger production volumes. The primary mineral industry plays a relatively smaller role in the larger US economy. The basic metals industry is of roughly the same size as the mining industry in the United States and the United Kingdom in terms of contribution to GDP, whereas in Canada and Australia it is much smaller, and in the other OECD countries it is much larger. The United States is different from the other countries in the study, in that it is not particularly export-dependent for any stage of its mineral sector, from crude minerals to fabricated metal products. The United States mining industry was characterized by falling production values and volumes in most commodities through the first half of the 1980s. There has been some recovery since 1985, but prospects for long-term renewal in many commodities are not good, due to depletion, environmental regulation, and other cost pressures. Canada faces some of these same pressures, which contributed to the downturn in the Canadian mineral sector in the first half of the decade.

In Sweden, mining's contribution to GDP is insignificant, far below that of Canada and Australia (Table 4.1). Sweden is in the early phases of decline in metal mining and has no coal. Mining contribution to GDP actually increased somewhat in the early 1980s in Sweden, through growth in the nonferrous and nonmetallic sectors, while iron ore production has fallen and substantial rationalization has occurred in the iron mining industry. Although there is little statistical evidence yet of the decline of the economic importance of the mining sector, depletion effects and rising costs will take their toll in the next decade. The metal mining industry is expected to cease altogether early in the next century, unless major new discoveries are made. Sweden depends on imports of metallic and energy minerals to support its very strong basic and fabricated metals industries.

The remaining four countries studied, Finland, France, West Germany and the United Kingdom, can all be classified as being well advanced in the decline phase of primary mineral production, although there are exceptions for certain commodities in some of these countries. For example, in the United Kingdom the various mineral sectors are in quite different stages: metal mining almost ceased in the previous century, and is soon expected to expire altogether; coal mining's continued importance is more a matter of political considerations related to employment and security of supply than of economic reality. This will change, with privatization and continued rationalization of coal mining, and will also lead to a further decline in U.K. coal production. The industrial minerals sector remains important, although these three sectors together contribute relatively little to British GDP. In mineral resources, the oil and gas sector is quite important but it is now approaching the decline phase. The basic metals and nonmetallic mineral product industries are declining in the U.K.; volume of production generally appears to be falling, and employment has fallen drastically.

Finland, France and West Germany are in similar stages of their mineral industries' life cycles. In each, as in Sweden, mining contributes little to overall economic activity, while the primary metals industry plays a much larger role. In all three, the metal mining industry, after centuries of activity, is nearing an end because resources are becoming exhausted. An uneconomical coal industry continues to exist in France and especially in West Germany where, as in the United Kingdom, subsidization of the industry is a means of regional economic support. In each of these three countries, the industrial minerals sector remains relatively important, with increased exploration and production. All three countries have seen reductions in total domestic mineral exploration, and have turned to mineral exploration abroad to secure access to mineral and energy raw materials. There has recently been a decline in these offshore activities by Finland and West Germany.

In summary, the mineral industry in Europe is in decline: exploration activities are declining; the complete demise of the metal mining industry is approaching; the coal industry remains more important politically and regionally than its economic potential would justify; the basic metal sector is suffering because of raw material import dependence (to a lesser extent in Finland and Sweden than in the

U.K., France and Germany), environmental costs, and structural changes in supply and demand factors; and only the industrial minerals sector displays any potential for continued or increased activity. This sector is important in domestic economic activity, but rarely plays an important role in exports.

The United States faces a situation that is somewhat similar to that in Europe, and the mineral sector there is of roughly similar significance in the overall economy, except for exports and imports, which play a relatively minor role in the U.S. economy. In contrast, the mineral sectors in Canada and Australia remain quite important. In the mid-1980s, the mining and basic metal products sectors accounted for over 4% of GDP in both these countries.

In each of the continental European countries the mining industry contributed in the order of .5% of GDP or about one-third of the contribution of the basic metals sector in the mid-1980s (Table 4.1 and Figure 4.1). In the United States and the United Kingdom, the two sectors made roughly the same contribution to GDP. In Canada and Australia, the basic metals industry contributed only about half as much to total GDP as did mining in the mid-1980s. Nevertheless, the basic metals sector was generally of greater overall importance in Canada and Australia than it was in the other countries. Note that the relative importance of the mineral sector in various countries in terms of contribution to GDP indicates nothing about the relative importance of the national mineral industries in terms of the world mineral industry. For example, the mineral sectors in Sweden and Finland make roughly the same contribution to national GDP as does the same sector in the United States. However, the value of mineral sector GDP in the United States is approximately equal to the combined mineral sector values of the other seven nations studied here (Figure 4.2).

The importance of the mineral sector to GDP is mirrored in its contribution to employment (Table 4.2 and Figure 4.3). Basic metals provide much more employment than mining in the European countries, with the exception of the United Kingdom, where the contributions to total employment are equal. Somewhat surprisingly, the basic metals sector provides many more jobs than does mining in the United States and the two sectors are about equal in Australia. These relationships are much different than the relative contribution of the sectors to GDP and may reflect a relative inefficiency in basic metal production in these two countries. In Canada, the difference between the two sectors in terms of GDP contribution and contribution to employment is substantial, expecially when contrasted with the other countries.

For most of the countries, including Canada, employment in both basic metals and mining declined during the first half of the 1980s. The exceptions were the mining industries in Australia and Finland, where increases in employment at the beginning of the decade were followed by reductions in later years. In Canada, employment in mining may have stabilized since 1985. The decline in Canada reflected the effects of the economic recession and poor mineral prices, and the resulting restructuring and rationalization. These factors also played a part in the European countries and the United States, but an important element in these countries has also been the winding down of the industry as economic reserves have been depleted.

## IMPORT-EXPORT DEPENDENCE

Foreign trade plays a very prominent role in the economic life of all the countries considered here, with the exception of the United States and, to a lesser extent, Australia. Crude minerals and basic metals each constitute a significant proportion of Canada's total commodity exports. Since domestic production far exceeds domestic requirements, Canada will continue to need access to export markets for its minerals. The countries that constitute Canada's traditional markets buy Canadian ores and concentrates as feedstock for their metallurgical operations, in some cases to replace their depleted resources. These countries do not offer much prospect for increased demand for refined metals, at least until their current generation of processing facilities closes down or requires replacement. Some newer markets, in the Pacific Rim for example, are leapfrogging directly into processing operations, utilizing the newest state-of-the-art technologies. It seems likely that Canada will continue to export much of its mineral output in unprocessed form, particularly in the case of base metals, for the medium term at least. Continued access to world markets for Canadian mineral commodities will depend in large part on cost-competitiveness, and therefore on technological leadership in production of ores and concentrates.

Only Australia shares Canada's heavy reliance on export markets for its mineral products and, like Canada, produces a broad range of energy, metallic and nonmetallic minerals and basic metal products in excess of domestic requirements. It is heavily export dependent in coal, gold, diamonds, alumina and iron ore. About one-quarter of its total exports are accounted for by crude minerals, while 15% are basic metals, much higher proportions than for any other country in this study.

In each of the countries, except in the United Kingdom and the United States, exports of basic metals account for approximately 2% of GDP (Figure 4.4). The importance of crude mineral exports is much more variable across the countries, ranging from their quite significant contribution in Australia and to a lesser extent in Canada, to a negligible contribution in Finland, France and the United States.

The European countries as well as the United States are import dependent for metallic ores and concentrates. Sweden is an exception to some extent, since it is export dependent for markets for its iron ore and lead and zinc concentrate production. In some of the European countries imports of ores and concentrates greatly exceed domestic requirements. The imports are used in processing facilities that feed the metal fabricating and machinery industries, much of the product of which is for export. This is true, for example, in Finland, Sweden and West Germany. It is also true to a certain extent in the United States, except that there most of the higher-value-added manufacturing serves domestic rather than export markets. In Canada and Australia there is relatively little export of fabricated metal products.

There are varying degrees of dependence upon imports of industrial minerals. In general, industrial minerals are much more important in domestic markets than in foreign trade. Neither West Germany nor the United States is import dependent for its supply of coal; nor are they export dependent, since most of their production is used domestically. The United Kingdom has a slight degree of dependence on coal imports.

## CONCLUSION

Patterns of the economic impact of the mining and basic metals sectors in the countries studied are clearly defined. Canada and Australia have seen readjustments in the 1980s that have put their industries in reasonable condition to maintain a competitive position and expand reserves over the medium to long term in many mineral commodities. Both will continue to export a significant proportion of metallic ores and concentrates and other crude minerals.

The remaining six countries in the study are in various stages of decline in the production of metallic minerals, with most facing termination of their metal mining industries by early in the next century. Sweden and Finland have no fossil fuel resources, and the coal resources of the remaining European countries studied are costly to produce and are subsidized. All are dependent on imports of metallic ores and concentrates.

Table 4.2 Trade and Employment Impacts of the Mineral Sector, 1985 or 1980–85, Percent Change
(1985 U.S. $ billion or percent)

| | Canada | Australia | Finland | France | West Germany | Sweden | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|
| Exports | | | | | | | | |
| Total | | | | | | | | |
| % of GDP | 26.9 | 14.5 | 29.8 | 23.6 | 29.2 | 30.1 | 22.4 | 5.1 |
| Mineral value | | | | | | | | |
| Mining | 5.5 | 5.4 | .1 [a] | .6 | 1.9 | .6 | 2.0 [a] | 7.2 |
| Basic metals | 6.1 | 3.2 | 1.0 [a] | 8.0 | 14.2 | 2.3 | 5.2 [a] | 4.4 |
| Total | 11.6 | 8.5 | 1.0 [a] | 8.6 | 16.1 | 2.9 | 7.2 [a] | 11.6 |
| % of total | | | | | | | | |
| Mining | 6.5 | 24.9 | .3 [a] | .5 | 1.1 | 2.0 | 2.1 [a] | 3.5 |
| Basic metals | 7.2 | 14.8 | 5.9 [a] | 6.7 | 7.8 | 7.7 | 5.4 [a] | 2.1 |
| Total | 13.7 | 39.7 | 6.3 [a] | 7.1 | 8.8 | 9.7 | 7.5 [a] | 5.6 |
| % change | | | | | | | | |
| Mining | −1.6 | 7.4 | −.7 [b] | 3.3 | na | 6.8 | −5.5 [d] | −9.1 |
| Basic metals | −4.6 | −.7 | 5.2 [b] | .2 | 2.4 | 2.7 | −2.0 [d] | −7.7 [c] |
| Total | −3.3 | 3.8 | 4.8 [b] | .4 | na | 3.3 | −3.1 [d] | −7.5 [c] |
| Fabricated metal products | | | | | | | | |
| Value | na | .1 | na | 2.8 | 7.6 | 1.6 | 2.2 [a] | 3.6 |
| % of total | na | .5 | na | 2.3 | 4.2 | 5.1 | 2.3 [a] | 1.8 |
| % change | na | −6.8 | na | 1.1 | 3.2 | 4.8 | 0.2 [b] | −17.8 [c] |
| % of fabricated metal GDP[f] | na | 5.3 | na | 47.5 | 53.8 | 82.2 | 30.2 [a] | 5.9 |
| Import dependency | | | | | | | | |
| Metallic ores and concentrates | no | no | yes | yes | yes | yes | yes | yes |
| Coal | no | no | yes | yes | no | yes | yes [e] | no |
| Employment | | | | | | | | |
| % of total employment | | | | | | | | |
| Mining | .7 | 1.1 [a] | .3 | .5 [a] | .9 | .3 | 1.0 [a] | .3 |
| Basic metals | .3 | 1.2 [a] | .8 | 1.3 [a] | 1.6 | 1.2 | 1.0 [a] | .8 |
| Total | .9 | 2.4 [a] | 1.1 | 1.8 [a] | 2.5 | 1.5 | 2.0 [a] | 1.1 |
| % change | | | | | | | | |
| Mining | −4.5 | 1.5 [d] | .3 | −4.6 | −2.4 | −4.0 | −6.9 [d] | −5.7 |
| Basic metals | −4.1 | −4.7 [d] | −1.2 | −4.4 | −8.1 | −5.2 | −12.7 [d] | −6.4 |
| Total | −4.6 | −1.9 [d] | −.9 | −4.6 | −6.4 | −4.9 | −10.2 [d] | −6.3 |

Table 4.2 (cont'd)

Sources: Background study for each country; OECD, *Industrial Structure Statistics*, various years; OECD, *National Accounts, 1973–1985, Volume II*; U.S. Department of Commerce, *Statistical Abstract of the United States*, 1988; and *Australian Bureau of Statistics, Yearbook*, various years

na – Not available
* Average of annual percent changes based on real domestic currency values

[a] 1984
[b] 1981 –1984
[c] 1982–1985
[d] 1980–1984
[e] U.K. coal imports are about 12% of domestic coal production
[f] Value added is used as a proxy sector GDP. These data are based on standardized OECD classifications for which data on Canadian exports were not available

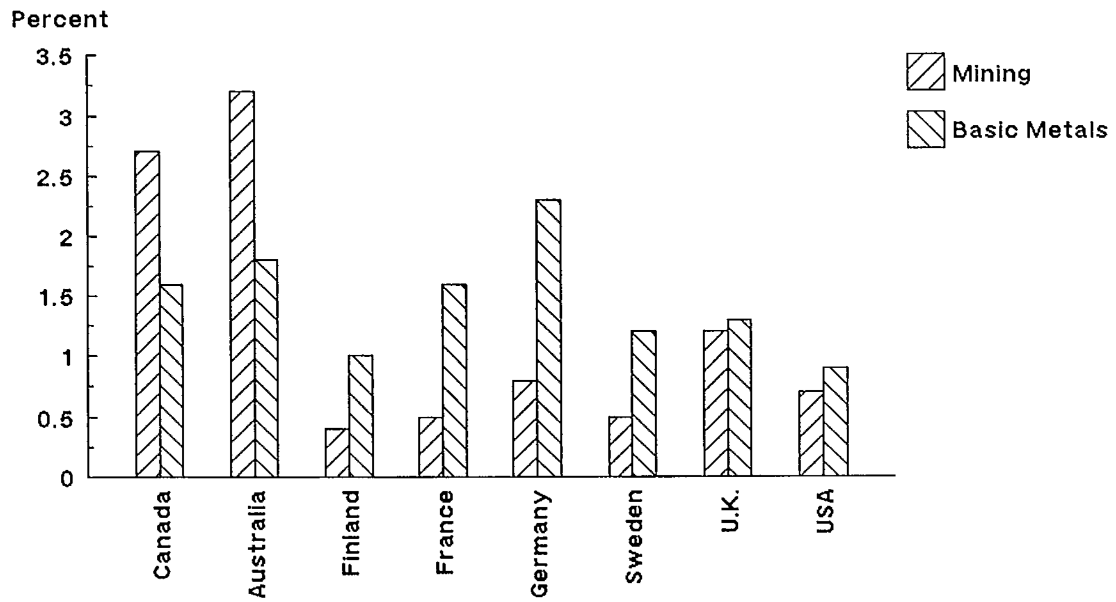


Figure 4.1 Mineral industry GDP as a percent of total GDP, 1985

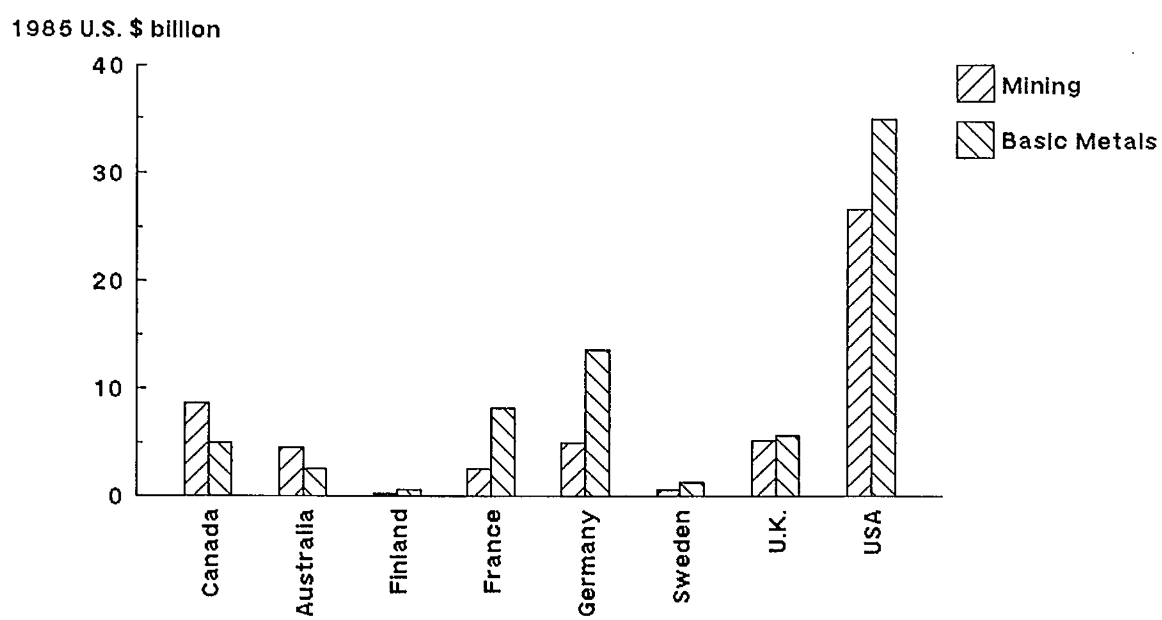


Figure 4.2 Value of mineral industry GDP, 1985

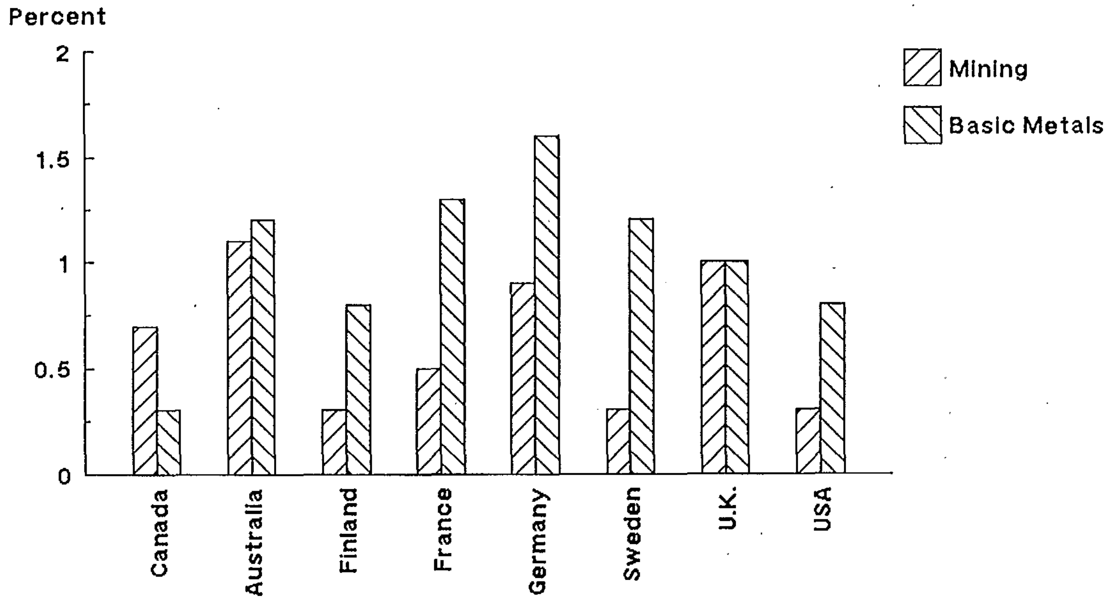


Figure 4.3 Mineral industry employment as a percent of total employment, 1985

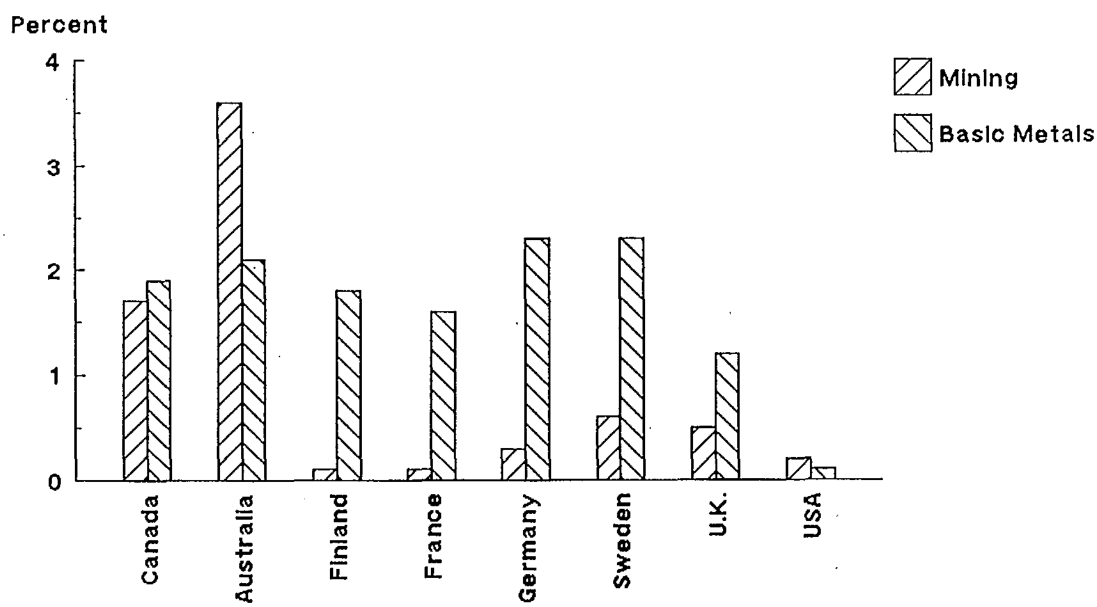


Figure 4.4 Importance of mineral sector exports, 1985
(mineral sector exports as a percent of total GDP)

# CHAPTER 5. INTERNATIONAL COMPARISONS: POLICIES AND ATTITUDES

This chapter will present a synopsis of the overall R&D effort in Canada and in the seven other OECD countries considered, in the context of policies and attitudes which influence R&D levels and trends (items 3 and 4 in the framework given in Chapter 3). The first section will examine the R&D implications of policies and attitudes in Canada; the second section will look at the other countries. The impact of economic, social and political factors as well as the "cultural" factors will be considered, in terms of effect on R&D effort and effectiveness.

## R&D IN CANADA

In terms of the socio-political environment affecting the mineral industry in Canada, and the effectiveness of the industry's R&D efforts in cost reduction, the most distinctive feature is the very broad range of social and political policies that impose costs or offer incentives. For the mineral industry, these policies include incentives and subsidies aimed at regional economic development and various forms of regulation costs. To the extent that mandated costs exceed the direct economic benefits of incentives, they will accentuate the troughs of the economic cycles during the mature phase and hasten the approach of the decline. The costs and benefits to the industry are difficult to measure, and they are even more difficult to measure in terms of social welfare.

The R&D implications for the mineral sector are most conspicuous in the area of environmental protection, which has been the motivation for 25% to 30% of the mineral-related R&D expenditures in Canada in recent years, both in industry and in the federal government. Regional development policies and policies related to security of energy supply have also been major factors in triggering federal government R&D expenditures.

R&D policies per se are particularly significant. In this area, two recent trends give rise to concern about Canada's capabilities in long-term R&D and innovation. In the traditional pattern of allocating responsibility for R&D funding and performance, governments have been the major funders of basic R&D and universities the major performers. Business enterprises have had the major role in applied R&D. In Canada, as in most other industrialized nations, this pattern has changed dramatically in recent years. Regional and industrial development policies, as well as environmental and health and safety concerns, have increased government involvement in primary and secondary industries. Basic research funding has been cut in favour of "strategic" research, long-term applied research, or unabashed short-term applied R&D. NSERC's recent five-year plan notes its focus on support for applied research and technological innovation in universities. The National Research Council has likewise shifted its focus to research with a greater emphasis on technology and problem-solving and less on "advancement of knowledge".

The result is that there is now no agency in Canada charged exclusively or even primarily with funding basic R&D. The universities have increasingly become performers of applied and sponsored R&D rather than basic R&D. Little effort has been made to link university R&D activities with industrial requirements, and the success rate for transfer of technology has been low. However, recent federal and provincial government initiatives such as the Network of Centres of Excellence Program and University Research Chairs are designed in part to improve linkages between industry, universities and governments in collaborative research and increase communication between researchers across the country. These initiatives may help to improve technology transfer. They will not resolve the dilemma caused by the fact that the decline in basic research reduces the prospects for major innovative breakthroughs.

A second questionable trend in Canadian R&D policies has been a shift away from the primary resource sectors into advanced technologies and the higher–value–added aspects of industrial production. While these areas are of prime economic importance for employment and wealth creation, there is little evidence so far of targeting specific aspects of such broad fields as microbiology, information technology or materials technology to direct R&D into areas where Canada already has a comparative advantage. For example, building on advantages arising from domestic sources of raw materials, including mineral commodities, could be a major research focus. The result of this trend to high tech is a shift away from R&D in primary resource production and processing, where we have an established comparative advantage and a base of technological expertise, into new areas where we are competing with a great many other countries with much better records of success in innovation in the high–value–added area than Canada has demonstrated.

One reason for Canada's poor record in commercialization of innovation may be that Canada is not well–placed on the scale measuring attitudes towards science and technology. While this characteristic is difficult to document, its implications are serious, as can be seen by examining its effects elsewhere: for example, the case of iron and steel and of coal in England. In the 19th century, while much of continental Europe had established strong research programs and technical training programs in many areas of engineering and technology, including steelmaking and mining, England continued to stress classical education. Its steel industry was already in trouble, characterized as being trapped in isolated, fragmented production systems, where "science was not only neglected ... it was scorned. There reigned instead the stultifying authority of customary practice and traditional wisdom", according to Correlli Barnett.[1] Nor did Barnett's "practical man" limit his injuries to the steel industry. The coal industry was equally badly served, and by the end of World War II, both the coal and the steel industries were in sorry shape in the U.K. (much worse, for example, than in Germany), along with much of the U.K.'s manufacturing capability.

Like the U.K., Canada shares many of the symptoms of the "two cultures" syndrome described in Chapter 2. It has very few scientists and engineers in management and operating positions or in government policy development roles, and it has its share of "practical men" who prefer tradition to innovation. The resulting constraints to innovation, no matter how pressing the need or how good the R&D, can weaken Canada's competitive position and hasten the approach of the decline in the mineral sector.

## R&D IN OTHER COUNTRIES

### Australia

Australia's science policies are relatively new, and frequent changes in programs and government organization have prevented development of a strong, coordinated and focused central R&D policy. Nevertheless the government does fund and perform a significant amount of R&D. An OECD study has concluded that the level of scientific activity in Australia compares favourably with that of leading developed countries. It does, however, have a poor record of innovation, and the contribution of industry to R&D is relatively low. Like Canada, and all the countries included in the study, the Australian mineral industry carries a heavy burden of socioeconomic costs resulting from government policies and programs related to environmental protection, health and safety, land use, and regional development.

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[1] C. Barnett, *The Audit of War*, Papermac, London, 1986, p. 97.

The "two cultures" perception of science and business, and the concomitant lack of communication and even mistrust which divide the two, do not seem to be as prevalent in Australia as in some other parts of the English–speaking world. For example, in Australia there seems to be a positive attitude towards joint endeavors in industry, and between industry, government and other organizations, and less concern over secrecy and protection of proprietary rights arising from joint–venture R&D findings than in Canada, notably in metals R&D. As noted, however, industry support for R&D is low.

The Australian government has taken the same path as Canada in shifting R&D support away from the natural resource sectors, including the mineral sector. "Designated growth areas" for R&D emphasis have been specified in Australia; for the most part, they deal with high–technology manufacturing. This seems to imply a further reduction in relative support for mining and exploration, and greater emphasis on higher–value–added activities, including physical metallurgy and new materials.

## Finland

In Finland the government provides strong direction and a focus for R&D planning. R&D has been a central concern since World War II, with a ministerial–level Science Policy Council, headed by the Prime Minister, directing policy. The government's guiding role in R&D is a reflection of its belief in the efficiency of central government coordination of industrial activity, and of R&D aimed at supporting national goals.

By the end of the 1970s, applied science and technology, rather than basic science, were being emphasized in government support programs. In the universities, nearly all funding for research is sponsored and technology–oriented rather than intended for "advancement of science". The emphasis on industrial and technology R&D is essentially a short– to medium–term policy perspective. It is not clear what the implications are of the relative lack of basic research, which is longer–term and may not yield a pay–back until well into the future. To some extent, Finland has adopted the view that it is too small to fund a large basic R&D effort. Although it does recognize the danger that a lack of basic R&D presents for long–term development; the Department of Industry has indicated that its plan is to have basic R&D increase by 15% a year, hopefully without decreasing funding for other R&D directions.[1]

The country continues to be very effective in technological innovation across a broad range of industries, including specialty steels, machinery and electronics. Part of the credit for excellence in technology transfer must go to the high level of integration of activities in government, university and industry research organizations.

## France

The R&D policies of France, like those of Finland, are highly centralized and organized. They have also been characterized as being project–oriented and very compartmentalized within scientific disciplines and within sectors. The tendency for R&D activity to be "project–oriented" implies a relative bias away from basic research, which is less goal–driven in perspective. The compartmentalization of government, industry and university research organizations and researchers discourages scientific communication and technology transfer between the sectors (not to mention collection of R&D statistics). Note that in France this lack of communication is not symptomatic of the two–cultures attitude; the separation is within the scientific and research community itself, rather than between the scientific community on one hand and business and government on the other.

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[1] B. Blomqvist, Head, Technology Bureau, Department of Industry. Interview, 10 June 1987

French R&D policy is very much integrated with the government's broad industrial and economic policies. In 1981, science and technology became an election issue, and in 1982, the Ministry of Industry and Research was created to promote technological change and encourage a "technical culture". Legislation was introduced fixing the growth rate for budgetary R&D expenditures at almost 18% per year. New research goals and areas of focus were identified, including major linked programs in electronuclear research, aeronautics and space, and the commercialization of advances in various areas, including the raw materials industries. One important aspect of the national program was a focus on enhancing communication between public and private sector organizations and researchers.

The French mineral industry has been the subject of three principal policy thrusts in industrial structure and R&D support. First, the government has used a combination of rationalization, nationalization and reorganization in an attempt to counter the effects of depletion, rising costs and import dependency. A second thrust has been the encouragement of offshore (foreign and French territorial) mineral exploration by French companies, in order to ensure a continuing supply of crude minerals. A third thrust, which is related to the second, has been an emphasis on maintaining a high level of expertise in all aspects of mineral production and processing. This has led to the continued life of some economically inefficient operations in order to provide a means by which French professionals can "keep their hand in" all facets of mineral production.

Environmental protection policies in France have added to the already–high cost burden of its basic metals industry, contributing to the sector's uncertain future.

## Federal Republic of Germany

Unlike most countries in this study, and certainly unlike Canada, the most immediately apparent characteristic of West German R&D is that it is conducted in an environment of widespread interaction among all sectors of research. There has been a long tradition of support for scientists and scientific development both in society and in government. This attitude has been fostered by the "one culture" mentality in which the scientist, businessman and administrator are perceived to be mutually dependent and sustaining. Careers spanning all three sectors are the rule rather than the exception for senior scientists.

A second area of difference is the strong emphasis on basic R&D. Among the countries studied, only Germany and Sweden include a major funding component for R&D in university budgetary funding. This funding is by definition unsponsored, and available for basic R&D at the discretion of university research directors.

A third area of difference is the extensive use of cooperative research institutions. R&D activity is undertaken by a wide variety of researchers and with funds from a wide variety of sources. Cooperative institutions help to maintain a high level of communication between government, industry and university. A particularly large role is played by the mixed government and private sector research organizations.

Security of supply of raw materials and of energy has been a continuing consideration in government policies affecting the mineral sector, including science and technology policies. In the 1980s, R&D focus has shifted somewhat towards applied science and technology, but there remains a strong emphasis on basic R&D. Technology transfer and exchanges between industry and researchers have also received renewed emphasis. Technology transfer has been quite successful because of the high mobility of scientific personnel between various research sectors, the proliferation of programs designed to encourage industrial research, and the "one culture" mentality in which engineers and scientists command considerable respect and play important roles in policy formulation and operating in industry and in government.

## Sweden

The organization of R&D in Sweden can be characterized as decentralized, sectorized and pluralistic. For example, there is no central controlling R&D ministry. Whereas in France this appears to have caused compartmentalization and lack of communication between R&D sectors, in Sweden an integrated but pluralistic decision process has arisen. A wide variety of groups have an influence on R&D policy and funding directions. The government provides active leadership in identifying targets for research and development.

The cooperative and consensus approach to R&D is expressed in the degree to which universities and industry play a role in the national R&D effort; both play a larger role than in most other countries. As noted, operating budgets in their universities receive a substantial component of R&D funding, which is available for basic research.

The 1980s have been characterized by a legislative effort to coordinate R&D and to provide a broad focus on both basic and applied research in various designated sectors. Government R&D support for industry and cooperative R&D organizations has stressed technological innovation. Although a number of specific industrial sectors have been targeted for R&D by government, the mineral sector is not one of them. Nevertheless, a number of interesting R&D joint ventures are underway in geoscience, mining technology and mineral processing.

The burden of socioeconomic policies, particularly in the area of environmental protection, is strong in Sweden and adds to costs in both mining and basic metals.

## United Kingdom

R&D in the United Kingdom appears to be very fragmented, with no strong government leadership in policy. There have been recent attempts to coordinate R&D, at least in the public sector, but it was only in 1982 that the government decided to introduce annual reviews of departmental research programs and budgets. Although the U.K., like France, West Germany and other countries, has set up some government research organizations, in the U.K. the universities remain the focus of basic research activity. However, there has been a reduction in support for universities as a whole; funding has fallen in real terms, and significant numbers of researchers have left the country. There has been a general move towards rationalization of education and research facilities. Earth sciences have been targeted, and a 1989 report of the University Grants Committee (UGC) recommended closing three of Britain's mining schools.

Applied R&D in the U.K. is receiving less support from government than in previous years, and industry has not yet picked up the slack. There is a feeling that university links with the private sector are not encouraged. Most of the university funding and staff cuts appear to be aimed at applied schools and programs, while the traditional and well known basic–research–oriented universities have suffered much less. Furthermore, the tradition of strong university programs in the mineral area to support overseas operations and to train experts from former colonies seems to have been abandoned. There is little evidence of strong connections between universities and industry, and there are few joint research establishments.

Among the socioeconomic burdens facing the mineral industry in the U.K., one that is particularly discouraging to investment in any facet of the industry is the very complicated system of ownership and inheritance of mineral rights. The two cultures syndrome discussed previously also continues to contribute to problems in R&D, technological innovation, and the competitiveness of British industry.

## United States

The United States places a strong emphasis on defence R&D, as do France and the United Kingdom. In the 1970s the share of defence R&D in total R&D fell, but under the Reagan administration the trend was reversed. In general, the emphasis in the United States is on development rather than on basic or even applied R&D; this may be in part a reflection of the interest in defence.

The United States government perceives its primary responsibility in R&D to be the support of long-term research, which industry is less likely to undertake, and in areas such as defence and environmental regulation. In which society as a whole has a stake. The government believes that, with respect to industrial R&D, government's role is to provide a climate conducive to business R&D initiatives, and that a free-market environment and the collective judgement of economic agents will ensure an appropriate R&D effort.

The two cultures phenomenon has been identified as a negative factor in the U.S. innovation effort and in links between its R&D and technology. In spite of U.S. preeminence in R&D and its strong market for high-technology goods, for example, it is argued that this problem has contributed to a wide range of failures in the U.S. industrial sector, including falling behind its competitors in productivity, quality of products, and technology trade balance.[1] Competitors such as Germany and Finland, where science and technology are better integrated into society, are quicker to commercialize and market technological breakthroughs and faster to adapt to changing supply and demand pressures.

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[1] L. Thurow, "A Weakness in Process Technology", *Science*, 18 December 1987.

# CHAPTER 6. COMPARISONS OF NATIONAL R&D EFFORTS

## TOTAL R&D EFFORT

Up to this point, the international comparison of R&D efforts has for the most part been qualitative, providing a flavour of what influences R&D and how the roles of government, industry, universities and other organizations vary among countries. This chapter will provide a brief quantitative and aggregate summary of R&D expenditures. A number of important caveats must be kept in mind when reading this chapter.[1] First, any international comparison is bound to be affected by statistical inconsistencies . As noted in the first chapter, R&D statistics suffer from incomparability in terms of quality and definition, even at the aggregate level. A second and ultimately much more important consideration is the reliance on a few simple stand–alone statistics of R&D intensity to capture an understanding of something so complex as R&D activity.

The goal of comparing R&D indicators is to determine how well Canada is doing in relation to other countries in maintaining or increasing R&D effort and focus, with the ultimate goal of comparing potential competitiveness, economic growth, and ability to capture new markets. However, the links between R&D and productivity and economic strength are difficult to evaluate. These statistics should, however, give some indication of where Canada stands. They also give important insights into who funds R&D and who performs it.

A third important consideration is the comparability of R&D intensity measures, beyond any issue of consistency of their derivation. Comparisons on an aggregate, nation–wide level do not take into account basic structural differences between countries, such as the sectoral composition of GDP and the importance of defence–related R&D. Different industrial structures and different degrees of import or export dependency imply quite different R&D needs. For example, for structural reasons, a relatively small and domestically–oriented manufacturing sector, as in Canada, implies that total business R&D expenditures (BERD) will be relatively lower than in countries with larger manufacturing and high technology sectors.[2]

A final point to keep in mind is that measures of R&D expenditure intensity are only one indicator of the R&D effort. The statistics must be interpreted in the context of a country's sociopolitical environment, its attitudes, and other factors that temper the effectiveness of R&D and its links to innovation and commercialization.

Table 6.1 presents summary statistics of national R&D efforts. Figures 6.1, 6.2 and 6.3 provide graphical representations of some of these data. It is clear that Canada and Australia, the two most heavily resource–based countries, spend much less on R&D than do most of the European countries and the United States. However, France, the United Kingdom and the United States have a large R&D effort in defence. When only non–defence R&D expenditures are considered, these countries' overall R&D intensity ratios fall significantly, although they still remain well above the GERD–to–GDP ratio for Canada (Table 6.1).

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[1] A good analysis of comparisons of R&D data is given in K.S. Palda and B. Pazderka, *Approaches to an International Comparison of Canada's R&D Expenditures*, Economic Council of Canada, Ottawa, 1982

[2] Statistics Canada, *Science and Technology Indicators*, Ottawa, 1987, p. 64

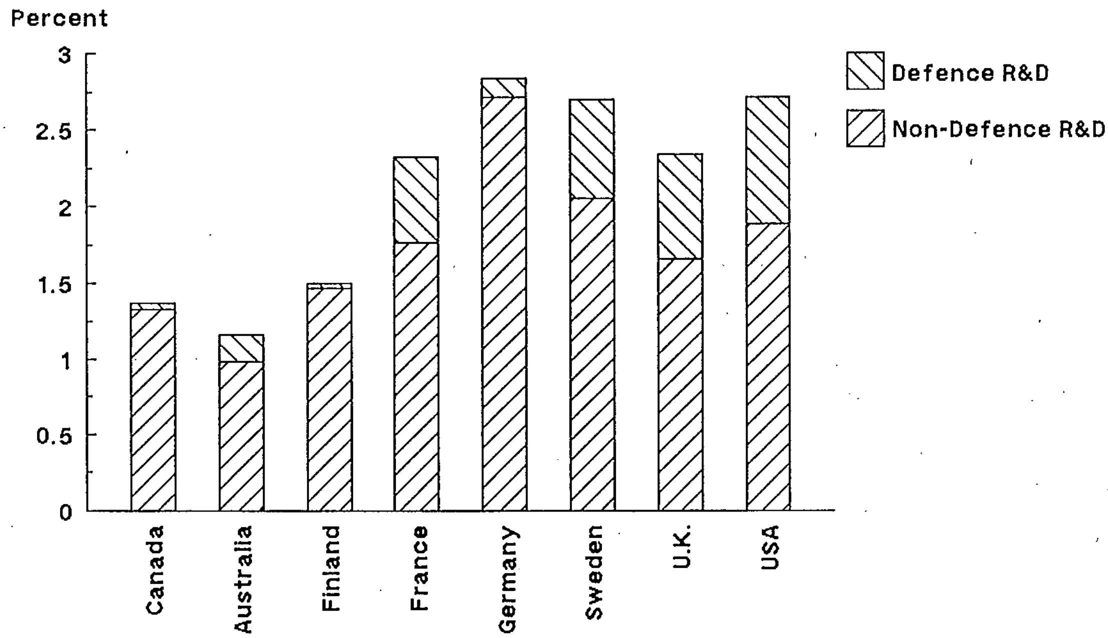


Figure 6.1 National R&D effort, 1985 (GERD as a percent of GDP/GNP)

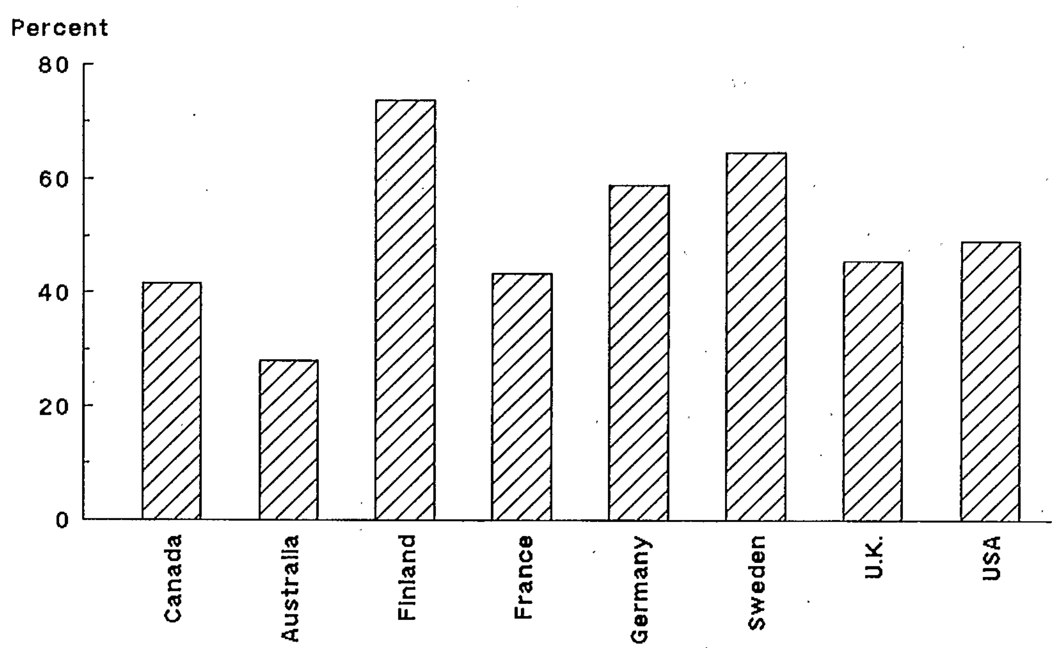


Figure 6.2 Business R&D effort, 1985 (BERD as a percent of GERD)

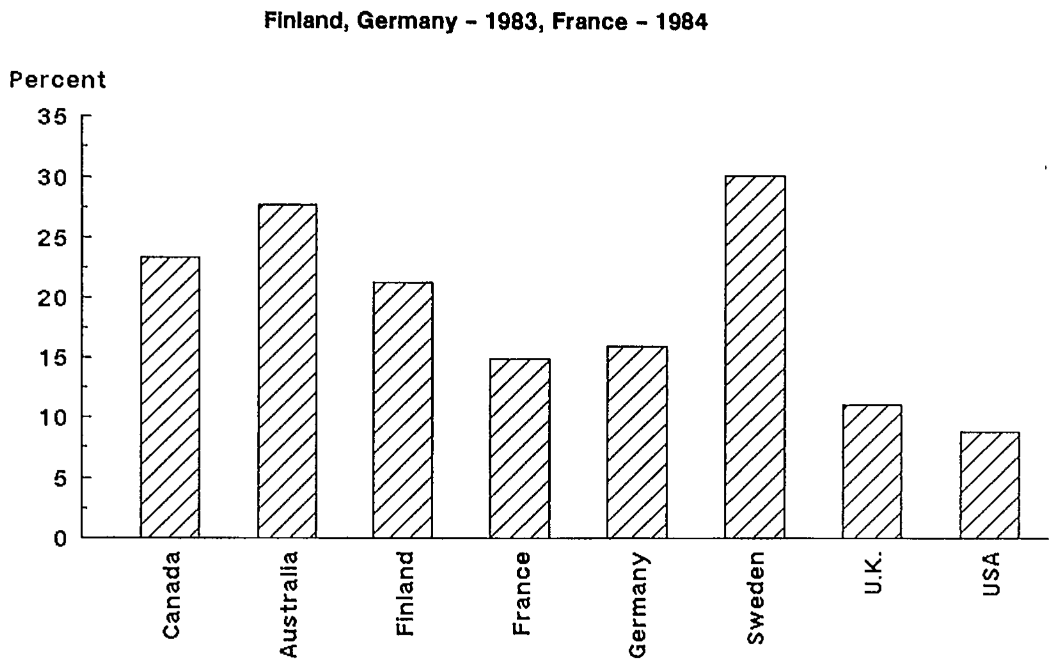


Figure 6.3 Performance of R&D by institutions of higher education, 1985
(higher education R&D expenditures as a percent of GERD)

The contribution of business to R&D in Canada appears to be roughly in the middle of the countries studied. In 1985, Canadian industry provided about 42% of all R&D funds, roughly in line with the proportion in France and the United Kingdom. In Sweden, West Germany and Finland, countries in which there is a fairly high degree of cooperation between sectors, the contribution of business was higher. Industry contributed relatively little in Australia, leaving the government as the key funder of R&D.

In most countries, higher education organizations perform a fairly large proportion of total R&D. The chief exceptions are the United Kingdom and the United States. In the United States, industry, with the help of government contributions, performs a much greater share of GERD than it funds, leaving relatively little funding for R&D performed by universities.[1] The relative lack of university R&D in the United Kingdom is perhaps indicative of two aspects of its R&D environment noted in the previous chapter: first, government funding for university research has not been stressed, and second, there has been little encouragement of industry–university interaction.

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[1] National Science Board, *Science Indicators: The 1985 Report*, Washington, 1985, p. 33

Table 6.1 Total National R&D Effort, 1985 or 1980–85 (Percent change*)
(Value in 1985 U.S. $ million or percent)

| | Canada | Australia | Finland | France | West Germany | Sweden | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|
| GERD | | | | | | | | |
| Total value | 4,782 | 2,118 | 678 | 11,853 | 17,745 | 2,705 | 10,607 | 107,436 |
| % of GDP/GNP | 1.37 | 1.16 | 1.50 | 2.32 | 2.84 | 2.70 | 2.34 | 2.72 |
| % change | 37.9 | 18.8 [b] | 23.8 [c] | 34.9 | 3.2 [d] | na | 7.5 [c] | 31.9 |
| Non-defence | | | | | | | | |
| % of GDP/GNP | 1.33 [f] | 0.98 | 1.47 | 1.77 [f] | 2.72 [f] | 2.05 | 1.66 [f] | 1.89 |
| BERD[g] | | | | | | | | |
| % of GERD | 41.7 | 28.1 | 73.8 | 43.4 | 58.9 | 64.6 [e] | 45.6 | 49.0 |
| % of GDP/GNP | .57 | .33 | .92 | 1.01 | 1.67 | 1.65 [e] | 1.07 | 1.33 |
| % change | 45.6 | 71.3 [b] | 61.6 [c] | 34.2 | 4.9 [d] | 6.1 [e] | na | 30.7 |
| Higher education R&D performance | | | | | | | | |
| % of GERD | 23.3 | 27.7 | 21.2 [a] | 14.9 [h] | 15.9 [a] | 30.1 [e] | 11.1 | 8.8 |
| % of GDP/GNP | .32 | .32 | .49 [a] | .33 [h] | .41 [a] | .80 [e] | .26 | .24 |

Sources: Background study for each country: Statistics Canada, *Science and Technology Indicators*, 1987; OECD, *Reviews of National Science and Technology Policy, Sweden* and *Finland*, 1987, *Australia*, 1986; Australian Bureau of Statistics, *Research and Experimental Development All-Sector Summary*, 1984/85; U.K. Cabinet Office, *Annual Review of Government funded R&D*, 1987; and United States National Science Board, *Science Indicators*, 1985

* Percent growth between 1980 and 1985 based on real domestic currency rates
na – Not available

[a] 1983
[b] 1981/82 –1984/85
[c] 1981–1985
[d] 1980 value taken as average of 1979 and 1981
[e] Natural sciences and engineering only; total social sciences and humanities R&D represents about .1% of GERD data
[f] Data for Canada, France, West Germany and the U.K. estimated for 1985, based on 1983 non-defence GERD
[g] BERD here is R&D funding by business, not R&D performed by business
[h] 1984

## MINERAL-RELATED R&D

Canada's good long-term prospects for its mining industry are based on its rich mineral endowment, strength in technology and human resource skills, and well-established distribution networks and markets. Canada's opportunities to maintain an internationally competitive position in primary minerals depend on its ability to retain a technological lead over newly emerging mineral producers in the low-cost and rapid-growth phase of mineral production.

This would seem to call for an increased R&D effort aimed at cost reduction in all phases of primary mineral production. The industry sector in Canada does seem to be moving in that direction, with increased cooperation in research planning and a small increase in spending forecasts for 1988. However, the increase is little, and late. It follows many years of economic difficulties and low R&D expenditures. Table 3.3 indicated that R&D in metal mining fell sharply from its anomalous 1981 peak, reaching lows in 1983 and 1986 that were almost 40% below the 1981 level. Nonmetallic mining showed some increase until 1983, and then stayed constant in real terms.

At the same time, CANMET total funding levels have declined slightly; forecasts indicate that budgetary funding will continue to decline in real terms and that CANMET expects that, in the future, an increasing proportion of its funds will come from industry in the form of contracts and joint ventures.

In the universities, mining departments are relatively small and receive very little in the way of NSERC support. NSERC and other federal funding for 1985 represented only 39% of the mining departments' research income as reported to CRS, as compared to 59% for federal contribution to all university-sponsored research income. The number of PhD students in mining has been very small.

The relatively static level of R&D activity in the mining sector reflects a failure to take aggressive steps to maintain competitiveness in primary mineral production, or to realize the opportunity to fill the gap in technology, R&D and education leadership being opened up by the decline in primary mineral production, particularly metallic metal mining, in Europe. There have been some moves in the direction of research coordination, but more such efforts and a great deal more funding will be required to raise the level of R&D research, innovation and education in the mining sector.

Looking at research in basic metals, it is clear that the ferrous metals sector has shown no growth in R&D funding over the 1980s, and that R&D in the nonferrous metals sector, excluding Alcan has fallen precipitately, from $42 million in 1981 to $26 million (1981 $) in 1986. Only R&D in the nonmetallic mining sector has shown growth over the period.

In universities, the level of metals-related PhD studies and research funding is much higher than that for mining, suggesting that this branch of the industry should eventually have much stronger human resources for R&D activities.

Canada continues to export much of its primary metallic mineral production as ores and concentrates, and the European countries continue to be strong in the basic metals sectors in terms of R&D effort and university programs. Nevertheless, there is some sign of weakening here as well as in mining R&D. European smelters and refineries are handicapped by the need to import raw materials and energy supplies to support their basic metals industries, and by costs of environmental protection. This presents an opportunity for Canada to anticipate a decline in this sector and to increase its role in smelting and refining, if this is seen to offer economic advantages to Canada. It will require particularly strong support of R&D in environmental protection. Research will also be essential to keep production costs down and to ensure that Canada's energy resources are used efficiently.

Table 6.2 Indicators of Mineral Sector R&D Activities. 1985 (1985 U.S.$ or percent) or 1980–85 percent change*

| | Canada | Australia | Finland | France | West Germany | Sweden | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|
| Mining R&D expenditures | | | | | | | | |
| Government | | | | | | | | |
| % of GDP | .2[d] | .2[b] | 1.0 | na | 1.2[h] | na | na | na |
| % change | na | na | −66.3[c] | na | −13.6 | na | na | na |
| Industry | | | | | | | | |
| % of sales | .2[d] | na | .6 | na | 1.1 | 1.1 | na | na |
| % of GDP | .3[d] | .5[b] | 1.1 | 3.2[fg] | 2.2[h] | 1.5 | na | na |
| % change | 9.5 | na | −32.1[c] | 4.1[g] | 3.3 | .5 | na | na |
| Total | | | | | | | | |
| % of GDP | .5[d] | .7[b] | na | na | 4.2[h] | na | 1.0[j] | na |
| % change | na | na | na | na | −3.7 | na | −12.4[j] | na |
| Basic metals R&D expenditures | | | | | | | | |
| Government | | | | | | | | |
| % of GDP | .5[d] | na | .2 | na | .5[h] | na | .2[k] | na |
| % change | na | na | −15.0 | na | −6.9 | na | na | na |
| Industry[e] | | | | | | | | |
| % of sales | .4[d] | na | na | 1.3 | .9 | 1.2 | na | .8[f] |
| % of GDP | .8[d] | 1.1[b] | 3.9[c] | 1.6[f] | 2.1[h] | 2.8 | 1.0[k] | 2.1[f] |
| % change | −3.0 | na | na | 3.6 | 6.6 | −10.4 | −4.8[k] | −.2[i] |
| Total | | | | | | | | |
| % of GDP | 1.4[d] | na | 4.1[c] | na | 2.7[h] | na | 1.2[k] | na |
| % change | na | na | na | na | 4.4 | na | na | na |
| Mining/Metallurgy University–Performed R&D | | | | | | | | |
| % change | na | na | na | na | na | na | na | 8.9 |
| % of total | 1.3 | .5 | na | na | .3 | 1.8[f] | na | 1.5 |
| Mining/Metallurgy degrees granted | | | | | | | | |
| Undergraduate | | | | | | | | |
| % change | 10.0 | na | −6.6[m] | na | 13.1 | na | −3.5 | −1.8[i] |
| % of total | na[i] | na | na | na | .6[f] | na | .6 | .1[f] |
| Graduate | | | | | | | | |
| % change | 20.3[i] | na | na | na | 9.5[i] | 6.5[n] | −1.9 | 5.9[i] |
| % of total | na | na | na | na | .3[f] | 6.1 | 1.1 | .2[f] |

Source: Background study for each country

[*] Average of annual percent changes based on real domestic currency values

[a] Government support of business enterprise R&D is used as a proxy for government R&D

[b] Value added rather than GDP is used. Industry expenditures are chiefly for total intramural R&D using own funds. 1984 for mining, 1985 for basic metals

[c] 1983–1985. For government, percent change is shown only for government support of industry intramural research. Average annual change 1981–1985 was 9%. For industry, 1981–1983 percent change was 69.1% for an average annual percent change of 18.5%

[d] 1985 for percent of sales (mining sales exlcude coal). 1986 for percent of GDP. Industry expenditures are estimated total industry intramural expenditures using own funds. The figures for percent of sales and percent of GDP for the basic metals industry are misleading here. They refer to domestic source company own funds. In the case of Alcan, a large part of R&D is undertaken with funds from the international parent company and is not included as R&D using own funds. Total R&D performed by the basic metals industry was 1.6% of sector GDP in 1986

[e] 1980–1985 for average annual percent change

[f] Funds provided by industry not R&D undertaken by industry

[g] 1984

[h] Percent of GDP figures are estimates for 1983. Data for total funding are proxied by total business R&D using all sources of funds

[i] 1983

[j] British coal only – includes government and industry funding and represents the vast majority of all mining R&D in the United Kingdom. 1983/84–1985/1986 for percent change and using 1983 value added for percent of GDP.

[k] Industry coal mining R&D only as percent of value added, 1983. Percent change for industry based on estimated industry financed total intramural R&D only for 1981–1985. Percent of GDP estimated using value added and estimated R&D for 1984

[l] Mining R&D only, 1984

[m] Helsinki University of Technology only

[n] 1982–1985

Table 6.2 provides a few figures as a basis for comparison of the R&D efforts of the countries included in this study. There are many gaps in these data. Qualitative information and more detailed data in the individual background studies provide some general impressions.

Almost all the countries included in the study seem to be turning away from R&D activities in the primary resource sectors, and towards the downstream manufacturing end of industry. Canada and Australia appear to be following this pattern as well. In other words, Canada seems to befollowing the pattern of decline prevalent in countries that have closed down or are closing down their metal mining industries, and whose basic metals industries are coming under increasing pressure due to import dependency for raw materials and to environmental protection regulations. In view of Canada's promising potential in primary mineral production, it would make good sense to set a different path and to strengthen Canada's R&D and technological capabilities in mining-related R&D.

The basic metals industry should also consider taking advantage of its access to raw materials and energy. The industry should devote greater R&D effort to energy efficiency and environmental protection, in order to make expansion of this sector more attractive in Canada.

# CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

## INTRODUCTION

The purpose of this investigation has been to compare R&D funding trends in the mineral sector in Canada with those in a group of other countries, selected because they have a tradition of expertise in minerals and because of data availability. Logically, the study's conclusions might be expected to answer the simple question: **How do Canada's R&D efforts in mining and metallurgy compare with those of the other countries in the study?** Unfortunately, the assembled data do not lend themselves to a simple answer. The data, from both published and original sources, are fragmented and incomplete and are frequently unreliable and not comparable.

Ratios comparing R&D to GDP, for example, show differences in the range of a few tenths of a percent which may seem inconsequential but which, in fact, can be quite significant. Percent change in various R&D categories is frequently large, but in some cases seems to represent trends that defy reality. Differences over time and between countries may in fact be real, or may reflect differences in definitions, changes in data collection procedures, or other relatively irrelevant intervening factors. The R&D data, in other words, often do not give reliable indications of R&D intensity or trends for comparative purposes. Furthermore, they are not sufficiently complete, comparable, or reliable in their raw form to lend themselves to more rigorous economic analysis to search out hidden implications.

The usefulness of the study arises from a different question, one that is constructive, and that can and must be answered if our mineral endowment is to be utilized effectively: **How should Canada's mineral-sector R&D efforts be planned and evaluated?** There is much to be learned from the international comparisons in this study that can help to answer this question. The framework for analysis set out in Chapter 2 provides a basis for identifying R&D needs in Canada; and the quantitative and qualitative information in the background studies helps to identify the opportunities and constraints that must be recognized if the R&D needs are to be met. Meeting the R&D needs, however, is not sufficient in itself. The analysis also offers insights into the successful transition from R&D to innovation and commercialization needed to support a competitive position.

## R&D STATISTICS

Statistics on mineral industry R&D efforts are simply not available in any useful form for sector evaluation. Statistics Canada collects and publishes survey data on industry efforts, but the shortcomings here include:

- inconsistencies in reporting by individual enterprises;
- failure to distinguish between intracompany and external funding sources within integrated firms;
- grouping of R&D information by SIC classification of firms rather than purpose of the R&D (for example, no distinction is made in the published data between R&D in exploration, in mining, in processing, or in product development – all are combined into whatever SIC category the firm is assigned to);
- changes in reported data in the course of revisions of previous publications – in some cases, the changes are unexplained but sufficiently large to invalidate conclusions they might have supported previously.

Published date for individual federal government departments, are generally based on total R&D outlays by department and on socioeconomic objectives. Neither form of categorization is readily useful for analysis by industrial sector. Provincial data are not provided at all in any useful form for analysis by industrial sector. Universities are not a source of R&D funding, but are significant performers of R&D. Here again, no data are published on university R&D expenditures by discipline, and even individual departments often seem to have difficulty reporting on R&D support by year and by source of funds.

**Recommendation: If good sector-wide R&D data are considered an essential ingredient of the R&D planning and evaluation process, then industry, university and government policymakers must meet with Statistics Canada to discuss data needs and possibilities, and devise data series that will meet the needs without imposing unreasonable burdens.**

## STAGE IN THE LIFE CYCLE

Canada is in the mature phase of the mineral industries' life cycle, with excellent long-term potential for a broad range of crude metallic, nonmetallic and energy minerals. This contrasts strongly with most of the countries in this study which are facing depletion of metallic mineral deposits and have either high-cost or no energy resources. However, these countries also represent a significant proportion of the existing R&D and technological expertise and of the educational tradition in primary mineral production.

At the same time, a number of newly developing countries (which were not part of this study) are, or are in the process of becoming, strong competitors as producers of crude minerals. Many are also making rapid progress in developing their own technological expertise. In order to compete with these countries, and to continue to realize the wealth inherent in its mineral endowment, Canada must remain among the low-cost producers. However, Canada cannot continue to rely on imported technology and expertise from Europe, if European countries wind down their R&D and educational efforts in primary mineral production. Even if European equipment manufacturers continue to supply mining operations with state-of-the-art technology, this will not provide Canada with any competitive edge because the technology will be available to the competition as well.

**Recommendation: Canada should build on its existing technological and human resource strengths in crude mineral production by targeting the mineral exploration and mining industries for R&D and innovation efforts, to maintain its competitive position in primary mineral production. It should also strengthen R&D and education in its university departments of exploration geology and mining.**

Canada's basic metals and metal fabrication industries are relatively smaller than the crude mineral sector, compared to most of the other countries in this study. The metals sectors in Europe and the United States, although relatively larger, are under severe pressure. They need modernization and rationalization, but are handicapped as attractive investment opportunities by their dependence on imported raw materials, high energy costs, and high costs for environmental protection. This presents a possible opportunity for Canada to increase the degree of further processing of its crude minerals over the long term, as cost and other pressures lead to less extractive metallurgy in Europe and the United States. Again, however, competition from newly developing countries is severe, and developing countries are aided initially at least by relatively lower costs for environmental protection, among other things.

**Recommendation: Canada should target extractive metallurgy for long-term basic and applied research, with particular emphasis on environmental protection and energy conservation.**

## IMPORT-EXPORT DEPENDENCE

Australia is the only country included in this study with a greater dependence than Canada on export markets for its domestic production of crude metallic and energy minerals. All the other countries are increasingly dependent on imported mineral commodities, and are increasingly focusing their R&D efforts on conservation of materials, substitution away from imports, and other downstream manufacturing areas. Both Canada and Australia are also turning away from natural resources and towards manufacturing and high-technology R&D activities. However, the likelihood of long-term dependence on export markets for crude minerals reinforces the recommendation that Canada should target primary mineral production as an R&D area, in order to maintain a competitive position.

## ECONOMIC, SOCIAL AND POLITICAL FACTORS

Canada shares with the other countries in this study a complex network of government policies and economic and social pressures that affect the mineral sector in the form of both costs and incentives. Some of these pressures have been instrumental in hastening the decline of the mineral sector in Europe and the United States, and place economic burdens on this sector in Canada and Australia as well. These pressures tend to be less burdensome in some of the newly developing countries, although these have cost burdens of their own that may in some cases be equivalent.

There is no systematic evaluation of the effect of these government-mandated costs and incentives on the Canadian mineral sector, or on its economic viability, profitability, and international competitive position. Without such analysis, it is impossible to measure the costs and benefits of incentives, regulations and other government policies and programs.

**Recommendation: Studies should be made of the effect of government policies and programs, with a systematic analysis of the total impact of the resulting costs and benefits on the mineral industry's economic performance, and ultimately of the impact on the value realized from Canada's mineral endowment.**

Industrial organization and concentration are important factors in determining R&D funding sources and performance. In Canada, ownership is private (with a few exceptions) and the industry R&D effort is strongly affected by fluctuations in cash flow. Furthermore, industry R&D efforts are concentrated in a few large firms, with strong concerns about protecting proprietary information. However, there is little competition on the basis of product differentiation in crude minerals; furthermore, the companies performing R&D in many cases process and market the output of the smaller firms. This situation is different from that in the European countries, where there are fewer firms, more publicly owned firms, and generally a small and fairly integrated mineral sector. It requires a more concentrated effort on the part of industry in Canada to join forces to smooth out the fluctuations in R&D funding levels and performance, and to collaborate in technology transfer and commercialization of the results.

**Recommendation: The Canadian mineral industry should build on its present initiatives to increase direct collaboration in joint research efforts aimed at productivity improvements, new products, and environmental protection in the mineral sector.**

## THE CULTURAL FACTOR

As noted previously, this factor is perhaps the most difficult to measure quantitatively. However, it is clear that Canada attracts relatively few of its own top students into mineral related PhD programs. It also places relatively few scientists and engineers in operations and management in industry or in government. This latter failing has many negative effects on R&D policies and effectiveness, not the least of which is that it exacerbates the lack of top students by limiting career opportunities. Although it may not be possible to change the underlying causes or nature of Canada's attitudes towards science and technology, it is possible to change the ways in which R&D efforts are organized and utilized. R&D and innovation efforts must include incentives and bridges to overcome the long-standing separation of scientists from senior management and policy formulation. Several possible approaches are suggested in the recommendations that follow.

**Recommendation: Industry should make greater use of university graduates in science and engineering, at both the undergraduate and graduate levels, in production and operations.**

This will have a number of positive effects, including transfer of knowledge acquired through research directly to operations, and opening up career opportunities at all levels of operations and management.

Government's role should be to encourage and support the efforts of the private sector in the identified target areas of exploration, mining and metallurgy.

**Recommendation: Government should encourage communication and technology transfer through support of collaborative R&D involving end-users.**

**Recommendation: Government should help industry to dampen swings in R&D funding that result from volatility in cash flow in the industry.**

**Recommendation: Government should place more scientists and engineers in operational and policy-formulation roles.**

Universities have a role to play as well, although they are among the worst offenders in isolating science and engineering from other disciplines.

**Recommendation: Universities should encourage greater interdisciplinary exposure among students and faculty.**

**Recommendation: Universities should encourage faculty in all applied disciplines, whether related to the social sciences, natural sciences, or engineering, to interact with industry end-users and government information and policymaking organizations.**

Careers spanning all three sectors should be the rule rather than the exception.

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* From M. Wojciechowski. "R&D Trends in the Mineral Sector in Canada", Centre for Resource Studies, Kingston, December 1988

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# APPENDIX A

# SUMMARY OBSERVATIONS FROM BACKGROUND STUDIES

## AUSTRALIA*

Economy:

- originally based on resources, overtaken by manufacturing in 1950s;
- little real GDP growth since 1970s;
- exports about 24% of GDP, principally wool and other rural products (25% of exports) and coal (15%);
- current account balance negative and growing.

R&D Policies and Funding:

- GERD 1.2% of GDP in 1985;
- science policy relatively new – since 1970s;
- frequent studies and reorganizations, not a strong policy focus or central leadership;
- strong federal government role in R&D performance (CSIRO) and funding;
- shift in focus from basic resources to value–added sectors.

Mineral Industry:

- strong in mining, primarily coal and also metallic;
- dependent on export markets for most of crude mineral production;
- privately owned sector is 30%–50% foreign–owned;
- relatively little domestic processing and fabrication;
- low profitability in coal sector.

Education:

- pressures for rationalization and consolidation of mining education.

Mineral R&D:

- government intramural R&D holding steady in exploration and coal mining, down in mining in general, up in metallurgy and materials;
- industry receives very little government funding for R&D;
- industry R&D expenditures down in metallic, up in nonmetallic;
- major industry effort in iron and steel, relatively little in nonferrous metals;
- successful joint industry R&D in non coal mining (AMIRA) and in coal (ACIRL).

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* M. Wojciechowski, "R&D Trends in the Mineral Sector in Australia", background study to this report, Centre for Resource Studies, Kingston, December 1988

## FINLAND*

Economy:

- GDP growth strong 1975–1985, dropping off in 1986;
- based largely on forest products and metal products;
- strongly export oriented: about 30% of GDP;
- import dependent for almost all energy supplies and metallic ores and concentrates.

R&D Policies:

- strong central direction;
- GERD 1.68% of 1987 GDP and increasing;
- strong applied focus;
- declining emphasis on primary resources; increasing emphasis on manufacturing and technology;
- strong collaboration among universities, industry and government.

Mineral industry:

- dominated by two state–owned metal firms and one state–owned industrial mineral firm;
- metal mining is in the last stages of decline;
- processing and fabricating industries are strong.

Education:

- earth sciences – enrollment limits and rationalization;
- mining – diversification into geotechnical and underground construction;
- physical metallurgy is strong.

Mineral R&D:

- declining in exploration and mining;
- in extractive metallurgy, focus is on energy conservation;
- in physical metallurgy, focus is on extreme conditions.

* M. Wojciechowski, "R&D Trends in the Mineral Sector in Finland", background study to this report, Centre for Resource Studies, Kingston, December 1988

## FRANCE*

Economy:

- since late 1970s, dominated by service sector, with manufacturing second;
- minimal role for mineral sector;
- much of economy and financial sector nationalized;
- moderate export orientation (about 24% of GDP);
- import dependent on mineral raw materials;
- emphasis on nuclear energy.

R&D Policies:

- highly centralized, organized, project–oriented, compartmentalized, isolated within sectors;
- GERD about 2.2% of GDP (1985);
- government contribution about 60%;
- defence 30% of R&D.

Mining Industry:

- mainly state–owned, mainly coal;
- metal mining in last stages of decline;
- considerable foreign mineral holdings;
- basic metals sector hurt by high energy and environmental costs.

Education:

- strong tradition in mining, less so in earth sciences;
- facing possibility of rationalization, diversification;
- separation of mining from other educational institutions – complicates diversification.

Mineral R&D:

- very little government assistance, even in energy, government share of BERD only 7%;
- isolation of basic and applied, university and industry R&D;
- industry R&D intensity highest in basic metals (1.5%);
- industry R&D expenditures highest in coal, but this includes utilization R&D.

* M. Wojciechowski, "R&D Trends in the Mineral Sector in France", background study to this report, Centre for Resource Studies, Kingston, December 1988

## FEDERAL REPUBLIC OF GERMANY*

Economy:

- GDP growth slow in 1980s;
- based on manufacturing;
- very little dependence on basic resource industries;
- strongly export oriented: about 30% of GDP;
- import dependent for mineral and some energy raw materials;
- emphasis on nuclear energy.

R&D Policies:

- strong state and federal government leadership;
- GERD 2.8% of GDP;
- strong role for mixed government/private sector research organizations;
- emphasis on university and basic R&D;
- very good government–industry–university communication.

Mineral Industry:

- privately owned except for aluminum and some coal;
- metal mining in last stages of decline;
- dominated by coal mining;
- metallurgical sector hurt by high energy costs and environmental costs.

Education:

- strong tradition in mining and metallurgy;
- funding and enrollment appear to be holding.

Mineral R&D:

- decline in mining and exploration–related R&D;
- major mining emphasis on coal;
- high proportion of mining R&D in joint institutions (30% vs 2% for all industry);
- decline in support for basic metals R&D;
- increased support for materials R&D.

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* M. Wojciechowski, "R&D Trends in the Mineral Sector in Germany", background study to this report, Centre for Resource Studies, Kingston, December 1988

## SWEDEN*

Economy:

- real GDP growth of about 9% from 1980 to 1985, down from mid–1970s rate of increase;
- economy hurt by rising costs in late 1970s and early 1980s, particularly energy and wage costs;
- export dependent (30% of GDP), mainly machinery and other metallic manufactured goods;
- import dependent for energy minerals and some metallic ores;
- low unemployment rate.

R&D Policies:

- R&D effort driven by export–dependence on higher–value–added goods;
- strong basic R&D focus, growing applied support;
- active government leadership in target identification;
- strong emphasis on cooperative R&D;
- leading industry role in R&D funding and performance;
- GERD 2.5% of 1985 GDP.

Mineral Industry:

- dominated by iron and steel, largely state–owned;
- nonferrous sector–concentrated, privately owned;
- ferrous mining facing depletion within a few decades, nonferrous mining sector looking for domestic deposits to continue operations;
- alloy and specialty steel sectors strong, but fighting for market share;
- exploration expenditures dropping.

Education:

- strong emphasis on R&D in higher education sector;
- mining education concentrated in one school (Lulea);
- number of earth science degrees climbing;
- metallurgy strong.

Mineral R&D:

- R&D effort driven by export dependence on machinery; strongest at high–value–added end;
- strong emphasis on cooperative funding and research performance;
- good liaison among government, mineral and equipment companies and universities;
- R&D intensity in mining steady, about 1% of sales;
- R&D intensity in ferrous metals declining, from 1.8% to 0.8 % between 1979 and 1985;
- R&D intensity in nonferrous low and declining, 0.4% in 1985;
- R&D intensity in metal products increasing, 1.7% in 1985.

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* M. Wojciechowski, "R&D Trends in the Mineral Sector in Sweden", background study to this report, Centre for Resource Studies. Kingston, December 1988

## UNITED KINGDOM*

Economy:

- GDP growth in 1980s, due mainly to oil and gas;
- high unemployment – 11.5% in 1985;
- resources very small, service sector almost double manufacturing in GDP.

R&D Policies:

- very fragmented, no strong government policy leadership;
- defence dominated;
- government/industry contribution about 40/60;
- performance sector characterized by relative isolation of sectors and institutions;
- government support of civil R&D weakening (both university and industrial).

Mineral Industry:

- dominated by government-owned coal production;
- metal mining in last stages of decline;
- steel and coal need modernization, rationalization;
- oil and gas industry strong, but past its peak and facing depletion.

Education:

- earth sciences facing severe cuts in rationalization program;
- mining enrollment rose in 1985; since declining;
- mining departments may be facing rationalization.

Mineral R&D:

- little data on R&D expenditures;
- very little metal mining R&D;
- ferrous metals R&D up since 1985, nonferrous R&D declining;
- coal mining R&D declining.

* M. Wojciechowski, "R&D Trends in the Mineral Sector in the United Kingdom", background study to this report, Centre for Resource Studies, Kingston, December 1988

## UNITED STATES*

Economy:

- real GDP growth erratic in 1980s, down in 1982, up strongly in 1984, up 5.5% from 1980 to 1985;
- based on manufacturing;
- resource sectors insignificant;
- not export-oriented, but growing negative trade balance;
- import dependent for most metallic minerals, some petroleum.

R&D Policies:

- dominated by defence R&D;
- government/industry contribution about 50/50;
- little overall central leadership;
- strong federal leadership in defence, health and energy.

Mineral Industry:

- privately owned;
- dominated by coal;
- metallic mining sector declining;
- nonferrous metals sector declining; ferrous metals holding steady after decline;
- heavy environmental and regulatory costs.

Education:

- limited mining and extractive metallurgy programs;
- number of mining degrees continues to decline in the 1980s; metallurgy degrees increasing in early 1980s.

Mineral R&D:

- R&D data difficult to locate, especially in mining;
- federal support appears very low and falling for mining;
- industry mineral sector R&D intensity low.

* M. Wojciechowski, "R&D Trends in the Mineral Sector in the United States", background study to this report, Centre for Resource Studies, Kingston, December 1988

# APPENDIX B

# PRICE INDICES, EXCHANGE RATES AND THE CANADIAN STANDARD INDUSTRIAL CLASSIFICATION OF THE MINERAL SECTOR

Table B.1 Classification of the Mining, Basic Metals and Nonmetallic Mineral Products Industries According to the 1980 Standard Industrial Classification (SIC)

| | |
|---|---|
| 06 | Mining |
| 061 | Metal Mines |
| 062 | Nonmetal Mines (except coal) |
| 063 | Coal Mines |
| 08 | Quarry and Sand Pit Industries |
| 081 | Stone Quarries |
| 082 | Sand and Gravel Pits |
| 29 | Primary Metal Industries |
| 291 | Primary Steel Industries |
| 292 | Steel Pipe and Tube Industry |
| 294 | Iron Foundries |
| 295 | Nonferrous Metal Smelting and Refining Industries |
| 296 | Aluminum Rolling, Casting and Extruding Industry |
| 297 | Copper and Copper Alloy Rolling, Casting and Extruding Industry |
| 299 | Other Rolled, Cast and Extruded Nonferrous Metal Products Industries |
| 35 | Nonmetallic Mineral Products Industries |
| 351 | Clay Products Industries |
| 352 | Hydraulic Cement Industry |
| 354 | Concrete Products Industries |
| 355 | Ready–Mix Concrete Industry |
| 356 | Glass and Glass Products Industries |
| 357 | Abrasives Industry |
| 358 | Lime Industry |
| 359 | Other Nonmetallic Mineral Products Industries |

Source: Statistics Canada, 12–501

Table B.2 Implicit GDP/GNP Price Deflators, 1975–88 (1981 = 100)

| Year | Canada GDP | Australia GDP | West Germany GNP | Sweden GDP | France GDP | United States GNP | United Kingdom GDP | Finland GDP |
|---|---|---|---|---|---|---|---|---|
| 1975 | 60.6 | 56.2 | 78.7 | 55.9 | 55.3 | 63.1 | 45.1 | 56.8 |
| 1976 | 65.8 | 63.9 | 81.5 | 62.6 | 60.7 | 67.2 | 51.7 | 64.0 |
| 1977 | 69.9 | 69.8 | 84.6 | 69.1 | 66.4 | 71.6 | 58.8 | 70.5 |
| 1978 | 74.2 | 74.9 | 88.2 | 75.7 | 73.2 | 76.9 | 65.4 | 75.9 |
| 1979 | 81.6 | 81.9 | 91.7 | 81.7 | 80.6 | 83.7 | 74.9 | 82.2 |
| 1980 | 90.3 | 91.4 | 96.2 | 91.3 | 89.8 | 91.2 | 89.7 | 89.8 |
| 1981 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1982 | 108.9 | 110.9 | 104.4 | 108.6 | 111.7 | 106.5 | 107.7 | 109.1 |
| 1983 | 114.3 | 120.6 | 107.8 | 119.2 | 122.6 | 110.6 | 113.2 | 118.6 |
| 1984 | 118.4 | 129.2 | 109.9 | 128.3 | 131.7 | 114.9 | 117.8 | 129.2 |
| 1985 | 122.4 | 136.9 | 112.3 | 137.2 | 139.3 | 118.7 | 124.8 | 137.0 |
| 1986 | 125.8 | 147.0 | 115.8 | 146.9 | 145.8 | 121.8 | 129.6 | 143.5 |
| 1987 | 129.2 | 165.7 | 118.2 | 154.5 | 150.4 | 125.1 | 135.4 | |
| 1988 | 132.6[a] | | | | | | | |

Source: International Monetary Fund, *International Financial Statistics*, 1987 and September 1988; and Bank of Canada, Review.
[a] First quarter, 1988.



Table B.3 Exchange Rates[a], Various Years (Domestic currency per U.S.$)

| Year | Canada | Australia | West Germany | Sweden | France | United Kingdom | Finland |
|---|---|---|---|---|---|---|---|
| 1975 | 0.0172 | 0.7632 | 2.4603 | 4.1522 | 4.2862 | 0.4501 | 3.6787 |
| 1979 | 1.1714 | 0.8945 | 1.8329 | 4.2871 | 4.2544 | 0.4713 | 3.8953 |
| 1980 | 1.1692 | 0.8776 | 1.8177 | 4.2296 | 4.2256 | 0.4299 | 3.7301 |
| 1981 | 1.1989 | 0.8701 | 2.2600 | 5.0634 | 5.4346 | 0.4931 | 4.3153 |
| 1982 | 1.2337 | 0.9829 | 2.4266 | 6.2826 | 6.5721 | 0.5713 | 4.8204 |
| 1983 | 1.2324 | 1.1082 | 2.5533 | 7.6671 | 7.6213 | 0.6592 | 5.5701 |
| 1984 | 1.2951 | 1.1369 | 2.8459 | 8.2718 | 8.7391 | 0.7483 | 6.0100 |
| 1985 | 1.3655 | 1.4269 | 2.9440 | 8.6039 | 8.9852 | 0.7714 | 6.1979 |
| 1986 | 1.3895 | 1.4905 | 2.1715 | 7.1236 | 6.9261 | 0.6817 | 5.0695 |
| 1987 | 1.3260 | 1.4267 | 1.7974 | 6.3404 | 6.0107 | 0.6102 | 4.3956 |

Source: International Monetary Fund, *International Financial Statistics*, 1988
[a] Rates are period averages of market exchange rates

Table B.4 Comparison of Canadian Price Indices, 1981–87 (1981 = 100)

| | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 |
|---|---|---|---|---|---|---|---|
| Consumer price index | | | | | | | |
| CPI total | 100 | 110 | 117 | 122 | 127 | 132 | 138 |
| CPI durable goods | 100 | 105 | 110 | 113 | 117 | 123 | 127 |
| CPI services | 100 | 113 | 120 | 125 | 130 | 136 | 143 |
| Raw materials price index | | | | | | | |
| Total excluding coal & oil and gas | 100 | 97 | 99 | 103 | 100 | 104 | 109 |
| Coal and oil and gas | 100 | 120 | 129 | 131 | 137 | 87 | 94 |
| Mineral raw materials price index | | | | | | | |
| Total | 100 | 113 | 120 | 122 | 126 | 90 | 97 |
| Excluding coal & oil and gas | 100 | 93 | 97 | 98 | 95 | 98 | 107 |
| Metallic materials | | | | | | | |
| Copper concentrates | 100 | 88 | 92 | 81 | 87 | 90 | 106 |
| Iron ore | 100 | 104 | 105 | 110 | 114 | 116 | 111 |
| Lead concentrates | 100 | 71 | 58 | 73 | 57 | 68 | 106 |
| Nickel concentrates | 100 | 91 | 85 | 93 | 99 | 87 | 97 |
| Other base metals, n.e.s.* | 100 | 91 | 95 | 105 | 95 | 97 | 104 |
| Precious metals | 100 | 83 | 99 | 85 | 77 | 88 | 99 |
| Gold ingots | 100 | 83 | 98 | 85 | 78 | 91 | 101 |
| Silver | 100 | 75 | 111 | 82 | 66 | 60 | 73 |
| Platinum | 100 | 77 | 100 | 88 | 74 | 119 | 139 |
| Radioactive concentrates | 100 | 110 | 99 | 95 | 92 | 91 | 89 |
| Zinc concentrates | 100 | 90 | 96 | 118 | 105 | 102 | 108 |
| Nonmetal materials | | | | | | | |
| Asbestos | 100 | 101 | 111 | 110 | 108 | 108 | 108 |
| Other nonmetallic materials, n.e.s.* | 100 | 111 | 110 | 114 | 116 | 118 | 118 |
| Sand and gravel | 100 | 109 | 109 | 108 | 109 | 112 | 117 |
| Silica sand | 100 | 111 | 117 | 115 | 118 | 122 | 123 |
| Stone | 100 | 113 | 124 | 128 | 134 | 139 | 143 |
| building | 100 | 112 | 123 | 128 | 133 | 137 | 141 |
| crushed | 100 | 115 | 128 | 135 | 143 | 151 | 157 |
| other | 100 | 112 | 123 | 128 | 133 | 137 | 141 |
| Sulphur | 100 | 113 | 99 | 114 | 167 | 179 | 146 |
| Mineral fuels | | | | | | | |
| Coal, thermal | 100 | 110 | 111 | 119 | 120 | 119 | 120 |
| Oil, crude | 100 | 121 | 130 | 132 | 139 | 80 | 89 |
| Natural gas | 100 | 128 | 134 | 132 | 132 | 129 | 125 |

Source: CPI and Raw Materials PI, *Bank of Canada Review*, September 1988, pp. S128–9; Statistics Canada, 62–011

* Not elsewhere specified

# THE CENTRE FOR RESOURCE STUDIES

The Centre for Resource Studies (CRS) was established in 1973, under the sponsorship of Queen's University, the federal Department of Energy, Mines and Resources, and The Mining Association of Canada, to carry out a program of research and publication on mineral policy issues.

The Centre provides opportunities for multidisciplinary research in resource studies at Canadian universities, furnishes reliable information on matters related to mineral resource policy, and promotes closer liaison between government, industry and other concerned groups. The research program is carried out both at the Centre and by means of contracts with qualified investigators, usually at Canadian universities. Small exploratory studies are also funded, through a system of grants-in-aid of research. CRS seminars involve representatives from governments, industry, universities, labour, and other interested groups in working sessions on issues of current concern. Through this program of research and seminars, and the resulting publications, the Centre contributes to informed discussions and a better understanding of significant issues.

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The Centre welcomes comments on its publications, proposals for research projects or for publication, and enquiries about any aspect of its work. For further information, contact:

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